Proceedings of the 12th International Conference on Construction in the 21st Century (CITC-12)

Amman, Jordan

May 16-19, 2022

Editors:

Syed M. Ahmed, Salman Azhar, Amelia D. Saul, & Kelly L. Mahaffy

CITC GLOBAL

Construction in the 21st Century

Proceedings of the

Construction in the 21st Century 12th International Conference (CITC 12)

May 16 – 19, 2022 | Amman, Jordan

Editors

Dr. Syed M. Ahmed

South Dakota State University

Dr. Salman Azhar

Auburn University, Auburn, Alabama, USA

Dr. Amelia D. Saul

East Carolina University, Greenville, North Carolina, USA

Kelly L. Mahaffy

East Carolina University, Greenville, North Carolina, USA

Foreword

While technology and innovation are shrinking, the distance between countries and industries and leadership and collaboration are actively shaping the construction industry, as well as guiding it towards success. Construction in the 21st Century (CITC) is an organization based in the Department of Construction Management at East Carolina University. The CITC-12 conference is being organized by CITC and supported by Auburn University. CITC organizes international conferences to bring together like-minded construction management professionals. The CITC-12 conference seeks to bring together an international group of practitioners, researchers, and educators to promote a novel exchange of ideas in a multidisciplinary fashion.

CITC-12 is a peer-reviewed conference that acts as a dynamic collaboration for the exchange of knowledge. New methods and techniques must be carefully scrutinized and rigorously tested before implementation, and CITC-12 plays an integral role in this process. As the industry movesforward in an ever-complex global economy, multi-national collaboration is crucial. Future growth in the industry will undoubtedly rely on international teamwork and alliance.

This May marks the twelfth CITC conference. Previous conferences include CITC-I in Miami, USA of 2002, CITC-II in Hong Kong, China of 2003, CITC-III in Athens, Greece of 2005, CITC-IV in Gold Coast, Australia of 2007, CITC-V in Istanbul, Turkey of 2009, CITC-VI in Kuala Lumpur, Malaysia of 2011, CITC-VII in Bangkok, Thailand of 2013, CITC-8 in Thessaloniki, Greece of 2015, CITC-9 in Dubai, UAE of 2017, CITC-10 in Colombo, Sri Lanka of 2018, and CITC-11 in London, United Kingdom of 2019. All conferences were tremendously successful. As with previous conferences, this effort has been greatly supported by our friends and colleagues across the globe. It is our pleasure to now present to you the Twelfth International Conference on Construction in the 21st Century (CITC-12, Amman). This three-day conference is being held in Amman, Jordan at the Inter-Continental Hotel. CITC-12 will bring together a diverse group of academics,professionals, government agencies, and students from all over the world to contribute to the future growth of the industry.

We gratefully appreciate your attendance and hope that you will support the future endeavors ofCITC.

Thank you and kind regards,

Editors:

Dr. Syed M. Ahmed

Dr. Salman Azhar

Dr. Amelia D. Saul

Kelly L. Mahaffy

CITC-12 Themes

- Leadership in Engineering & Construction
- Building Information Modeling
- Lean Construction Practices
- 3D Printing
- Augmented and/or Mixed Reality
- Legal Issues in Construction
- Value Engineering
- Project and Program Management
- Quality and Productivity Improvement
- Sustainable Design and Construction
- Concrete Technology
- Construction Contracts
- Construction Safety
- Construction Scheduling
- Cost Analysis & Control
- Cultural Issues in Construction
- Design-Build Construction
- Engineering & Construction Materials
- Ethical Issues in Engineering and Construction
- Information Technology and Systems
- Infrastructure Systems and Management
- International Construction Issue
- Materials and Technology Research
- Structural Design

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Keynote Speakers

Dr. Yiannis Xenidis

BIO: Dr. Yiannis Xenidis is an Associate Professor of Risk Management in the Life Cycle of Civil Engineering Projects at the Department of Civil Engineering in the Aristotle University of Thessaloniki (AUTH), Greece. He has also taught at the department of Spatial Planning and Development in AUTH during 2005 – 2008, and the school of Science and Technology in the Hellenic Open University during 2013 – 2020.

He is the vice chair of the Education Committee of the European Council for Computing in Construction (EC3), and a member of the Audit Committee of the European Association On Quality Control of Bridges and Structures (EuroStruct). He is also a member of the Task Group 1.08 - Design Requirements for Infrastructure Resilience of the International Association for Bridge and Structural Engineering (IABSE), and a member of the Project Management Institute (PMI), the Society of Risk Analysis (SRA), and the International Association for Life-Cycle Civil Engineering (IALCCE). He has a professional experience as a constructor of public works and private projects and as a consultant of civil engineering projects.
He has authored several peer reviewed papers in scientific journals and conferences, and he has contributed, upon invitation, with book chapters to several publications. He has participated as member of the organizing and scientific committees and session chair at several scientific conferences. He is, also, a reviewer at several scientific journals and conferences and an evaluator of research proposals.

His current research interests are focused on the design, assessment, and monitoring of resilience of infrastructure systems, risk analysis and decision-making in civil engineering projects and infrastructure.

TITLE: Re-engineering Nature: A Comprehensive Paradigm for Physical Infrastructure Development

Keynote Speakers

Dr. Khalid Siddiqi, Ph.D.

BIO: Professor Dr. Khalid Siddiqi is Professor Emeritus of Construction Management at Kennesaw State University. Prior to his academic career spanning twenty-five years, Khalid served the Construction Industry in various capacities in organizations for fifteen plus years. His industry experience involved working with architects, developers, and contractors around the world in his employment with the World Bank, US Army Environmental Policy Institute, Public Housing Development, Master Planning, managing Building Permitting agencies, and working for Structural Engineering firms.

Advocacy of students and bold initiatives towards university advancement activities are the hallmarks of Khalid's career with the University System of Georgia. He initiated and sustained a variety of fund-raising efforts in support of department, college, and Kennesaw State University (KSU). Construction Industry has established *Dr. Khalid Siddiqi Endowed Scholarship* at KSU to acknowledge his contributions to the industry. This endowed scholarship will help pursue Dr. Siddiqi's commitment to excellence in education and student success.

Khalid earned his Ph.D. in Civil & Environment Engineering from Georgia Institute of Technology. He was awarded a full scholarship by the Australian Government to pursue masters in Structural Engineering and Construction from Asian Institute of Technology, Bangkok Thailand. He completed bachelor's degree in Civil Engineering with Highest Honors (First in class) from NED University of Engineering and Technology Karachi, Pakistan.

During his academic and teaching career Khalid has received several distinguished teaching awards including Outstanding Faculty Award, Teacher of the Year Award, and Outstanding Educator Award from Associated Schools of Construction and was selected to participate in prestigious programs at the State level including Executive Leadership and Accelerated Leadership Programs of University System of Georgia. Khalid has served the construction community throughout his academic career. During the last twenty-three years he has judged projects for Build Georgia Awards (AGC), Excellence in Construction Awards (ABC), Project Achievement Awards (CMAA), and Georgia Concrete Industry Award Competitions (ACI). In addition, Khalid has collaborated with Bennett Thrasher, one of the country's largest full-service public accounting and consulting firms, to present Construction Outlook Survey findings to CEOs and CFOs of Georgia's Construction Organizations. The survey is conducted each year and findings are shared with the community to provide insight into how construction companies can remain relevant in an increasingly competitive environment.

TOPIC: Quality in a Construction Project – Who's Asking?

Keynote Speakers

Prof John Smallwood

BIO: Prof John Smallwood is the Professor of Construction Management in the Department of Construction Management, Nelson Mandela University, and the Principal, Construction Research Education and Training Enterprises (CREATE). Both his MSc and PhD (Construction Management) addressed construction health and safety (H&S). He has conducted extensive research and published in the areas of construction H&S, ergonomics, and occupational health (OH), but also in the areas of the environment, health and well-being, primary health promotion, quality management, and risk management.

TOPIC: Health, safety, and well-being is the current term used in may countries globally, which evolved from the initial safety, and then health and safety (H&S). This evolution is attributable to increased awareness, the development of knowledge and skills, and the development of construction materials, methods, plant and equipment, activities, and the overall process. A further aspect in terms of evolution is the transition from 'injuries and fatalities are a part of construction' to, among other, 'zero harm' and 'one injury or fatality is one too many'. The evolution has continued to include 'work life balance', and a focus on 'mental health' due to compressed project schedules, overtime work, shift work, six- or seven-day working weeks, and suicides. Furthermore, due to the relationship between occupational health and primary health issues, H&S endeavors were accompanied by primary health promotion and interventions in many countries. This was underscored by the COVID-19 pandemic and the resultant workplace-related interventions.

Historically, safety and then H&S, was viewed as the contractor's problem. However, landmark construction H&S legislation promulgated in the European Union in 1992, expanded the responsibility for H&S to include clients and designers. This legislation in turn engendered interrogation of the role, influence, and impact of clients, designers, and other project stakeholders on H&S, which in turn resulted in major related research globally.

The evolution inevitably resulted in the recognition of H&S as a 'project parameter' and a paradigm shift from the passe paradigm of cost, quality, and time. However, the advent of Industry 4.0 technologies has resulted in the realization that the persistent H&S-related problems can be resolved, and that the physical and harsh nature of many construction activities and the overall process can be mitigated.

TOPIC: Health, Safety, and Well-being in Construction

Workshops

TITLE: Historic Building Information Modeling – Use Advanced Design and Construction Technologies to Record and Conserve Heritage

INSTRUCTOR 1: Prof. Junshan Liu, *Associate Professor in the McWhorter School of Building Science at Auburn University*

BIO: Prof. Junshan Liu is an Associate Professor in the McWhorter School of Building Science at Auburn University. Prof. Liu has extensive experience of LiDAR scanning, scan-data processing and extrapolations, photogrammetry, HBIM, 3D modeling, and UAS. He has had numerous publications on HBIM, BIM, LiDAR and also led multiple digital documentation and heritage preservation projects.

Description:

As one of the fastest-developing research and practice fields, Historic Building Information Modeling (or Heritage Building Information Modeling, HBIM) is a multi-disciplinary process that requires the contribution and collaboration of scholars and professionals with very different skillsets. Unlike BIM workflows for new constructions, the tried and tested tools and methods must be adapted, and even reinvented, for HBIM applications. The digital revolution and opportunities to leverage modern technologies, such as light detection and ranging (LiDAR), photogrammetry, 360-degree photography, virtual reality (VR), artificial intelligence (AI), and unmanned aircraft systems (UAS), provide innovative means to document, interpret, preserve, and even restore heritage structures. The very same technologies and workflows associated with HBIM can also be applied to develop digital twins for elements of new construction.
In this workshop, participants will learn the concept of HBIM, its applications, and a feasible workflow with data management strategies. They will explore a few case studies for using HBIM to digitally document, restore, and interpret significant historic structures associated with the American Civil Rights Movement, assisted by LiDAR, 360-degree photography, photogrammetry, UAS, VR, and AI. The participants will also get the opportunity to interact with some of the cutting-edge equipment used for collecting data for HBIM.

Tentative Agenda (90 minutes):

- Opening Section — 5 minutes
- Introduction to HBIM — 20 minutes
- Case Study: project-1 — 15 minutes
- Case Study project-2 — 15 minutes
- Experiment with 360-degree camera — 20 minutes
- Questions and Answers — 15 minutes

Workshops

TITLE: Purdue University's New Paradigm for Construction Management Education: Lessons Learned

INSTRUCTOR: Z. (Željko) Torbica, Ph.D., F.ASQ

BIO: Z. (Željko) Torbica is Professor and Head of the School of Construction Management Technology at Purdue University. Dr. Torbica's international experience of over 35 years includes both academic positions at several leading U.S. universities and an extensive and industry-recognized background in construction, engineering, real estate development, leadership and strategic planning. During the course of his career, Dr.Torbica has received a number of distinguished awards; served as the conference keynote speaker at international conferences; published articles in the most selective professional journals; directed real estate development operations, with projects ranging from $50- to $550 million; served on prestigious Baldrige National Quality Award Board of Examiners; and completed leadership programs at Harvard University and Columbia University. Dr.Torbica received a Ph.D. degree from the University of Florida (Construction Management). Dr. Torbica is a Fellow of American Society for Quality, Certified General Contractor in the state of Florida, and holds Project Management Professional (PMP) and Quality Engineer (QE) certifications.

DESCRIPTION:

During the Fall 2015 School's retreat meeting the faculty were asked "*If you could start over from scratch, what would you do*?" The School took the challenge and set a goal to transform curriculum into an innovative learning environment that creates a "*seamless transition from college to industry*". The main idea behind curriculum transformation was horizontal and vertical integration of student learning outcomes in an authentic, project-based, team-taught environment. The horizontal integration refers to the integration of multiple subjects in a single course organized around the project life cycle ("pre-construction" and "construction") and vertical integration focuses on distributing the subject-oriented course material throughout the entire four-year curriculum.

The new curriculum was launched in the Fall 2017 semester. This undertaking is one of the most complex and unique transformation initiatives in a long history of Purdue University- we are not aware of any other academic program that has attempted to implement the integration of this magnitude encompassing the entire four-year curriculum. Since there is no roadmap to follow, the SCMT faculty have had to demonstrate a great deal of creativity and ingenuity in implementing this transformation.

The vertically and horizontally integrated construction courses provide students more opportunities to synthesize material earlier in their college career rather than waiting for a senior capstone and allows the students to potentially retain more of their education by scaffolding construction content throughout the four-year program rather than condense all information into a single 3-credit-hour course. As an example, the subject area of "estimating", which, in the "old" curriculum, was covered in a "stand-alone" 3-CH Estimating course in the junior year, is now included in (at least) 5 courses and is taught throughout the entire four-year curriculum, in the first year in CM 100, in second year in CM 200, in third year in CM 300, and in fourth year in CM 400 and CM 450.

ESTIMATING	CM 100	CM 200	CM 300	CM 400	CM 450

Figure 1: Courses in which "estimating" is taught/ covered

Similarly, every course in the new curriculum is covering a number of subject areas, instead of being focused on a single subject area. As an example, CM 200, a 9-credit-hour course, is covering material from (at least) 15 different subject areas (see figure below), and is taught by a team of 10+ instructors.

CM 200	ESTIMATING	PLAN READING	ACCOUNTING	CAREER PREPARADNESS	COMMUNICATIONS
	SCHEDULING	SUSTAINABILITY	HISTORY	PROJECT MANAGEMENT	DESIGN MANAGEMENT
	STRENGTH OF MATERIAL/ SOILS/ STRUCTURES	SAFETY	MEP	COMPANY MANAGEMENT	OTHER

Figure 2: Subject areas that are covered in CM 200

The inaugural cohort that followed the new curriculum graduated in Fall 2020, one semester ahead of schedule. It will take at least 3-5 more years before we will be able to assess the success of this new educational model, but we are optimistic that the students indeed are acquiring the skills and capabilities that will enable them to quickly develop in top-notch professionals.

ID 1

The Difference Between IRR and NPV in Capital Investment Appraisals

S.L. Tang PhD, FICE[1]

[1] University of Macau, Taipa, Macau, China (Retired Professor)
irsltang@gmail.com

Abstract
In the fields of architecture, engineering and construction, a clear concept of the appraisal methods of capital investment alternatives is very important. The NPV ranking of mutually exclusive alternatives is a correct approach if the MARR (minimum attractive rate of return) is based. The IRR ranking is an incorrect approach. If the IRR method is ever used to rank alternatives, the Incremental IRR Analysis must be used, and its result will be the same as the NPV ranking. In using the Incremental IRR Analysis, one may face the problem of multiple IRRs, but this is not really a hindrance to the Incremental IRR Analysis. The multiple IRR problem alleged in some articles is probably due to a misunderstanding of the multiple IRR theory. The author attempts to explain it in this article. The conclusion states that all other methods such as Modified IRR, Marginal Growth Rate, Incremental IRR Analysis, etc., are supplementary to the NPV method. The NPV is an economic indicator and always correct in evaluating the economic value of an investment and in ranking mutually exclusive alternatives based on the MARR. The IRR is a financial indicator and incorrect to be used for ranking mutually exclusive alternatives, but is to be used for finding the best financial strategy to achieve optimal gain for a single investment alternative.

Keywords
Engineering Management; Engineering Economics; Internal Rate of Return; Net Present Value; IRR; NPV

1. Introduction

An article entitled "The variable financial indicator IRR and the constant economic indicator NPV" (Tang and Tang 2003) was published in *The Engineering Economist*. For the past 15 years (from 2004 to 2018), there has been a number of citations of the said article, both in *The Engineering Economist* and in other international journals. The concept that IRR is a financial indicator and NPV an economic indicator was firstly proposed in 1991 in a book entitled *Economic Feasibility of Projects*, the 1st edition of which was published by McGraw-Hill (Tang 1991, Chapter 5). This current article is to respond to a number of important questions found in a number of important articles in the past 15 years (2004 - 2018), many of which cited the article written by Tang and Tang (2003). The responses in this current article, written in 2019/20, are mainly made to Hajdasinski (2004), Magni (2010), Robison *et al*. (2015), and Lefley (2018), besides others.

In the fields of architecture, engineering and construction, a clear concept of financial and economic appraisals of capital investment alternatives is very important. The word "financial" usually relates to private investors' perspective and "economic" to society's (or community's) perspective. This article is written with the following arrangement. It starts with the discussion of whether or not ranking mutually exclusive investment alternatives by ranking their IRRs is justified. It is a misunderstanding made by Hajdasinski (2004) that the article (Tang and Tang 2003) implied that ranking alternatives by ranking their IRRs is justified. The current author says it is a misunderstanding because Tang and Tang (2003) never justified this, and on the contrary, said IRR ranking could lead to wrong conclusions. This point is to be clarified in this article with the use of an example, in which both the direct IRR method and the Incremental IRR Analysis are used to rank five alternatives. Then, the Incremental IRR Analysis is applied again to rank three other cash flow streams, which were taken by Hajdasinski (2004) from (Tang and Tang 2003) for discussion in the former's 2004 article. The result of the ranking using the Incremental IRR Analysis shows that these three cash flow streams are equally good (equal ranking). This result is the same as that of the NPV method – same economic values (or economic returns) of the three cash flow streams. Such an observation is important because the three cash flow streams are derived from a single (the same) investment cash flow stream but with three different financial arrangements. The three cash flow streams so derived have different IRRs but the same NPVs.

The phenomenon of having identical NPVs but different IRRs can be interpreted as: the NPV is an economic indicator and the IRR a financial indicator.

Following that, the discussion is devoted to resolving the problem when multiple IRRs occur during the performance of the Incremental IRR Analysis. This question was raised by Hajdasinski (2004) in his responses to Tang and Tang (2003). In fact, Hazen (2003) had mentioned that each IRR of the multiple IRRs is meaningful, explainable and non-contradictory, and is consistent with the NPV evaluation of the investment cash flow stream. Hajdasinski's own example in his own article (Hajdasinski 2004) is used in this current article to show how Hazen's method can satisfactorily tackle Hajdasinski's multiple IRR question. Moreover, the multiple IRR problem brought out in Magni (2010) is also discussed.

After that, Robison *et al*.'s (2015) article entitled "Consistent IRR and NPV rankings" is looked into. That article attempts to find a consistent IRR and NPV ranking, or more exactly, consistent MIRR (modified IRR) and MNPV (modified NPV) ranking (Robison *et al*. 2015; Lefley 2018). There are, however, two major drawbacks in their method when it is applied in capital investment appraisals; the details are to be discussed later in this current article.

In summary, the author's purpose of writing this current article is to respond to a number of important questions about the IRR and the NPV found in a number of important articles in the past 15 years (from 2004 to 2018; this paper was submitted in May 2020 and the conference has been, due to the covid-19 incident, postponed several times to May 2022). During responding to the questions, that the NPV is an economic indicator and the IRR a financial indicator is further explained and reaffirmed.

2. The Incremental Analysis

In Hajdasinski article (Hajdasinski 2004), there was a misunderstanding that Tang and Tang (2003) implied ranking investment alternatives by ranking their IRRs is justified. Having said that, the author agrees (also agreed by Hajdasinski) that the incremental IRR ranking approach is necessary to remedy this shortcoming (i.e., possible wrong ranking of alternatives by just using direct IRR ranking). The following example shows the different ranking results of using the direct IRR ranking and the incremental IRR ranking.

Example: Rank the five investment alternatives shown in Table 1 using IRR ranking and NPV ranking:

Table 1: NCFs (Net Cash Flows in million$) of five mutually exclusive alternatives, IRRs and NPVs

End of year	Alternative A	Alternative B	Alternative C	Alternative D	Alternative E
0	-50	-70	-110	-140	-180
1	5.2	7.0	9.0	13.5	17.0
2	5.2	7.0	9.0	13.5	17.0
:	:	:	:	:	:
:	:	:	:	:	:
:	:	:	:	:	:
30	5.2	7.0	9.0	13.5	17.0
Direct IRR	9.8% p.a.	9.3% p.a.	7.2% p.a.	8.9% p.a.	8.7% p.a.
IRR Ranking	1st	2nd	5th	3rd	4th
NPV	21.57	26.35	13.88	45.83	54.00
NPV Ranking	4th	3rd	5th	2nd	1st

(The discount rate or the minimum attractive rate of return *i* is taken as 6% p.a.)

From Table 1, it can be seen that the direct IRR ranking of the five alternatives has a different result from the NPV ranking. Only the NPV ranking is correct and the IRR ranking is not (see reasons in the paragraphs below). While Lefley (2018, page 48) correctly quotes from Tang & Tang (2003) and Hajdasinski (2004) "the two models are said to have intrinsic differences from each other, with the NPV being an economic indicator and the IRR a financial indicator of a capital investment", he however is not so correct to say "when considering mutually exclusive projects, on the basis of the NPV, the project with the highest NPV would be accepted, while with respect to the IRR, the project with the greatest IRR/yield would be accepted". Such a statement is true in the first half but not in the second half. The NPV ranking is indeed a correct approach but the IRR ranking - the alternative with the greatest IRR/yield would be accepted - is not a correct approach. The same incorrect statement can be found on page 500 of Robison *et* *al*. (2015). It is said there "Alternatively, investments (assumed to be mutually exclusive – a judgment from the context on that page) can be ranked using the challengers' IRRs" (for the meaning of challenger please see below). This is exactly the IRR ranking approach that this current author does not agree with.

Now, this current author would like to show how the result of the Incremental IRR Analysis is different from that of the IRR ranking. The "Incremental IRR" is a term or name given to the IRR calculated from a series of Incremental NCFs (Incremental Net Cash Flows), where an Incremental NCF is equal to the NCF of the j^{th} alternative minus the NCF of the $(j-1)^{th}$ alternative. In the analysis, the alternative with the lowest initial capital cost is arranged as the first alternative and the one with the highest as the last. The following criteria are adopted in the analysis:

If Incremental IRR > i, then the j^{th} alternative is better than the $(j-1)^{th}$ alternative, and
if Incremental IRR = i, then the $(j-1)^{th}$ alternative and the j^{th} alternative are equally good, and
if Incremental IRR < i, then the $(j-1)^{th}$ alternative is better than the j^{th} alternative,
where i is the discount rate used or the minimum attractive rate of return.

As a remark, the above criteria are only true for a series of Incremental NCFs that has one real Incremental IRR only (i.e., no multiple Incremental IRRs). If a series of Incremental NCFs has multiple Incremental IRRs, the analysis can still be performed. In that case, another set of criteria will be used instead of the set shown above. This important point will be further elaborated in this article.

To start to perform the Incremental IRR Analysis, compare Alternatives A and B as shown in Table 2:

Table 2: Incremental NCFs in million$ of (Alternative B minus Alternative A)

End of year	Alternative A	Alternative B	$(\text{Incremental NCF})_{B-A}$
0	-50	-70	-20
1	5.2	7.0	1.8
2	5.2	7.0	1.8
: : :	: : :	: : :	: : :
30	5.2	7.0	1.8

Some people may like to call Alternative A a defender and Alternative B a challenger. The Incremental IRR calculated from the series of Incremental NCFs (-20; 1.8; 1.8; … ; 1.8) is 8.1% p.a. Since 8.1% p.a. > 6% p.a. (the minimum attractive rate of return) and according to the above-said criteria, Alternative B is better than Alternative A. So, Alternative A is out. Next, compare Alternatives B and C.

This time, Alternative B is a defender and Alternative C a challenger. (In fact, the author considers that to distinguish between a defender and a challenger in many cases (e.g. this example) is unnecessary). The Incremental NCFs in million$ of (Alternative C minus Alternative B) are represented by -40 at the End of Year 0 and 2.0 each year from the End of Year 1 to the End of Year 30 (refer to Table 1), forming a series of Incremental NCFs (-40; 2.0; 2.0; … ; 2.0). The Incremental IRR calculated is 2.8% p.a. Since 2.8% p.a. < 6% p.a., Alternative B is better than Alternative C according to the above-said criteria. So, Alternative C is out. Next, proceed with comparing Alternative B with Alternative D.

In a similar manner, the calculation shows the Incremental IRR of the $(\text{Incremental NCFs})_{D-B}$ to be 8.5% p.a. Since 8.5% p.a. > 6% p.a., Alternative D is better than Alternative B. Alternative B is out.

Following this, repeat calculating the Incremental IRR of the $(\text{Incremental NCFs})_{E-D}$, which is 7.8% p.a. Since 7.8% p.a. > 6% p.a., Alternative E is better than Alternative D. Hence, Alternative E is the best.

From the above Incremental IRR Analysis, one can see that the result of the ranking of the five alternatives is the same as the NPV ranking in Table 1. It confirms what Hajdasinski (2004) said – a direct comparison of the IRRs is not a recommended approach and the incremental ranking approach is needed. This is also what the author agrees with. As a matter of fact, it has been said in Tang (1991, Chapter 5, page 79) and Tang (2003, Chapter 5, page 80) that "In conclusion, in the economic appraisal of projects, the best way for selecting alternatives is to use NPV method or the Incremental Analysis. The direct IRR method may lead to wrong decisions". Both places were written earlier than the article written by Hadjasinski (2004). So, it was definitely a misunderstanding made by Hadjasinski (2004) to say that Tang and Tang (2003) implied ranking investment alternatives by ranking their IRRs is justified. In fact, Tang and Tang (2003) did not justify this or imply to justify this.

It should be noted another phenomenon happens if *i* = 9% p.a. (instead of 6% p.a.) is used to calculate the NPVs of the five alternatives in Table 1. Table 3 below shows the results of using this new *i* (9% p.a.):

Table 3: NCFs (Net Cash Flows in million$) of five mutually exclusive alternatives, IRRs and NPVs

End of year	Alternative A	Alternative B	Alternative C	Alternative D	Alternative E
0	-50	-70	-110	-140	-180
1	5.2	7.0	9.0	13.5	17.0
2	5.2	7.0	9.0	13.5	17.0
: : :	: : :	: : :	: : :	: : :	: : :
30	5.2	7.0	9.0	13.5	17.0
Direct IRR	9.8% p.a.	9.3% p.a.	7.2% p.a.	8.9% p.a.	8.7% p.a.
IRR Ranking	1st	2nd	5th	3rd	4th
NPV	3.42	1.92	-17.54	-1.31	-5.35
NPV Ranking	1st	2nd	5th	3rd	4th

(The discount rate or the minimum attractive rate of return *i* is taken as 9% p.a.)

It can be observed that the IRR ranking is the same as the NPV ranking. This phenomenon is to be explained later. It is also important to observe that the Incremental IRR Analysis has a new ranking result similar to Table 3 after *i* is changed to 9% p.a. Readers can verify these by themselves using the method just described. The result of the NPV ranking is always consistent with that of the Incremental Analysis.

Another situation that the IRR ranking is always the same as the NPV ranking is when the initial capital costs of all the investment alternatives are equal. In this situation, the alternatives are no longer called mutually exclusive alternatives because they have the same datum for comparison – same capital outlays. Because they are not mutually exclusive and have a same basis (same initial capital costs) for comparison, the ranking of their direct IRRs is sufficient to be a reference to know their true ranking and this ranking must be consistent with the ranking of their NPVs. Readers may refer to Tang (1991, page 75) or Tang (2003, page 77) for the detailed discussion.

Table 4 below shows an example of such a situation:

Table 4: NCFs (Net Cash Flows in million$) of three alternatives with similar initial investments, IRRs and NPVs

End of year	Alternative A	Alternative B	Alternative C
0	-30	-30	-30
1	4	9	10
2	5	9	8
3	6	9	7
4	7	9	7
5	8		6
6	9		
Direct IRR	7.04% p.a.	7.71% p.a.	9.24% p.a.
IRR Ranking	3rd	2nd	1st
NPV at 6% p.a.	1.13	1.19	2.46
NPV Ranking	3rd	2nd	1st
NPV at 9% p.a.	-1.96	-0.84	0.17
NPV Ranking	3rd	2nd	1st

(The discount rates or the minimum attractive rates of return *i* are taken as 6% p.a. and 9% p.a.)
(6% p.a. and 9% p.a. are taken arbitrarily)

From the example illustrated in Table 4, readers can see that the IRR ranking is always consistent with the NPV ranking for such so called "homogeneous investment size" alternatives. This statement, however, is not applicable to alternatives with multiple IRRs. An example is given by Robison *et al*. (2015, pages 500-501). Two homogeneous investment size alternatives, (-4, 12, -9) and (-4, 12, -8) are investigated, and it is found that the IRR ranking is inconsistent with the NPV ranking. This is because the alternatives have multiple IRRs. This point will be further discussed later in this article.

3. Comparing the three Cash Flow Patterns of three different financial arrangements

Hajdasinski (2004, pages 186-187) continued to discuss the numerical example of Tang and Tang (2003, pages 71-73). (1) below is the CFP (cash flow pattern) of an all-equity case (no borrowing) investment:

(-10000; 5000; 5000; 5000) (1)

Then, (2), a PFA (project financing alternative) where the original 10,000 investment that is financed in full by the equity capital as shown in (1) is now created by leveraging (1) with a market borrowing of 6,000 at i = 10% per period, is as follows:

(6000; -2600; -2400; -2200) (2)

The above PFA (2) is derived as shown in Table 5:

Table 5: Calculation of project financing alternative (2), i.e., PFA (2)

End of period	(1) Amount borrowed	(2) Principal amortization	(3) Balance of principal unpaid	(4) Interest (10% per period)	(5) Total periodic payment (2)+(4)
0	6,000		6,000		
1		2,000	4,000	600	2,600
2		2,000	2,000	400	2,400
3		2,000	0	200	2,200

As a result of introducing PFA (2), CFP (1) becomes CFP (3) as shown in (3):

(-4000; 2400; 2600; 2800) (3)

If (1) is leveraged even further, that 1,000 equity capital and 9,000 borrowing are combined to form the initial investment capital of 10,000, the PFA this time is (9000; -3900; -3600; -3300) as calculated by a similar method as shown in Table 5, and CFP (1) becomes CFP (4):

(-1000; 1100; 1400; 1700) (4)

CFPs (1), (3) and (4) in fact represent the same investment but with different financial arrangements (i.e., different PFAs). The NPVs of these three CFPs are the same, equal to 2,434.26 each. This represents that the economic value (or economic return) of the investment is 2,434.26 so there is only one economic value (or economic return) for a single investment. (The author would like to highlight Lefley's good and prudent wording "The NPV of 279,xxx is said to be the economic return from the investment" in his article recently published (Lefley 2018, page 49)). The IRRs of CFPs (1), (3) and (4), however, are 23.4%, 41.2% and 113.1% per period respectively. This does not mean that economically (4) is better than (3) and (3) is better than (1), which is the result of the IRR ranking. This is apparently Hajdasinski's (2004) misunderstanding on what was conveyed by the article of Tang and Tang (2003). Therefore, a clarification is necessary on what was really conveyed by Tang and Tang's (2003) article. The clarification is shown below:

First, use the Incremental IRR Analysis to compare CFPs (1), (3) and (4).

Initially, compare CFPs (3) and (4), and the (Incremental NCFs)$_{3\text{-}4}$ are shown in (5):

(-3000; 1300; 1200; 1100) (5)

The Incremental IRR calculated from (5) is 10% per period. It is exactly equal to the borrowing rate i (or treated here as the MARR (minimum attractive rate of return i) --- the concept of opportunity cost is not discussed here due to the limitation of the length of the article). According to the criteria of the Incremental IRR Analysis, CFPs (3) and (4) are equally good. Next, choose either CFP (3) or (4) to compare with CFP (1). If CFP (3) is chosen, the (Incremental NCFs)$_{1\text{-}3}$ are (-6000; 2600; 2400; 2200) and its Incremental IRR is 10% per period. If CFP (4) is chosen, the (Incremental NCFs)$_{1\text{-}4}$ are (-9000; 3900; 3600; 3300) and its Incremental IRR is also 10% per period. All these mean that CFPs (1), (3) and (4) are equally good. Such a result is consistent with the NPV ranking that the three CFPs are equally good (i.e., having the same NPVs equal to 2,434.26).

Second, it is necessary to explain why IRR is not good to rank mutually exclusive multiple alternatives but good to be a financial indicator for a single project's financial strategy.

From the example of CFPs (1), (3) and (4) above, one can see that the IRR, unlike NPV, is "capricious" or "fickle". The IRR of an investment changes when the financial arrangement changes. Such changes do not happen in NPV and a rigorous mathematical proof on this was given in Tang and Tang (2003). Because NPV (at the minimum attractive rate of return) remains to be the same constant value for all the other associated CFPs derived from the original CFP, this constant (economic) value is much more reliable than the varying IRR values. Hence, the NPV was proposed to be called an economic indicator because it represents the economic value of an investment; it does not change but has only one constant value. The IRR, however, is situational and unstable, and it changes when the financial arrangement of an investment changes. Hence, it is not suitable to be used for ranking mutually exclusive multiple alternatives. Tables 1 and 3 reveal the unreliable result of the IRR ranking and the reliable result of the NPV ranking when mutually exclusive multiple alternatives are to be ranked. The IRR, however, is suitable to be a financial indicator for ranking the PFAs (project financing alternatives) of a single (not multiple) alternative.

4. IRR as a financial indicator

As said above, IRR is a financial indicator. Private investors usually like to play around with financial arrangements to optimize the rate of return under the circumstances of limited availability of funds. For example, CFP (1), that is (-10000; 5000; 5000; 5000), only gives an investor a constant rate of return of 23.4% per period for three periods. In other words, the investor will pay out 10,000 and obtain 15,000 (i.e., 5000 + 5000 + 5000; time value of money has not been considered). But if one divides the equity capital into ten equal shares (1,000 each share), then he or she can invest in ten CFP (4), that is (-1000; 1100; 1400; 1700), and obtain a constant rate of return of 113.1% per period for three periods. In other words, the investor will pay out 10,000 but obtain 42,000 (i.e. (1100 + 1400 + 1700) × 10); time value of money has not been considered). This is why IRR is a financial indicator. It is a financial indicator because it varies and tells the investors how to choose the optimum financial strategy under different financial constraints for a single investment project. Readers are recommended to read this current article in conjunction with Tang and Tang (2003) to fully comprehend that the NPV is an economic indicator and the IRR a financial indicator.

5. Misleading NPV-function profiles?

Hajdasinski (2004, pages 194-195) opined the NPV-function profile in Figure 1 of Tang and Tang (2003, page 70) is misleading and oversimplified. That Figure (called Figure 1 in this current article too) is reproduced below for easy reference.

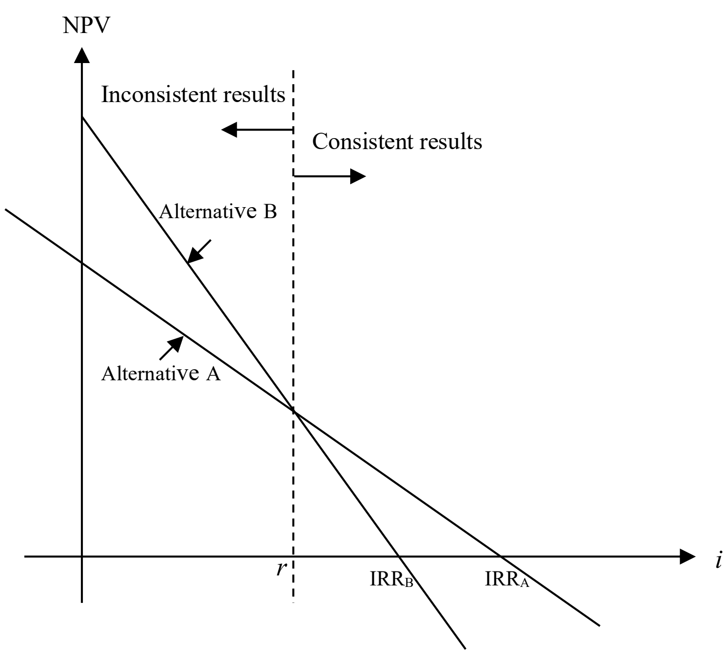

Fig. 1: Potential Inconsistency of NPV and IRR

Alternatives A and B in Table 1 is used to illustrate what this diagram tells, though the author agrees with Hajdasinski (2004) that the two straight lines representing Alternatives A and B are oversimplified. They are oversimplified firstly because they should not be straight lines but curves (close to straight line curves) and the left side of the line for Alternative A should be shown as an asymptote. Secondly, the two curves could take such an approximate shape (for a portion of the curve actually) only if each of the NPV-functions (or the CFPs) has only one sign variation and hence has only one real value of IRR, like Alternatives A and B that is being referred to. This point will be discussed in greater detail later in this article. Nevertheless, Hajdasinski (2004) also said "using free-style graphs for conceptual illustration purposes is a common, helpful, and accepted practice; however, such graphs should always reflect the basic features of the functions involved". Here, the two alternatives A and B (see Table 1) can be reflected by the approximate shapes of the two lines in Figure 1, which is a "free-style graph" that is useful for conceptual illustration. The following is an illustration.

Relate the following values to Figure 1:
On the left hand side of the vertical dotted line of Figure 1 (i.e. for $i < r$)
NPV of Alternative A (assume i = 6% p.a.) = 21.57
NPV of Alternative B (assume i = 6% p.a.) = 26.35
(Alternative B has a higher NPV than Alternative A)
IRR of Alternative A = 9.8% p.a.
IRR of Alternative B = 9.3% p.a.
(Alternative A has a higher IRR than Alternative B)
So, the NPV ranking is inconsistent with the IRR ranking.

Next, on the right hand side of the vertical dotted line of Figure 1 (i.e. for $i > r$)
NPV of Alternative A (assume i = 9% p.a.) = 3.42
NPV of Alternative B (assume i = 9% p.a.) = 1.92
(Alternative A has a higher NPV than Alternative B)
IRR of Alternative A = 9.8% p.a.
IRR of Alternative B = 9.3% p.a.
(Alternative A has a higher IRR than Alternative B)
So, the NPV ranking is consistent with the IRR ranking.

The value of r (as shown in Figure 1) is about 8.5 % p.a., which is between 6% p.a. and 9% p.a. Therefore, the above illustration explains what Figure 1 describes, and hence explains both Tables 1 and 3 for Alternatives A and B.

6. Multiple IRRs of a CFP

Hajdasinski (2004, page 193) also said Tang and Tang (2003) did not address the problem of the financial interpretation of multiple IRRs. The multiple IRR problem was not addressed in Tang and Tang's (2003) article because the main purpose of it was to propose that IRR is a financial indicator and NPV an economic indicator and this proposal was supported by a rigorous mathematical proof in that article. The multiple IRR issue seemed to be quite irrelevant to it. The author feels, however, now is a suitable occasion to address the multiple IRR problem.

Multiple IRRs occur when a CFP contains more than one sign variations, or in other words, when an NPV-function contains more than one sign changes. The author wishes to use the same CFP, here called CFP (6), that was originally used and called CFP (14) by Hajdasinski (2004, page 192). This CFP is reproduced below.

(-8000; 39200; -62500; 32200) (6)

The NPV of CFP (6) shows a positive economic value/return of 175.81 at the minimum attractive rate of return i = 10%.p.a. (one period is assumed to be one year), indicating that it is a viable project because the NPV 175.81 is a positive value. The NPV result is always true, usable and reliable when based on a reasonable MARR (minimum attractive rate of return). For finding the IRR of CFP (6), there are three sign variations in CFP (6) so there are probably three positive real roots (IRRs). But in order to prove that this is absolutely true, CFP (6) has to be transformed into a polynomial equation (see (7) and (8) below).

$$\mathrm{NPV} = -8000 + \frac{39200}{(1+i)} - \frac{62500}{(1+i)^2} + \frac{32200}{(1+i)^3} \tag{7}$$

When the NPV in (7) is set equal to 0, it becomes the polynomial equation (8) as shown below, which can be used for exploring the number of real IRRs and evaluating them.

$$-8000\,i^3 + 15200\,i^2 - 8100\,i + 900 = 0 \qquad (8)$$

To explore the three roots (IRRs) of equation (8) to see whether they are real and positive, or real and negative, or complex-valued, one may apply the Descartes' Rule of Signs (Brodie, from Wikipedia) testing procedures as follows:

$f(i) = -8000\,i^3 + 15200\,i^2 - 8100\,i + 900$ --- 3 sign variations so there are 3 or 1 positive real root(s);
$f(-i) = 8000\,i^3 + 15200\,i^2 + 8100\,i + 900$ --- zero sign variation so there is no negative real root.
So, there are two possibilities: (1) 3 positive real IRRs, or (2) 1 positive real IRR and 2 complex IRRs.

As an important remark, readers' attention is drawn to the fact that the NPV versus *i* curve (Figure 1) for a CFP of more than one sign variations in *f(i)* will have entirely different shapes and will no longer looks like the shape that is shown in Figure 1. Only a CFP with one sign variation (like all examples prior to this section) will have an approximate shape as shown in Figure 1 and has only one real IRR.

Three positive real IRRs (without complex-valued IRR) are found, that is possibility (1) as said above, by solving the polynomial equation (8). The solutions are 15% p.a., 75% p.a. and 100% p.a. The same were found by Hajdasinski (2004) too. From appearance, none of the three IRRs is meaningful. Just by looking at the magnitude of the NCFs of CFP (6) and its NPV (+175.81 only), and by common sense, one cannot be convinced by any meaningful reason that the IRR could be 15% p.a., not to say 75% p.a. or 100% p.a. This will be further discussed a bit later.

Another method of applying Descartes' Rule of Signs is as follows:
Let $y = 1 + i$, then (7) becomes:

$$\mathrm{NPV} = -8000 + \frac{39200}{y} - \frac{62500}{y^2} + \frac{32200}{y^3} \qquad (9)$$

When the NPV is set to be zero, (9) becomes:

$$-8000y^3 + 39200y^2 - 62500y + 32200 = 0 \qquad (10)$$

Apply the Descartes' Rule of Signs to (10):
$f(y) = -8000y^3 + 39200y^2 - 62500y + 32200$ --- 3 sign variations so there are 3 or 1 positive real root(s);
$f(-y) = 8000y^3 + 39200y^2 + 62500y + 32200$ --- zero sign variation so there is no negative real root.
So, there are two possibilities: (1) 3 positive real roots, or (2) 1 positive real root and 2 complex roots.

Solving equation (10), the roots are 1.15, 1.75 and 2.00, and this is possibility (1). By substituting these values into $y = 1 + i$, the IRRs (*i* values) are calculated to be 0.15, 0.75 and 1.00, which are similar to the solutions of equation (8). From this example, it can be seen that the number of sign variations of CFP (6) is the same as that of (9) or (10), and the number of sign variations of CFP (6) therefore is directly related to the number of real IRRs of CFP (6). This is generally true for CFPs with two or more sign variations.

It has been said above that the IRRs obtained from solving (8) or (10) seem to be not meaningful. However, the few decades' long opinion that multiple IRRs are meaningless was found incorrect by Hazen as reported in his article on the new perspective on multiple IRRs (Hazen 2003). According to Hazen, each and every IRR calculated from a CFP, whether real and positive, or real and negative, or complex-valued, is meaningful. In order to explain Hazen's finding, CFP (6) is transformed, based on each of the three IRRs, into three investment streams --- either pure investment stream(s) or pure borrowing stream(s). The transformation is performed as follows:

If a CFP is defined by (NCF_0; NCF_1; NCF_2; …; NCF_t; …; NCF_n), then there are n investment streams associated with this CFP and each investment stream (C_0; C_1; C_2; …; C_t; …; C_n) is obtained by the following relations. Readers may refer to Hazen (2003) and/or Tang (2003, Chapter 3).

$C_0 = -NCF_0$
$C_t = (1+k)C_{t-1} - NCF_t$ where k is an IRR of the n IRRs
$C_n = 0$

For CFP (6), or (NCF_0; NCF_1; NCF_2; NCF_3) = (-8000; 39200; -62500; 32200), n = 3 years and therefore investment streams 1, 2 and 3 are having *k* equal to 15% p.a., 75% p.a. and 100% p.a. respectively. Table 6 below shows how these investment streams are calculated.

Table 6: The three investment streams (C_0; C_1; C_2; C_3) associated with the (NCF_0; NCF_1; NCF_2; NCF_3) of CFP (6)

	C_0	C_1	C_2	C_3	NPV at *i* = 10% p.a.
Stream 1 (*k* =15% p.a.)	C_0 = $-NCF_0$ = 8000	$C_1 = (1+k)C_0 - NCF_1$ = (1+*k*) (8000) – 39200 = -30000	$C_2 = (1+k)C_1 - NCF_2$ = (1+*k*)(-30000) – (-62500) = 28000	$C_3 = (1+k)C_2 - NCF_3$ =(1+k)(28000) – 32200 = 0	+3867.77
Stream 2 (*k* = 75% p.a.)	C_0 = $-NCF_0$ = 8000	$C_1 = (1+k)C_0 - NCF_1$ = (1+*k*) (8000) – 39200 = -25200	$C_2 = (1+k)C_1 - NCF_2$ = (1+*k*)(-25200) – (-62500) = 18400	$C_3 = (1+k)C_2 - NCF_3$ =(1+k)(18400) – 32200 = 0	+297.52
Stream 3 (*k* =100% p.a.)	C_0 = $-NCF_0$ = 8000	$C_1 = (1+k)C_0 - NCF_1$ = (1+*k*) (8000) – 39200 = -23200	$C_2 = (1+k)C_1 - NCF_2$ = (1+*k*)(-23200) – (-62500) = 16100	$C_3 = (1+k)C_2 - NCF_3$ =(1+k)(16100) – 32200 = 0	+214.88

From Table 6, all streams 1, 2 and 3 are called pure investment streams because each of all the three (C_0; C_1; C_2; C_3) have a positive NPV at *i* = 10% p.a. (see the last column). Hypothetically speaking, if the NPV of (C_0; C_1; C_2; C_3) is negative at *i* = 10% p.a., the stream is called a pure borrowing stream. For CFP (6), there is no pure borrowing stream and all the three streams are pure investment streams. And according to Hazen's criteria, for stream 1, *k* = 15% p.a. > *i* = 10% p.a., CFP (6) is viable since it is a pure investment stream. Similarly, for stream 2, since *k* = 75% p.a. > *i* = 10% p.a., CFP (6) is viable because it is a pure investment stream. For stream 3, *k* = 100% p.a. > *i* = 10% p.a., hence CFP (6) is viable again for the same reason. Theoretically speaking, if there is an investment stream that is a pure borrowing stream, then $k < i$ is needed in order to be a viable CFP, and vice versa. The results or the viability obtained from all the streams, according to Hazen (2003), are bound to be consistent with each other and are always consistent with the NPV evaluation of the CFP (i.e. the stream of NCFs) using *i*, and in this case, *i* = 10% p.a. This means that if one knows only one (and anyone) IRR of the multiple IRRs of a CFP, he or she will be able to evaluate the viability of the CFP with that known IRR using the method just described.

The multiple IRRs, therefore, do not cause any "so-far-unresolved financial interpretation problems", a question raised by Hajdasinski (2004, page 193). Hazen's method is, besides positive IRRs, also applicable to negative IRRs and complex IRRs (Hazen 2003) and examples are given in Hazen's article. Therefore, for the Incremental IRR Analysis the current author describes in the early part of this article, using only one (and anyone) Incremental IRR obtained from a stream of Incremental NCFs (e.g., CFP_B - CFP_A) is sufficient to compare two CFPs at a time and this should always be successful. The Incremental IRR Analysis is always workable and the multiple IRR issue is not a hindrance to this Analysis. If the Incremental IRR is a single and real IRR, the use of only the criteria stipulated before Table 2 in Section 2 is already sufficient. But if the Incremental IRR is one of the multiple Incremental IRRs, then the criteria described following Table 6 will prevail. Of course, the latter criteria are applicable also to the single and real Incremental IRR case by substituting *k* equal to this single and real Incremental IRR.

7. The multiple real IRRs calculated from a CFP are not the CFP's true rates of return

At this juncture, it must be pointed out that the IRR can truly represent a CFP's rate of return only if the line (or more accurately, curve) representing the investment is of the approximate shape as shown in Figure 1 such that the CFP has only one real IRR. A related remark has already been given in the paragraph immediately before Table 2 in Section 2. Furthermore, the example explaining why IRR is called a financial indicator in the paragraph under the Section "IRR as a financial indicator" is true only for a CFP with only one real IRR. In these cases, the magnitude of the single real IRR obtained from a CFP can truly represent the rate of return of that CFP. However, for a CFP with multiple IRRs, the magnitudes of the IRRs do not represent the true rates of return. The multiple IRRs in such cases are useful only for transforming a CFP into a number of (C_0; C_1; C_2; …; C_n), the pure investment streams or the pure borrowing streams, by which the investment decision can be made. But for these multiple IRRs, Hazen (2003, page 46) said "the magnitude of the IRR by itself carries no further information". For example, 15% p.a., 75% p.a., or 100% p.a. are the multiple IRRs of CFP (6); none of them represents the true rate of return of CPF (6) --- (-8000; 39200; -62500; 32200).

Similarly, the CFP (-4; 12; -9) given as example by Magni (2010, page 151) has two double roots (for y = 1+ *i*) as follows:

$$-4y^2 + 12y - 9 = 0$$
$$\text{or} \quad (2y - 3)(2y - 3) = 0$$

So, y = 1.5 and 1.5 (double roots), but since y = 1+ *i*, the IRRs (i.e., *i*) are 0.5 (50%) and 0.5 (50%). By common sense, the CFP (-4; 12; -9) can in no way have a rate of return of 50%. The NPV is -0.53, which is reasonable for the CFP (-4; 12; -9). In Robison *et al*. (2015, page 500), Magni's (2010) CFP (-4; 12; -9) was changed to (-4; 12; -8). This example has been mentioned earlier at the end of Section 2. Robison *et al*. calculated the IRR of it to be 0% and the NPV to be 0.30. The IRR decreases from 50% to 0% while the NPV increases from -0.53 to +0.30 by assuming a 10% discount rate. The IRRs calculated are entirely lack of sense but the NPVs are sensible. The magnitudes of the multiple IRRs are not representing the true rates of return and this confirms Hazen's statement "the magnitude of the IRR by itself carries no further information" for multiple IRR cases (Hazen 2003, page 46).

8. Modified IRR and Modified NPV (Robison *et al*. 2015)

The idea of working out a MIRR (modified IRR) and a MNPV (modified NPV) is also proposed to attempt to find a consistent IRR and NPV rankings. The title of the paper "Consistent IRR and NPV rankings" (Robison *et al*. 2015; Lefley 2018) is somewhat misleading because actually it mainly talks about consistent MIRR and MNPV rankings but not consistent IRR and NPV rankings. The concept of calculating MIRR and MNPV is somehow similar to that of calculating ERR (external rate of return). For this concept, the number of sign variations of a CFP is reduced to one by transforming the CFP by means of periodic reinvestments based on the minimum attractive rate of return so only one real IRR will occur at the end (Tang 2003, Chapter 3, pages 47-51)). MIRR and MNPV, in the current author's opinion, are only supplementary methods to the IRR/NPV. There are also two major drawbacks. The following is a brief discussion of the article in question.

For alternatives with no initial investment size differences, they should not be called, as discussed earlier, mutually exclusive investment alternatives but homogeneous investment size alternatives. As given as an example in Table 4 of this current article, the IRR ranking must be consistent with the NPV ranking for homogeneous investment size alternatives. According to Robison *et al*. (2015), the mutually exclusive investment alternatives could have their initial investment size differences adjusted and made equal by scaling or adding approaches. The former approach leads to evaluating scaled MIRR/MNPV and the latter approach to evaluating added MIRR/MNPV, with both approaches using a periodic reinvestment calculation. From Table 4 of this current article, since the initial investment sizes are made equal, the scaled MIRR ranking must be consistent with the scaled MNPV ranking. Similarly, the added MIRR ranking must be consistent with the added MNPV ranking. However, the scaled MIRR/MNPV ranking may not be consistent with the added MIRR/MNPV ranking. This is not so appealing and is a drawback. Furthermore, the calculation as shown in Table III on page 507 of Robison *et al*. (2015) would not be possible if the investment alternatives have multiple IRRs. It is also mentioned in Table V on page 512 of that article that no ranking is possible if multiple IRRs exist. This is another drawback. But for the Incremental IRR Analysis described earlier, it is immune to multiple IRR problems. That is why the current author considers that the Incremental IRR Analysis is more appealing, although it is not the main theme of this article. After all, the IRR and the NPV rankings, in the current author's opinion, need not be consistent provided the concepts on all the issues are clearly understood.

9. Misreading of IRR's real proposition?

Silva *et al*. (2018, page 160) wrote "Due to potential flaws of the IRR, academics have a preference for the NPV method. This was also said by Osborne (2010) eight years earlier than Silva *et al*. However, practitioners apply IRR more frequently than NPV to analyze their investments (Magni 2014). As a remark of the current author to the above statement, the NPV is a number (or figure) that is quite cognitively inefficient, unlike the IRR that can give investors a definite rate of return in percentage per period. The latter is easier than the former to be understood by an investor what he or she can get from an investment, and so probably because of this, practitioners (usually less academic) like to adopt the IRR approach. On the other hand, academics have a preference for the NPV approach because its concept is sound although it (the number or figure) is a bit harder to comprehend. This reason was also observed by Lefley (2018, page 48). Lefley, moreover, mentioned that MGR (marginal growth rate) (Lefley 2015) is a natural extension of NPV, and the MGR (expressed in the form of a rate) should act in the latter's support. Whenever a project shows a positive NPV it will also have an MGR greater than zero and therefore support the same accept/reject decision for mutually exclusive projects (Lefley 2018, page 50). The current author, however, considers that the MGR is, as also said by Lefley, supplementary to the NPV, and because of the need to keep this article within its purpose, MGR is not going to be discussed further here.

Furthermore, Silva *et al*. (2018, page 160) continued to say "there are researchers who assert that the NPV versus the IRR debate only exists because of a misreading of IRR's real proposition", and then the article of Tang and Tang (2003) was cited at that point by Silva *et al*. Tang and Tang (2003) mentioned that it was pointed out in an article related to linear programming (Battaglio *et al*. 1996; Tang 1999) that IRR is meant for a consumer's point of view and NPV for a banker's point of view. To this point, Tang and Tang (2003) added that Battaglio *et al*.'s definition is quite close to the true definition as the consumers usually have relatively limited money and the banks usually have relatively unlimited money. Tang and Tang (2003) then further added that an even more fundamental definition can be given, that is, the IRR gives the private investor's point of view and the NPV the society's (or the community's) point of view. In other words, the IRR is a financial indicator and the NPV an economic indicator. Therefore, together with the earlier arguments in several different Sections in the current article, there should not be a misreading of IRR's real proposition, as Silva *et al*. questioned. The IRR is a financial indicator and is different from the economic indicator NPV intrinsically. This has been explained by a number of examples in this current article. Finally, the author wants to share his experience with the readers: the NPV method is always simple, correct, and accurate; it avoids all the troubles associated with the IRR method. The NPV is the best method for engineering economists.

10. Conclusions

This article firstly demonstrates that the NPV ranking of mutually exclusive multiple alternatives is always correct if the MARR (minimum attractive rate of return) is based. The IRR ranking is not always correct. The IRR ranking is unreliable and is therefore not recommended. The Incremental IRR Analysis (not direct IRR ranking), however, is always consistent with the NPV ranking, and hence is always correct in ranking mutually exclusive multiple alternatives.

When the Incremental IRR Analysis faces the multiple Incremental IRR problem, no matter the Incremental IRRs are real and positive, or real and negative, or complex-valued, the same procedure can be applied in performing the Analysis by using anyone of these multiple Incremental IRRs to rank two alternatives at a time. The procedure is to find an investment stream (C_0; C_1; C_2; …; C_n) by the use of anyone Incremental IRR (or k) of the multiple Incremental IRRs. Then test whether it is a pure investment stream or a pure borrowing stream, and by comparing k with i (MARR), the two alternatives can be ranked (Hazen 2003). Then, two by two at a time and step by step, all alternatives can be ranked.

Then, the function of NPV as an economic indicator and that of IRR as a financial indicator is illustrated by an example (Tang and Tang 2003). The economic indicator NPV should be used to rank multiple projects, but the financial indicator IRR should be used to rank financial arrangements of a single project. The term IRR ranking, however, is used widely to mean ranking multiple projects by ranking their direct IRRs. Hence, that a financial indicator which is only suitable to rank financial arrangements of a single project is wrongly used to rank multiple projects (in an economic sense) is bound to cause problems.

Descartes' Rule of Signs is then applied to explain the total number of real and positive, real and negative, and complex-valued IRRs in a CFP (cash flow pattern). Examples taken from Hajdasinski (2004), Magni (2010), and Robison et al. (2015) are used to illustrate Descartes' Rule and multiple IRRs. Each of the multiple IRRs, no matter real and positive, real and negative, or complex-valued, is meaningful and can be used to make investment decisions (Hazen 2003). Each and anyone of them gives the same result of the investment decision.

In the author's opinion, all other methods such as the MIRR (modified internal rate of return), the MGR (marginal growth rate), the Incremental IRR Analysis, etc. are only supplementary to the NPV method. The NPV method is simple and easy to use for finding the economic return (or economic value) of an investment or for ranking investment alternatives. Throughout the article, the author uses the Incremental IRR Analysis, the comparison of three CFPs with the same NPVs but different IRRs, the multiple IRR theory, and the IRR's real proposition to illustrate that the NPV is an economic indicator and the IRR a financial indicator. The financial indicator IRR is incorrect to be used to rank multiple mutually exclusive investment alternatives, but is useful to be applied by investors to find out the best financial strategy or arrangement to obtain an optimal gain from a single investment project. The economic indicator NPV can tell investors their gain or loss accurately and is suitable for ranking multiple mutually exclusive investment alternatives. The NPV is always simple, correct, and accurate. It is the best method for engineering economists.

11. Note

(1) In the previous article (Tang and Tang 2003), there is a printing error in the last line of page 70: "as the consumers and the banks usually have relatively unlimited money" should read "as the consumers usually have relatively limited money and the banks usually have relatively unlimited money". This change has been announced several quarters later in an issue of *The Engineering Economist*. (2) Another printing error that has not been announced is the last item (Item 12) in the References of the same article that "2nd edition" should read "3rd edition".

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ID 2

A Review of Facilities Management Guidelines for the Living Environment of the Elderly

Ibukun Oluwadara Famakin[1], Ramabodu Molusiwa[1]; Clinton Aigbavboa[1]

[1]Department of Construction Management and Quantity Surveying, University of Johannesburg, Johannesburg, South Africa.
famibuks@gmail.com

Abstract

The population of elderly people is significantly increasing across different parts of the world. In fact, it is estimated that the number of elderly people in the world will exceed the number of children in 2022. Due to the increasing number of cases of decline in the health of the elderly, there will be increased demand for special additional facilities to enable them to maintain their independence in the living environment. To understand the needs of the elderly, there is the need to identify the basic and special facilities required by the elderly in their living environment. Therefore, this study seeks to identify the facilities management (FM) needs of the elderly and the corresponding guidelines for different countries across the world. A comprehensive literature search was conducted to identify the FM guidelines for residential apartments of the elderly in different countries of the world. The FM guidelines were assessed to understand the basic and special needs for the comfort of the elderly in their living environment, while content analysis of the guidelines was conducted and presented under three different categories identified in literature namely space management, building services and supporting facilities. The study reveals that many of the suggested FM components in the guidelines were general needs of disabled individuals without adequate consideration of the specific health needs of the elderly. The study recommends that a comprehensive anthropometric measurement of different elderly groups is conducted in order to provide detailed FM guidelines for meeting both the basic and special needs of the elderly in the living environment.

Keywords

Elderly; Facilities Management; Living Environment; Sustainability

1. Introduction

Increasing life expectancy, declining fertility and improved healthcare is responsible for the significant rise in the elderly population around the world (Hui and Yu 2009; United Nations 2013). The number of elderly persons is expected to outnumber the population of children aged 0-14 for the first time in human history within the next few years (United Nations 2006). According to the United Nations, the number of people aged 65 and above living in the world is 727 million, which is about 9.3% of the population in 2020. The percentage of elderly people in around the world is expected to reach 1.5 billion (i.e. 16.0% in 2050 (United Nations 2020). This means that the number of elderly people will be doubled within the next 2.8 decades. Therefore, it is urgent to investigate issues affecting the comfortability of the elderly in their living environment (Murphy et al. 2006).

Housing is a basic need, and its quality is one of the best indicators of a person's standard of living (Alagbe 2011; OECD 2011). To meet the diverse needs of the ageing population, the government of different countries have formulated different policies to guide in the provision of comfortable housing for the elderly. For instance, the principle of ageing-in-place to enable elderly people live in their home environment with minimum disruption was adopted by the Hong Kong government (Hong Kong Policy Address 2016), the United States government provides rental assistance for those on low incomes and promotes home-ownership through interventions in mortgage markets (Olsen and Zabel 2015); and the Chinese government advocates home-ownership for middle and high income families and social housing for low-income families (Zenou 2011).

Ageing-in-place is facilitated by ensuring adherence to Universal Design standards for interior facilities of new residential apartments to meet seniors' needs (Wai 2006), and provision of diverse housing choices and schemes (Cheng 1999). However, most elderly residents reside in old residential apartments which may be over 50 years and lacking facilities required for meeting their daily needs. Hence, practical steps are required to improve old apartments and, when necessary, provide new flats with facilities that will meet the needs of the teeming elderly population.

Facilities refer to the space, living environment, support and services enabling the achievement of key business objectives, and integrating development, operation and needs of the business (Alexander 1999). Management, on the other hand, involves the process of planning, leading, organizing and controlling the resources of an organization to meet its objectives through the commitment of employees (Weihrich and Koontz 1993). It incorporates the people (referring to the elderly in this study), place (the residential apartment) and processes (the facilities) to provide an enabling environment (Springer 2004).

The provision of quality facilities management (FM) components becomes very important for the elderly because they largely depend upon the facilities to make up for the inherent disabilities and deficiencies associated with old age. In fact, the elderly becomes more susceptible to various health challenges requiring the provision of appropriate facilities to enhance their livelihood. Hence, the design of the building must be aligned to address the age-related functionality and supportive role required to improve their quality of life (QoL). The current study thus seeks to identify the current guidelines for the living environment of the elderly which will serve as a basis for comprehensive design requirements for aligning and meeting elderly needs.

2. Research Methodology

To understand the FM needs of the elderly in the living environment, a content analysis of international guidelines across different countries was conducted, including United States, United Kingdom, Canada, Hong Kong, Ireland, New Zealand, Nepal and India. These countries were chosen because they had a comprehensive FM guideline and requirements specifically prepared for the elderly. The content of the guidelines considered in this study consists of the following sections: (1) identification of the FM needs of the elderly under the three major categories, including space management, building services and supporting facilities; and (2) the requirements of the guidelines as it affects the comfortability of the elderly in the living environment.

A systematic procedure was followed in the review of guidelines for this study as follows: firstly, a thorough literature review was conducted to ascertain some of the FM needs in the residential apartment of the elderly. Secondly, an electronic search of relevant guidelines for the living environment of elderly people was conducted using the housing department website of different countries, and references in different published articles indicating housing requirements of different countries. In addition, google scholar was also used in the search for the guidelines using words such as "facilities", "accessibility design standards", "living environment requirements", "universal design requirements", "housing standards", etc. The guideline for 13 countries were identified from the electronic search conducted.

A total of 19 FM needs were identified from literature for the residential apartment of the elderly, including 3 space management components, 7 building services components and 9 supporting facilities components (Famakin 2018; Leung et al. 2019). The key words as identified from literature for the FM components were searched in the guidelines to explore the minimum requirements from each identified country. For inclusion in the study, countries with guidelines for at least five (5) of the FM needs for the elderly outlined from literature were considered. Each of the FM needs have been introduced, findings presented under the three major categories and outcomes from the different guidelines have been outlined in Table 1.

3. Results and Discussion

The outcome of the comprehensive study of the guidelines of different countries have been outlined in Table 1. The FM needs of the elderly in their living environment have been grouped under three components, namely space management, building services and supporting facilities. For the space management components, the study focuses on turning spaces, clear spaces and sizes of different spaces available in a typical residential apartment. On the other hand, building services considers the lighting, ventilation, temperature (i.e. room and water temperatures), electrical fittings, safety and security gadgets, lift service (if any) and fire service. Lastly, supporting facilities takes a look at the colour, furniture, floor finish, signage, doors, windows, acoustics, handrails and grab bars.

3.1 Space Management

Space management focuses on the building design and layout (Cotts 1999). It includes sizes of rooms, distance between rooms as well as turning and clear spaces within the apartment. Turning spaces and clear spaces are essential housing design requirements for facilitating elderly's essential activities within the interior spatial areas. It supports their independent movement and manoeuvring for the elderly within the home. It is particularly important because some elderly may require a walking assistance or support (e.g., a walking frame or wheelchair) for movement within the home to engage in daily activities. Therefore, a sufficient turning and clear space is necessary in the different spaces within the home.

Turning spaces as provided in the requirement of different countries reveal that spaces made available allow for a 360^0 turning of a walking assistant such as wheelchairs, scooters for the easy manoeuvring of the elderly within the living environment. The spaces provided (e.g., 1500mm circular space for UK elderly; Lifetime Homes 2010) are dependent on the average size of the walking assistant used by the elderly in the country. Some other countries e.g., Ireland and Nepal (i.e. 675mm for able bodied elderly, and 750-900mm for those using walking frame/crutches) also made provision for elderly people with mild changes in walking conditions.

A few countries have specific guidelines for the provision of clear spaces for the elderly in the living environment. For instance, in the United States, a 305mm clear space parallel to at least one side of the bed is required to ensure easy mobility for the elderly in their residential apartment; this may not accommodate those using a walking assistant (United States Department of Justice 2010). On the other hand, Canada stipulates the provision of a minimum of 760 x 1370mm clear space to accommodate a wheel chair (City of London 2007). The provision of adequate clear space for the elderly will help ensure their independent movement within the home (able-bodied and mild changes in walking) and for easy transfer from wheelchair to the bed (wheelchair users).

3.2 Building Services

Building services refer to services that aid the effective functioning and fulfilment of the elderly's basic needs and consists of lighting, ventilation, temperature, electricity fittings, safety and security, lift and fire service within the residential apartment of the elderly (Bitner 1995; Leung et al. 2019). Lighting is a powerful design tool for visual perception effectiveness (Zhang and Ma 2010); ventilation removes contaminated and stale air, and creates optimal conditions for air quality and comfort (Dimitroupoulou 2012); temperature influences the thermal comfort of elderly residents; electricity fittings are pivotal to communication efficiency, cooking, comfort and many other activities in the living environment; lift services are useful for vertical movement in a high-rise environment, while fire services is a significant facility for ensuring safety of elderly people during a fire.

The specific requirements for building services were very scanty in many of the guidelines for different countries (refer to Table 1). Lighting is a measure of the illuminance (i.e. luminous flux per unit area) with the lux as the international system of units. It is a measure of the intensity as perceived by the human eye. A suggestion of fluorescent tubes with uniform illumination measuring 300 lux and 1000 lux for ambient and task light respectively were found appropriate for US elderly (Figueiro 2001); while a lighting intensity of 108 lux was suggested for sleeping which should be measured at 760mm above ground level was also provided (IES 2001). For Hong Kong guidelines, it is required that residential apartments for the elderly provide a minimum uniform illumination of 85 lux and a maximum of 120 lux internally (Hong Kong Buildings Department 2008).

For the ventilation of the residential apartment, a percentage of the floor area in the rooms was required as available for inflow of air into the room for natural ventilation, while the air changes per hour was provided for mechanical ventilation for the elderly (refer to Table 1 for details). On the other hand, the guidelines also made provisions for room temperature as well as the water temperature in the bathroom of the elderly. Similar range of temperature for the room temperature and water temperature was found in the different guidelines, including 21.6-27.2^{0}C in the United States and 21-26^{0}C in Toronto for room temperature, while 43^{0}C in the United States and Ireland for the water temperature.

Electrical fittings as an instrumental building service in the home was not given adequate consideration in many of the guidelines observed. The requirements provided by few countries have focused on height for lighting switches and electrical sockets within the home. For instance, lighting switches are required to be positioned between 900-1200mm high in Canada and India (City of London 2007; Central Public Works Department 2014), 750-1000mm high in Ireland (International Wheelchair Association 2009) and 610-1200mm high in Toronto; while electrical sockets are expected to be positioned 400mm high in Canada, 400-1000mm high in Ireland, and 400-500mm high in India.

The safety and security is crucial to the health and protection of the elderly from injury, theft, vandalism and personal attack (Kratcoski and Edelbacher 2016). However, only three of the nine countries in this study have at least a guideline for the safety and/or security of the elderly in the residential apartment. For the United Kingdom, the walls and furniture were to be rounded off, while gas leak detection with alarm was to be installed (LIN 2007); Hong and India provides for a 13mm grating or walking surface unparalleled with the direction of travel path (Hong Kong Housing Society 2005; Central Public Works Department 2014); and Ireland ensures that a call system with accessible alarm facility is provided for each bed unit for the safety of the elderly (International Wheelchair Association 2009).

Lift service for vertical transportation of the elderly focussed on the space size of the lift, height of lift control/button panel, opening time of lift at landing and door closing speed of the lift. Many of these lift requirements do not align with the turning space requirement for the wheelchair within the lift, which may be necessary during usage. For instance, lifts in the UK are to be within 1100x1400mm, where a turning space of 1500mm circular or 1700x1400mm turning eclipse was the requirement (Lifetime Homes 2010). For fire service, only two out of the 9 countries for consideration have a guideline (refer to Table 1). In the United States, provision is made for fire alarm systems with smoke detectors in all sleeping rooms and outside of a separate dwelling unit within 6400mm of any door to a sleeping room with unobstructed escape route (NFPA 2013). On the other hand, audible and visible components of fire alarms 1200mm high which should alert elderly with sensory limitations is required in Tornto (Healthy City Office 2004).

Table 1: International Guidelines for FM Component Needs of Elderly People in Residential Apartments

FM Components	United States	UK	Canada	Hong Kong	Ireland	New Zealand	Toronto	Nepal	India
Space Management									
Turning spaces	1525mm (T-shaped) with arms and base 915mm[1]	1500mm circular or turning eclipse of 1700x1400mm[2, 28]	2440mm circular[3]		675-1800mm[6]	1500-1950mm[7]		550-950mm[9]	1500-2000mm[10]
Clear spaces	305mm parallel to at least one side of bed[1]	750mm width for essential circulation[2]	760 x 1370mm[3]	900mm on side of one side of bed[4]					
Size				800x1500mm bathroom size; 2900-3400 x 3000mm bedroom size[4]	2500x2500mm bathroom and/or toilet size[6]		1500x1675mm toilet size[8]	2000x2000mm bathroom and/or toilet size[9]	
Building Services									
Lighting	108-1000 lux[11,12]		100-200 lux; evenly distributed light for non-glare illumination[3]	75-300 lux[4,5]	150-250 lux[6]	100 lux minimum[27]	100 lux, fixtures mounted to ensure headroom of 2030mm[8]		
Ventilation	4-8% of floor area; 0.35 air changes per hour[13,14]			1.5-5 air changes per hour; glazing area, 10-20% of floor area[27]					
Temperature	21.6-27.2^{0}C room temp.[16]	43^{0}C water temp.[18]	20-25^{0}C; 40-70% humidity room temp.[19]		60^{0}C storage, 50^{0}C distribute, 43^{0}C supply, water temp.[17]	55^{0}C water temp; adequate controlled interior temperature[7]	21-26^{0}C; 30-40% humidity room temp.; 49^{0}C supply max. water temp.[8]		
Electricity fittings			Lighting switch, 900-1200mm high; electrical sockets, 400mm high[3]		Electrical sockets, 400-1000mm high; lighting switch, 750-1000mm high[6]	Lighting switch aligned with door handles, 900-1200mm high; electrical socket, 500-1200mm high[7]	Lighting switch, 610-1200mm high[8]		Electrical sockets, 400-500mm high; lighting switch, 900-1200mm high[10]
Safety and security		Round off corners of walls and furniture; install gas leak detection with alarm[21]		13mm grating or walking surface unparalleled with direction of travel path[5]	Call system with accessible alarm facility for each bed unit[6]				13mm grating or walking surface unparalleled with direction of travel path[20]

Lift service		1100x1400mm; lift control 900-1200mm high[2]		1200x1100mm; lift button, 20mm size and 900mm high; 3s, lift opening time at landing[5]	1800x1800mm/ 1400x2000mm; lift control /button panel, 900-1100mm high; 20s, lift opening time at landing[6]	1400x1400mm; car button, 20mm width/ diameter; lift control, 900-1350mm high; door, 900mm width[7]	1065x1370mm for normal; 1725x2285mm for serving seniors and disabled persons		1100x2000mm, lift control /button panel, 900-1100mm high; 20mm lettering size; 0.25m/s, lift door closing speed[10]
Fire service	Fire alarm system with smoke detectors and notification appliances within 6400mm of any door[22]						Audible and visible fire alarm signals, 1200mm high[8]		
Supporting Facilities									
Colour	3:1 light reflection ratio within space[23]		Careful selection of pattern to avoid visual confusion[3]			Luminance contrast of 30%[27]	70% contrast from background colour; 40% contrast for industrial yellow[8]	Use of distinguishing colours between doors and surrounding walls[9]	
Furniture		Bed surface, 400-450mm high; wardrobe drawers and shelves, 600mm high; wardrobe rails, 1400mm high		900x2000mm bed size for single elderly[4]					
Floor finish	Carpet securely attached to have firm cushion[1]						Careful selection to avoid unduly amplified noise, reflected glare[8]		
Signage	15-51mm character height; San Serif font; upper case[1] 16-51mm lettering height for 1830-6400mm distance at 1015-3050mm height[24]				25mm, information signage size; 37mm, directional signage size; 1400-1700mm high[6]	Signage should be clear and legible as well as informative, directional and locational, positioned at 1400-1700mm high[7]		Clear signage in large letters and at eye level[9]	600-200mm plain and legible lettering using international symbols; 900-1500mm high[20]

Doors	815-915mm; 1980mm high for door closers and door stops; 22.2N force[1]		850-950mm width; handle, 900-1000mm high; 22-38N force[3]	800mm width; handle, 950-1050mm high; 20mm threshold; 22-30N force[5]	900-1000mm width; lever handle, 900-1000mm high; 20N force[6]	760mm width; handle with lever action positioned at 900-1200mm high; 22-38N force[7]	915mm width; 75-100mm D-type handle, 760-1065mm high[8]	900mm width; lever handle, 800-1000mm high[9]	900mm width; handle, 950-1050mm high; 20mm threshold; 22-30N force[20]
Windows			Window sill, 760mm high; handle, 400-1200mm from floor[3]	Window sill, 1000mm high[26]	Lever handle, 800-900mm high; transom, 1200mm high; sill, 850mm high[6]	Operating locks and latches should have lever action, positioned 900-1200mm high[7]	Lever handle, 1065mm high; transom, 1200mm high; sill, 760mm high[8]		Handle, 900-1200mm high; Sill, 800mm high[20]
Acoustics	47dB(A)[25]								
Handrails	32-51mm ϕ or 57x100-160mm non-circular; 38mm minimum clearance; 865-965mm high from floor[1]		30-40mm ϕ or 45x100-125mm non circular; 50-60mm space between handrail and wall; 865-920mm high from floor; 0.9kN load resistance[3]	32-50mm ϕ tubular; 30-50mm clear of wall, 300mm beyond surface of facility; 850-950mm high; 1.3kN load resistance[5]	32-45mm ϕ or 50mm oval; 60-75mm space between handrail surface and wall; 300mm projection beyond edge of wall; 600-900mm high[6]	32-45mm ϕ; 50-60mm clear space between handrail and wall surface; 840-1000mm high; 1.1kN load resistance[7]	30-50mm ϕ; 40-65mm space between handrail and wall surface; 300mm projection beyond edge of wall; 865-965mm high[8]	35-45mm round; lower handrail, 700-750mm; top handrail, 860-920mm; 300mm extension beyond top and bottom of wall/ stair/ramp[9]	32-50mm ϕ; 30-50mm clearance between handrail surface and wall; 850-950mm high; 1.3kN load resistance[20]
Grab bars	32-51mm ϕ or 51x100-120mm non-circular; 38mm spacing; 840-915mm high from floor; 1065mm length for side wall grab bar[1]			32-50mm ϕ; lower bar, 700-800mm high; upper bar 850-950mm high[4]		30-40mm ϕ; 50-60mm clearance between grab bar and wall; 840-1000mm high; 1.1kN load resistance[7]			

Note: [1]United States Department of Justice (2010); [2]Lifetime Homes (2010); [3]City of London (2007); [4]Hong Kong Housing Society (2005); [5]Hong Kong Buildings Department (2008); [6]Irish Wheelchair Association (2009); [7]New Zealand Standard (2001); [8]Healthy City Office (2004); [9]Handicap International Nepal (2009); [10]Central Public Works Department (1998); [11]Figueiro (2001); [12]Illumination Engineering Society (2001); [13]International Code Council (2007); [14]State Virginia Mechanical Code (2006); [15]Hong Kong Buildings Department (2015); [16]Woronchak (2004); [17]Health Information and Quality Authority (2008); [18]Department of Health (2003); [19]Hong Kong Department of Health (2012); [20]Central Public Works Department (2014); [21]LIN Housing (2007); [22]National Fire Protection Association (2013); [23]Mahnke (2012); [24]International Code Council (2010); [25]National Joint Committee for the Communicative Needs of Persons with Severe Disabilities (1992); [26]Hong Kong Buildings Department (2012); Barrier Free NZ Trust (2013).

3.3 Supporting Facilities

These are facilities that enhances the indoor environment of the elderly, including color, furniture, floor finish, signage, doors, windows, acoustics, handrails and grab bars (Duncan-Myers and Huebner 2000). For furniture, only one (i.e. Hong Kong) of the nine countries considered provided the bed size for a single elderly (Hong Kong Housing Society 2005). Specific colour requirements are not available in the guidelines, but generic information including careful selection of pattern to avoid visual confusion for Canada (City of London 2007); use of distinguishing colours between doors and surrounding walls as in Nepal (Handicap International Nepal 2009), etc. (refer to Table 1).

Similarly, floor finish for the elderly was generic in description with suggestions for secure attachment for firm cushion in the United States (United States Department of Justice 2010) and careful selection to avoid amplified noise and reflected glare in Toronto (Healthy City Office 2004). The concept of signage as reflected in different guidelines focuses on the size and height of lettering in all three countries (i.e. United States, Ireland and India); font size as in the United States and use of symbols as in India (refer to Table 1). On the other hand, doors and windows centers on width of doors ranging between 815-915mm for all countries, type and height of door or window handle, maximum force required for opening the door, transom and sill height of the windows amongst others.

Lastly, similar features were considered for handrails and grab bars in the residential apartment of the elderly. The following are the requirements: the diameter and/or perimeter of the handrail and grab bar in all seven countries involved in the study, minimum space and/or clearance between the handrail/grab bar and wall surface, minimum and maximum height of the handrail and/or grab bar from the floor surface, and minimum load resistance of the handrail and grab bar (United States Department of Justice 2010; Hong Kong Buildings Department 2008).

4. Conclusion

The study has explored the FM needs of the elderly and the corresponding guideline requirements in selected countries around the world. This will provide designers and facilities managers with a thorough understanding of the needs of the elderly for ensuring their comfortability in the living environment. It will also ensure that the various requirements for consideration in the design and management of facilities for the elderly in their living environment is adequately understood and catered for. However, many of the FM requirements in the guidelines were not directly provided for the elderly but for disabled persons within the living environment. To ensure that the needs of the elderly are adequately met, it is essential to conduct a quantitative study for assessing the importance of the identified facilities in this study and their current satisfaction with the facilities available in their residential apartment. In addition, further studies using anthropological measurement of the elderly and the physical measurement of facilities needed to ensure that the requirements will directly meet their specific demand should be carried out. This will ensure a more objective approach in ensuring that facilities provided in the apartment of the elderly meet their specific needs in the living environment.

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Comparative Analysis of Critical Success Factors for Smart and Sustainable Developments Between Organizations and Among Construction Professionals

Ibukun Oluwadara Famakin[1], Clinton Aigbavboa[1], Ramabodu Molusiwa[1]

[1]Department of Construction Management and Quantity Surveying, University of Johannesburg, Johannesburg, South Africa.
famibuks@gmail.com

Abstract
The development of smart and sustainable infrastructure projects requires great teamwork and a common understanding of the success requirements. There seems to be no general agreement among organizations and construction professionals about critical success factors (CSFs) for smart and sustainable development. This study thus compares CSFs for achieving smart and sustainable developments between organizations and among construction professionals. A questionnaire survey, including 40 CSFs was designed and distributed among various construction professionals working in different organizations and involved in smart construction activities in Abuja, Nigeria. The responses were analysed using the mean score for identifying the level of agreement of the different construction professionals with different CSFs; and one-way analysis of variance for exploring the significant difference among the perception of the construction professionals. The result of the mean score indicates that the different organizational types and construction professionals rated all the CSFs high indicating that there is an agreement with the factors as critical to the success of smart and sustainable developments. The independent samples t-test shows the significant difference with cooperation and participation of stakeholders as well as energy efficiency; while the one-way analysis of variance reveals significant difference with clearly defined goals, cooperation and participation of stakeholders, project procurement system, energy efficiency, waste management and land use change. The study suggests the involvement of organizations and professionals at every stage of the development starting from the design brief to commissioning and maintenance of the project.

Keywords
Construction, Critical Success Factors, Smart Buildings, Sustainability, Nigeria

1. Introduction

Although the construction industry performs an essential role in enhancing the quality of life of users through the provision of critical infrastructure, it has also been a source of depletion of the natural environment and its resources (du Plessis 2007). There have been series of harmful activities traced to the construction industry, including the depletion of non-renewable resources, destruction of landscapes, creation of health and safety problems as well as generating large quantities of wastes and altering the natural ecosystem, (Azapagic 2004; Kibert 2013). This has led construction industry experts to adopt different strategies for tackling the problems posed to recipients of infrastructural developments from the construction industry, particularly involving a more thoughtful and responsible approach with the future generation in mind (Bakens 2005; Dania 2016).

In the last few years, smart city concepts and sustainable developments have been positive urban planning practices and initiatives to ensure the increasing population in urban areas live comfortably, enjoy a good quality of life and improve the performance of the construction industry. The underpinning principle for these concepts has been to concurrently align the economic, social and environmental dimensions in the development of infrastructure as well as the performance and functionality of construction projects (Dania 2016). However, teamwork and a common understanding of the concept of sustainable development and smart city, as well as the knowledge of critical success factors (CSFs) for smart and sustainability development among the different construction professionals that execute construction projects, is vital. Therefore, this study seeks to compare CSFs for achieving smart and sustainable developments among construction professionals. This will enhance the mutual understanding of the CSFs factors among the construction professionals for the success of infrastructural developments.

2. Professionals Involved in Construction Developments

A construction professional refers to individuals with a career in a construction-related discipline, including architects, quantity surveyors, engineers, builders, etc. They have adequate training, skills, competence and technical know-how to produce aesthetically, affordable and structurally sound living environment for the comfort and liveability of humans. For instance, an architect is a licensed professional trained with the art and science of building design and concept for structured which provides images and plan for the overall aesthetics and appearance of buildings (Fame Pyramids Limited 2017). The architects preserve, improve and create the quality required of the built environment through the integration of the concept of sustainable community development (Chansomsak and Vale 2009).

Quantity surveyors are construction economists who fulfill varied and comprehensive duties to support cost-effective construction and property development projects (Famakin et al. 2014). Engineers involved in construction include structural engineers (i.e. they provide design drawings showing details of the structural element to enable fabrication, installation and connection); mechanical engineers (i.e., they prepare contract drawings for mechanical services required in the building, namely plumbing, ventilation and air condition, fire services, etc); and electrical engineers (who prepare complete drawing showing the electrical services needs, including lighting and power, HVAC systems, alarm systems, etc) (Olatunji et al. 2014). On the other hand, builders are trained construction professionals who study the drawings, schedules and specifications and analyses the buildability and maintainability of the drawings (Fame Pyramids Limited 2017).

3. Critical Success Factors for Smart and Sustainable Development

Critical success factors have been an explorative tool for selecting the most important and decisive factors for achieving the success of construction projects and infrastructure developments. For instance, there have been numerous studies exploring important factors for success of construction projects, including for large-scale construction projects (Nguyen et al., 2004; Toor and Ogunlana 2009); joint venture procurement (Famakin et al. 2012); implementation of public-private partnerships (Alinaitwe and Ayesiga 2013); smart cities (Aldegheishem 2019) etc. Although there is a need to identify a set of common success factors for measuring the success of construction projects, the agreement of construction professionals on the list of identified factors is essential considering the diverse nature of construction projects (Nguyen et al., 2004; Toor and Ogunlana 2009). Based on an extensive literature review, CSF for smart and sustainable developments have been identified and will be discussed subsequently.

The technical factors of sustainability refer to prerequisite skills and expertise needs for implementing smart and sustainable development, including experience and competence, effective project monitoring, management commitment, current technology and methods, project procurement system, etc. Experience and competence are necessary for construction professionals to understand client's expectations and execute according to their specific requirements (Shen et al. 2017). High-quality workmanship as a requirement is central to integrating sustainability into construction projects because of the use of current construction technology for implementation (Banihashemi et al. 2017; Sfakianaki 2019). Education and training have been a long-term beneficial factor for integrating sustainability in the construction industry (Whang and Kim 2015).

Economically, smart and sustainable buildings often lead to life cycle savings despite the high initial investment and cost (Kats et al. 2003). The enactment of sustainable policies by government and professional institutions aid the implementation of smart and sustainable principles in construction projects (Gan et al. 2015; Banihashemi et al. 2017). In fact, regulations and related legislation are to be updated periodically to the standard requirements of sustainable construction to enhance smart and sustainable urbanization. Land use change, energy efficiency, and waste management have been identified as success factors that contribute significantly to the environment for smart and sustainable developments (Cox et al. 2013; Whang and Kim 2015; Luangcharoenrat et al. 2019).

4. Methodology

4.1 Questionnaire design

Based on extensive literature, a questionnaire survey was designed to investigate the different agreement level of construction professionals with CSFs for smart and sustainable development. The questionnaire consists of two sections: (1) demographic characteristics of construction professionals; and (2) degree of agreement with 40 CSFs.

Respondents were required to rate the degree of agreement with the CSFs ranging from 1 (highly disagree) to 7 (highly agree). The questionnaire was distributed among construction professionals working on smart and sustainable developments in Abuja, Nigeria.

4.2 Data collection and sampling

The survey was distributed to registered construction professionals practicing in Abuja, Nigeria. To identify the respondents for the study, the following criteria were used: (1) they were registered construction professionals working in the Federal capital territory (FCT); and (2) they were currently working on a construction project within the FCT. A total of 75 questionnaires were retrieved from the respondents, including 42.7% working in consulting organizations and 57.3% in contracting organizations. More than one-third (i.e. 34.8%) of the respondents were architects, 26.1% were quantity surveyors, 15.9% were engineers and 23.2% were builders.

4.3 Data analysis

The data collected were analyzed using SPSS 21.0. Firstly, mean score was conducted to identify the level of agreement of the different construction professionals with different CSFs. Lastly, a one-way analysis of variance (ANOVA) was conducted to compare the level of agreement of construction professionals with CSFs for smart and sustainable developments.

5. Results

5.1 Independent Samples T-test for Organizational Agreement with Critical Success Factors of Smart and Sustainable Developments

The differences in the level of agreement with CSF items in consulting and contracting firms were determined using the Independent Samples T-test (refer to Table 1). The results revealed that all the CSFs were not significantly different between the organizations except for cooperation and participation of stakeholders (t = 2.856, p = 0.005) and energy efficiency (t = 2.953, p = 0.004). It is also worthy of note that the different types of organizations rated all the CSFs high, indicating the level of agreement with the factors as critical to the success of smart and sustainable developments.

Table 1 Independent Samples T-test for Organizational Agreement with Critical Success Factors of Smart and Sustainable Developments

CSFs	Consulting		Contracting		Mean Diff	t	Sig.
	Mean	SD	Mean	SD			
Strong commitment	5.531	0.915	5.419	1.332	0.113	0.411	0.682
Enacting required policies	5.750	0.762	5.279	1.436	0.471	1.831	0.072
Clearly defined goals	5.438	1.014	5.256	1.416	0.182	0.647	0.519
Knowledge and awareness	5.688	1.176	5.326	1.393	0.362	1.188	0.239
Constructive relationship	5.281	0.991	5.349	1.193	-0.068	-0.260	0.795
High quality workmanship	5.406	0.979	5.558	1.201	-0.152	-0.585	0.560
Accountabilities and responsibilities	5.531	1.191	5.628	1.113	-0.097	-0.361	0.719
Experience and competence	5.750	1.078	5.814	1.006	-0.064	-0.264	0.792
Minimization of water and noise pollution	5.656	1.035	5.628	0.900	0.028	0.126	0.900
Effective project monitoring mechanism	5.906	0.689	5.837	0.949	0.069	0.348	0.729
Availability of resources	5.625	1.008	5.698	0.939	-0.073	-0.321	0.749
Current construction technology and methods	5.563	0.914	5.581	1.052	-0.019	-0.081	0.935
Governments' support and incentives	5.125	1.314	5.395	1.275	-0.270	-0.897	0.373
Consumer acceptance	5.875	0.907	5.674	1.286	0.201	0.753	0.454
Education and training	5.844	1.194	5.651	1.232	0.193	0.678	0.500
Support from financial institutions	5.281	1.397	5.395	1.116	-0.114	-0.393	0.695
Related technology and sustainable materials	5.656	1.260	5.721	1.141	-0.065	-0.232	0.817
Industrial and/or organizational culture	5.375	1.385	5.558	1.278	-0.183	-0.592	0.556
Initial investment and/or construction costs	5.750	1.107	5.628	1.134	0.122	0.466	0.643
Qualified workers and expertise	5.844	1.110	5.837	1.090	0.007	0.026	0.980
Available construction time	5.750	1.218	5.628	1.024	0.122	0.471	0.639
Support from professional institution	5.625	1.129	5.326	1.210	0.299	1.091	0.279
Cooperation and participation of stakeholders	5.875	0.833	5.233	1.109	0.642	2.865	**0.005****
Project procurement system	5.656	1.234	5.279	1.182	0.377	1.342	0.184
Legal and regulatory framework	5.594	0.979	5.233	1.250	0.361	1.353	0.180

Energy efficiency	5.938	0.669	5.233	1.360	0.705	2.953	**0.004****
Efficient use of resources	5.469	1.459	5.465	1.162	0.004	0.012	0.990
Waste management	5.688	1.306	5.372	1.363	0.315	1.009	0.316
Land use change	5.188	1.355	5.465	1.297	-0.278	-0.900	0.371
Indoor environment quality	5.438	1.190	5.558	1.076	-0.121	-0.459	0.648
Long-term costs	5.469	1.047	5.395	1.237	0.073	0.271	0.787
Affordability	5.656	1.285	5.535	1.054	0.121	0.449	0.655
Production planning	5.750	0.950	5.674	1.063	0.076	0.318	0.751
Impact on health and community	5.906	1.118	5.535	1.077	0.371	1.454	0.150
Awareness	6.031	0.740	5.651	1.089	0.380	1.703	0.093
Durability	5.594	1.188	5.767	0.947	-0.174	-0.705	0.483
Innovation	5.781	0.832	5.651	0.923	0.130	0.629	0.531
Communication	5.625	0.907	5.651	0.897	-0.026	-0.124	0.901
Facilitating green practices	5.719	1.198	5.791	1.059	-0.072	-0.275	0.784
Management and commitment	6.156	0.954	5.860	1.246	0.296	1.120	0.266

Note: S.D. = Standard deviation; Sig. = significance level; and **ANOVA is significant at the 0.01 level (2-tailed).

5.2 One-way Analysis of Variance (ANOVA) for Professionals' Agreement with Critical Success Factors of Smart and Sustainable Developments

The study considered four groups of construction professionals popularly involved in the Nigerian construction industry, namely architect, quantity surveyors, engineers, and builders. To compare their level of agreement among the four groups of construction professionals, the study adopted the one-way between-groups ANOVA. In comparing with the different professionals' groups, the findings (refer to Table 2) reveal that clearly defined goals ($F = 3.179$, $p = 0.030$), cooperation and participation of stakeholders ($F = 3.240$, $p = 0.028$), project procurement system ($F = 2.771$, $p = 0.049$), energy efficiency ($F = 6.595$, $p = 0.001$), waste management ($F = 4.042$, $p = 0.011$) and land use change ($F = 3.071$, $p = 0.034$) were statistically and significantly different.

Table 2 One-way Analysis of Variance (ANOVA) for Professionals' Agreement with Critical Success Factors of Smart and Sustainable Developments

CSFs	Professionals	Mean	SD	F	Sig.
Clearly defined goals	Architect	5.667	0.868	3.179	**0.030***
	Quantity Surveyor	5.611	0.698		
	Engineer	5.091	1.868		
	Builder	4.563	1.548		
	Total	5.304	1.275		
Cooperation and participation of stakeholders	Architect	5.542	0.779	3.240	**0.028***
	Quantity Surveyor	5.944	0.873		
	Engineer	5.636	1.120		
	Builder	4.875	1.360		
	Total	5.507	1.066		
Project procurement system	Architect	5.458	1.103	2.771	**0.049***
	Quantity Surveyor	5.889	0.676		
	Engineer	5.636	1.748		
	Builder	4.750	1.291		
	Total	5.435	1.230		
Energy efficiency	Architect	5.917	0.881	6.595	**0.001****
	Quantity Surveyor	5.889	0.758		
	Engineer	5.727	0.786		
	Builder	4.563	1.548		
	Total	5.565	1.157		
Waste management	Architect	6.000	0.780	4.042	**0.011***
	Quantity Surveyor	5.611	1.145		
	Engineer	5.909	0.944		
	Builder	4.750	1.693		
	Total	5.594	1.240		
Land use change	Architect	5.917	0.929	3.071	**0.034***
	Quantity Surveyor	5.278	1.018		
	Engineer	5.091	1.300		
	Builder	4.813	1.601		

Total	5.362	1.248	

Note: S.D. = Standard deviation; Sig. = significance level; **ANOVA is significant at the 0.01 level (2-tailed); and *ANOVA is significant at the 0.05 level (2-tailed).

5.3 Post-Hoc Tests for Professionals' Agreement with Critical Success Factors of Smart and Sustainable Developments

Post-hoc tests were conducted to explore the differences among the means of three or more groups so as to provide definite information on which groups are significantly different from each other (Pallant 2011). To ascertain which group of construction professionals were responsible for the significant differences among the CSFs, post hoc tests were conducted in this study (refer to Table 3). The results of the post hoc tests revealed significant differences in the respondents' agreement level with clearly defined goals as well as cooperation and participation of stakeholders occurred between the builder and the architect, and between the builder and quantity surveyor. For project procurement system and land use change, the significant difference occurred between the builder and quantity surveyor, and the builder and architect respectively. Lastly, energy efficiency and waste management showed a significant difference between the builder and all other construction professionals.

Table 3 Post-Hoc Tests for Professionals' Agreement with Critical Success Factors of Smart and Sustainable Developments

CSFs	Professionals		Mean Diff.	SE	Sig.
Clearly defined goals	Builder	Architect	-1.104	0.393	**0.007****
		Quantity Surveyor	-1.049	0.419	**0.015***
		Engineer	-0.528	0.477	0.272
Cooperation and participation of stakeholders	Builder	Architect	-0.667	0.328	**0.046***
		Quantity Surveyor	-1.069	0.349	**0.003****
		Engineer	-0.761	0.398	0.060
Project procurement system	Builder	Architect	-0.708	0.382	0.069
		Quantity Surveyor	-1.139	0.407	**0.007****
		Engineer	-0.886	0.464	0.061
Energy efficiency	Builder	Architect	-1.354	0.334	**0.000*****
		Quantity Surveyor	-1.326	0.356	**0.000*****
		Engineer	-1.165	0.406	**0.006****
Waste management	Builder	Architect	-1.250	0.376	**0.001****
		Quantity Surveyor	-0.861	0.400	**0.035***
		Engineer	-1.159	0.456	**0.013***
Land use change	Builder	Architect	-1.104	0.386	**0.006****
		Quantity Surveyor	-0.465	0.411	0.261
		Engineer	-0.278	0.468	0.554

Note: S.E. = standard error; Sig. = significance level; ***ANOVA is significant at the 0.001 level (2-tailed); and **ANOVA is significant at the 0.01 level (2-tailed); and *ANOVA is significant at the 0.05 level (2-tailed).

6. Discussion

The result of the t-test revealed that cooperation and participation of stakeholders and energy efficiency were the statistically significant CSF items between consulting and contracting organizations for smart and sustainable developments; while clearly defined goals, cooperation and participation of stakeholders, project procurement system, energy efficiency, waste management and land use change were the statistically significant CSF items among the construction professionals for smart and sustainable developments.

Table 4 Statistically Significant CSF items in the Study

CSFs	Organizations	Construction Professionals
Clearly defined goals		✓
Cooperation and participation of stakeholders	✓	✓
Project procurement system		✓
Energy efficiency	✓	✓
Waste management		✓
Land use change		✓

The study revealed a significant difference in the agreement of construction professionals with clearly defined goals for the success of smart and sustainable developments. The goals to be attained by each construction professional in any form of development are not often the same. For instance, the architect is concerned with the aesthetics of the design; the builder is focusing on the buildability and functionality of the development; while the quantity surveyor is seeking ways to ensure the cost of the development is within budget and affordable. The difference in the mindset and goals of the construction professionals could affect their perception of the goals for smart and sustainable developments.

Cooperation and participation of stakeholders were revealed to have a significant difference between organizational types and among construction professionals. Many of the developmental projects in the study area do not involve stakeholders at the initial stage of conception. For instance, architects and clients decide on the design. On completion, they may decide to involve the quantity surveyor. This does not give room for stakeholders' involvement in the design and planning for such projects. This could affect their understanding of stakeholder participation and cooperation in smart and sustainable developments.

The project procurement system also shows a significant difference between the builder and the quantity surveyor for smart and sustainable developments. The specific goals of construction development determine the procurement system adopted. For instance, a development that is focussed on buildability could choose the design and build, construction management or management contracting as a procurement route, while a cost-oriented development may choose procurement routes that will indicate the price certainty before the start of the project which suggests a traditional mode of procurement. Therefore, the difference in goal perception could affect the procurement system chosen for smart and sustainable developments.

7. Recommendation and Conclusions

The success of smart and sustainable developments includes many factors ranging from technical, social, economic, legal and environmental. However, organizations and construction professionals may hold different opinions about factors that contribute to the success of smart and sustainable developments. The divergent opinions of organizations and professionals involved in smart and sustainable developments will affect teamwork among the construction members and subsequently affect the achievement of objectives set for the project. The study identified 40 CSFs for smart and sustainable developments and explored the perception of organizations and construction professionals. The findings show that cooperation and participation of stakeholders and energy efficiency were the statistically significant CSF items between consulting and contracting organizations for smart and sustainable developments; while clearly defined goals, cooperation and participation of stakeholders, project procurement system, energy efficiency, waste management and land use change were the statistically significant CSF items among the construction professionals for smart and sustainable developments.

To ensure that the objectives for smart and sustainable developments are achieved, it is essential that organizations and professionals are involved at every stage of the development starting from the design brief to commissioning and maintenance of the project. This will also ensure that all the stakeholders have common goal and understanding of the construction projects. It will also make it easier to agree on the best method of procurement after considering all the available options, and also help to identify other areas requiring discussions and alignment for the success of the project. The present study has only adopted a quantitative method using a self-reported survey to investigate the difference in agreement with CSFs for smart and sustainable development. The study suggests that an objective approach (e.g. on-site observation of the activities of professionals and organizations in a smart and sustainable development) is adopted in the future to cross-validate the current results.

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Career Choice and it's Influencing Factors: Perception of Female Construction Students

Mariam Akinlolu[1] and Theo C. Haupt[2]

[1] [1] Department of Construction Management and Quantity Surveying, Mangosuthu University of Technology, Durban, South Africa
[2] Faculty of Engineering, Mangosuthu University of Technology, Durban, South Africa.
akinlolumariam@gmail.com@gmail.com

Abstract
This study explores the career preferences of female undergraduate studnets in construction programs and examines the factors that predict their choices to undertake a career in construction. Data was collected using close-ended questionnaire in a survey of 229 conveniently sampled university students enrolled in construction-related programs in South Africa. Results from the questionnaire survey revealed that outcome expectations, perceived barriers, goal representations, social supports and gender stereotypes had the most influence on the career choice of women in the construction industry. Although an extensive review of existing literature on the topic was conducted, the scope of the study is limited to the perceptions of women enrolled in construction-related undergraduate programmes in two universities in the Kwa-Zulu Natal province of South Africa.

Keywords
Career Choice, Construction, Gender, SCCT, Women

1. Introduction

Gender-related studies have revealed that women's career choices are affected by social and cultural role expectations (Powell et al., 2009). Due to cultural influences, many women are brought up with the understanding that they cannot undertake non-traditional careers such as construction and are advised to follow instead 'soft skills' occupations such as nursing (Sangweni, 2015). Their primary roles are to take care of the family and nurture their children, while their spouses are the breadwinners and are entitled to the workplace (Madikizela and Haupt, 2010; English and Le Jeune, 2012). Putting women's roles in such stereotypical boxes is one of the hindrances that shorten the working life of women and makes it impossible to maintain an upward trend in the number of women in construction (Moodley, 2012; Enshassi and Mohammaden, 2012).

Despite several initiatives and legislations advocating for equality and diversity, the construction industry remains excessively gender stratified and conservative in the recruitment and retention of women (Aulin and Jingmond, 2011; Sang and Powell, 2012). This has been particularly evident in the African construction industry, where patriarchy is an obstacle to women's growth and development (Koch et al., 2009). A lack of understanding of girls and women's career choice and development is a significant obstacle to attracting women into the construction industry. Although the industry has sought to find solutions to the problem of under-representation of women, progress seems to be very slow and erratic. Despite the existence of a significant range of studies on gender and women's career choice and development in construction (Ahuja and Kumari, 2012; English and Hay, 2015; Madikizela and Haupt, 2010; Powell et al., 2009), limited progress has been to develop interventions and strategies that can be applied to the women and minorities in the construction industry (Brown, 2002; Moore, 2006).

Much of the current literature describes a variety of formidable constraints facing women in the construction sector ranging from sexual harassment, the industry's low image, glass ceiling, sexist attitudes, discrimination, unfavorable policies, and regulations to lack of education and training programs suited to accommodate the roles of women as being mothers and career women (Haupt and Fester, 2012). The institutionalized discrimination, which is deeply rooted in the industry, make construction less attractive to non-traditional entrants and prevents women from considering careers within the industry (Alves and English, 2018).

Worldwide, the construction industry is currently facing skill shortages, and diversity-based levels are inadequate in meeting the skill gap (Worrall et al., 2010; Vainikolo, 2017). English and Hay (2015); Worrall et al. (2010) suggested that encouraging the participation of women would enable untapped resources, promote inclusivity, and improve the skill gap in the industry. Women possess a unique set of skills which could diversify the industry organisational culture and provide a competitive advantage (Fernando et al., 2014).

Numerous studies examining career choices have emphasized individual cognitive factors, paying little attention to environmental factors. However, this study sought to investigate the significance of environmental variables, which are perceived to have a greater influence on career decisions and focuses specifically on women's decisions in undertaking work in construction-related disciplines as a significant outcome in construction careers.

Table 1 shows a comparison of existing literature with regards to the predictors of career decision and development.

Table 1: Core Predictors of career choice identified from the literature

SCCT Constructs	Saifuddin *et al.* (2013)	Hunt *et al.* (2016)	Ali *et al.* (2006)	Daniels (2012)	Chronister *et al.* (2003)	Kelly (2009)	Lent *et al.* (2008)	Patton *et al.* (2007)
Self- Efficacy	✓	✓	✓	✓	✓	✓	✓	✓
Outcome Expectations	✓	✓	✓	✓	✓	✓	✓	✓
Goal representations	✓				✓	✓	✓	
Social supports	✓	✓					✓	
Learning Experience	✓	✓	✓					
Interest					✓		✓	
Gender Stereotypes			✓	✓		✓		
Perceived Barriers	✓	✓	✓		✓	✓		✓
Access to Opportunity Structures							✓	✓

Self-efficacy has been found to play a crucial role in the career choices of individuals (Charity-Leeke, 2012; Hackett and Betz, 1981; Sawtelle et al., 2012). Self-efficacy belief typically influences a person's academic and professional aspirations is influenced by learning experiences (Saiffudin et al., 2013). In Outcome expectations are anticipations of possible consequences from chosen actions and work-related behaviours (Lent et al., 2008; Kelly, 2009). Goal representations are achievement-related choices (Lent and Brown, 2006). All these factors in combination with background factors and personal inputs such as gender, race and ethnicity are the most prevailing predictors of career decision making as they are also suggested to influence learning experiences (Kelly, 2009, Charity-Leeke, 2012). Learning experiences are verbal encouragements, supports and modelling from significant others used to maximise the performance accomplishment of a person (Flores et al., 2010). Interests are hypothesized to result in actual engagement in activities which lead to performance outcomes (Kelly, 2009).

Opportunity structures tend to promote or hinder obligatory control in career choice behaviour (Lent et al., 1994). Career development and choice theories acknowledge that although a person acts as a free agent in the selection of a career path, circumstances and external influences may restrict personal career choices (Lent et al., 2008). While the proposed conceptual model permits the practice of personal agency, it also stresses the factors that serve to restrict, promote, invalidate personal obligation in the career choice process. Noteworthy are the differential barriers experienced by men and women, and among women from different socio-economic backgrounds in the career, choice process assumed to result from socialization and learning experiences as it has been highlighted in numerous studies (Charity-Leeke, 2012; Eccles, 1984; Pio et al., 2013).

Opposing trends in the professional development of South African women in construction suggest that contextual and environmental factors play a significant role in shaping their career choices. Sangweni (2015) argued that numerous studies aimed to examine the declining participation in construction among South African women may not fully capture the dynamics of career choices for women aspiring to undertake careers in construction. The study deals explicitly with the influence of social and environmental on the career choice behaviour of girls and women to pursue careers in construction in the South African context.

2. Materials and Methods

2. 1 Study Design

The study implemented a descriptive survey design adopting a quantitative research approach. The study conveniently selected two public universities in the KwaZulu-Natal province of South Africa to participate in the study. The two universities were conveniently chosen because of their proximity to the researcher. In this study, a sample size of 229 was used for the analysis. The sample size reduced the chance of arriving at negative results and determined the truth while engendering reproducibility of results.

2.2 Study Subjects

Students enrolled in construction-related programmes such as construction management, land surveying, building, civil engineering, quantity surveying and architecture were chosen as the sample frame.

2.3 Data Collection Tool

The study used a close-ended questionnaire in a survey. The questionnaire administered was developed from the Delphi study and supported by the review of the literature. The survey questionnaire was administered for five weeks. The questionnaires were designed using Google forms and administered electronically by sending out hyperlinks to the questionnaire via email and the WhatsApp platform. Students were asked to indicate to which extent the nine provided variables may influence their current preferred specialty using a Likert scale ranging from 1 (strongly disagree) to 4 (strongly agree).

3. Results

3. 1 Demographic Statistics

Table 1 shows the demographic distribution of the respondents. First year students had the largest number of participants with 94 students (41%), followed by 2nd year students at 87 (38%). This rate of participation is possible because of the 1st year cohort of students at South African Universities being usually larger than the later years or more advanced levels of study.
There were 116 men (50.7%) in the sample. Most respondents were enrolled in the discipline of Construction Management (n= 110; 48%), which also accounted for the largest number of participants because of both of the participating universities offering the programme. Architecture had the lowest number of students (n=1; 0.4%) in the sample because only one of the universities offered the programme and typically had smaller numbers of students compared to the other disciplines and programmes.

Table 1. Demographic Distribution

Gender	Frequency	Percent
Man	116	**50.7%**
Woman	113	**49.3%**
Total	**229**	100.00%
Year of Study		

1st year	94	**41.0**
2nd year	87	**38.0**
3rd year	30	**13.1**
4th year	18	**7.9**
Total	**229**	100.00%
Programme of Study		
Construction Management	110	**48.0**
Land Surveying	4	**1.7**
Quantity Surveying	50	**21.8**
Civil Engineering	17	**7.4**
Building	47	**20.5**
Architecture	1	**0.4**
Total	229	100.00%

3.2 Student's Perception of Career Choice Predictors

Table 2 presents the normality test and descriptive results for the factors and predictors of career choice in construction. The assessment of the influence of the predictors on student's career choices revealed that the item "*I would like to perform well at my job"* with a mean score of 4.62 had the most influence on student's career choices. The statistics showed that the item "*Because of my gender, I will earn a lower salary than my counterparts for similar work*" had the lowest mean score (1.89), indicating least influence on the career choice of students.
It was further revealed that outcome expectations (mean score =57.10), perceived barriers (mean score = 40.46), goal representations (mean score= 29.16), social supports (mean score=23.12) and gender stereotypes (mean score =21.92) had the most influence on career choice. The mean scores obtained revealed learning experiences as the career choice predictor with the least influence.

Kolmogorov-Smirnov Z and Shapiro-Wilk were adopted for the normality tests of the elements. The Shapiro-Wilk test and Kolmogorov-Smirnov test makes comparisons between the scores obtained from a sample to normally distributed score sets with the same mean and standard deviation. The tests assess the normality of the distribution of scores. A non-significant test result, namely the test significance is greater than .05, means that the difference is insignificantly different from a normal distribution, therefore indicating normality. Numerous studies have asserted that the Shapiro-Wilk test is the most effective test for normality compared to other tests (Razali and Wah, 2011).
As shown in Table 2, the Kolmogorov-Smirnov Z and Shapiro-Wilk tests indicated a non-normal distribution at 0.000 for all the variables.

Table 2. Perception of Career Choice Predictors

		Mean	Std. Dv.	Rank		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
						Stat	**df**	**Sig.**	**Stat**	**df**	**Sig.**
Self-Efficacy	I have confidence in my ability to identify resources, limitations, and personal characteristics that might influence my career choices.	3.97	.982	**30**	**7**	.292	229	.00	.793	229	.000
	I am confident about being able to collect information about training and employment opportunities for myself and manage them effectively.	4.05	.923	**26**		.222	229	.00	.832	229	.000

	I am confident about being able to develop lists of priorities on the effective actions to successfully manage my own personal professional development	4.02	.908	**28**		.253	229	.00	.826	229	.00
	I am confident about being able to plan the steps needed to realize a project related to my profession	4.02	1.02	**28**		.277	229	.00	.805	229	.00
	I am confident about being able to address any difficulties related to my career	4.01	1.06	**29**		.231	229	.00	.820	229	.00
Outcome Expectations	I expect to earn a good and satisfactory salary	4.37	.862	**11**	**1**	.304	229	.00	.697	229	.00
	I expect to get experience and get better jobs in future	4.45	1.007	**6**		.357	229	.00	.616	229	.00
	I expect to get promoted and get regular salary increases	4.23	.961	**19**		.281	229	.00	.755	229	.00
	I expect to work in a decent and satisfying work environment	4.33	.933	**14**		.315	229	.00	.713	229	.00
	I expect to have a stable and secure job	4.32	1.018	**15**		.315	229	.00	.698	229	.00
	I expect to have a stable career and guaranteed employment	4.29	1.007	**17**		.300	229	.00	.697	229	.00
	I expect to have a positive image and contribute to the society	4.39	.947	**9**		.329	229	.00	.648	229	.00
	I expect to have a satisfying lifestyle	4.34	.949	**12**		.302	229	.00	.704	229	.00
	I expect to have a happy future	4.45	.870	**6**		.337	229	.00	.657	229	.00
	I expect to feel productive and have a sense of purpose and worth	4.44	.919	**7**		.340	229	.00	.618	229	.00
	I expect to achieve my career goals	4.49	.989	**4**		.387	229	.00	.560	229	.00
	I expect to be successful in my career	4.50	.958	**3**		.386	229	.00	.568	229	.00
	I expect to learn new skills and be able to use these skills and talents in my job	4.53	.929	**2**		.393	229	.00	.549	229	.00
Goal Representations	I will obtain technical/functional skills in my chosen career	4.17	.965	**20**	**3**	.281	229	.00	.741	229	.00
	I will have opportunities for training and development in my chosen career	4.08	.984	**25**		.289	229	.00	.776	229	.00
	I will have the opportunities for interesting work in my chosen my career	4.09	1.009	**24**		.273	229	.00	.772	229	.00
	My chosen career will allow me to meet my financial obligations	4.12	1.0179	**21**		.287	229	.00	.753	229	.00
	I will be successful in my chosen career	4.33	.952	**13**		.306	229	.00	.695	229	.00
	I will occupy leadership positions in my chosen career	4.09	.992	**23**		.233	229	.00	.799	229	.00
	My chosen career will make my family, friends and society have a good and positive opinion of me	4.30	1.000	**16**		.325	229	.00	.707	229	.00
Social Supports	I receive support from both my parents	3.17	1.480	**43**	**4**	.191	229	.00	.863	229	.00
	I receive support from my teachers	3.21	1.158	**40**		.202	229	.00	.908	229	.00
	I receive support from my family members	3.64	1.178	**33**		.231	229	.00	.874	229	.00

	I receive support from my peers (e.g. friends, colleagues)	3.50	1.137	**34**		.237	229	.00	.875	229	.00
	I receive support from my father	2.86	1.663	**49**		.223	229	.000	.809	229	.00
	I receive support from my mother	3.90	1.435	**31**		.306	229	.00	.738	229	.00
	I receive support from my significant other (e.g. husband, wife, partner)	2.83	1.369	**50**		.159	229	.00	.889	229	.00
Learning Experiences	I receive positive feedback and encouragement, especially from influential people in my life such as my parents and teachers	4.04	.999	**27**	**9**	.234	229	.00	.812	229	.00
	I learn through observing others perform tasks related to my own career	4.01	1.002	**2**		.268	229	.00	.808	229	.00
	I experience feelings of anxiety, nervousness and fear of failure when performing tasks and activities related to my career	3.67	1.117	**32**		.218	229	.00	.882	229	.00
	I successfully complete tasks and activities related to my career	4.10	.970	**22**		.271	229	.00	.784	229	.00
Interests	I enjoy performing tasks and activities related to my choice of profession	4.24	.901	**18**	**6**	.275	229	.00	.726	229	.00
	I would like to make a lot of money	4.48	.846	**5**		.361	229	.00	.641	229	.00
	I would like to receive recognition in the society	4.17	1.061	**20**		.271	229	.00	.743	229	.00
	I would like to perform well at my job.	4.62	.832	**1**		.421	229	.00	.491	229	.00
	I enjoy thinking and solving problems	4.38	.883	**10**		.318	229	.00	.691	229	.00
	I like highly challenging activities and taking risk	4.12	1.039	**21**		.255	229	.00	.777	229	.00
Perceived Barriers	Discriminatory attitudes	2.51	1.289	**57**	**2**	.169	229	.00	.881	229	.00
	Work-life conflict	2.65	1.112	**56**		.179	229	.00	.909	229	.00
	Wage gap	3.03	1.088	**46**		.198	229	.00	.914	229	.00
	Masculine workplace culture	2.95	1.043	**48**		.237	229	.00	.898	229	.00
	Lack of access to opportunities	3.14	1.358	**45**		.155	229	.00	.897	229	.00
	Poor working conditions	2.95	1.323	**48**		.165	229	.00	.899	229	.00
	Long working hours	3.18	1.119	**42**		.227	229	.00	.899	229	.00
	Challenges in career progression	3.21	1.117	**40**		.197	229	.00	.908	229	.00
	Gender stereotypes	2.86	1.337	**49**		.146	229	.00	.899	229	.00
	Glass ceiling (Invisible barrier to career advancement)	2.79	1.107	**51**		.233	229	.00	.898	229	.00
	Lack of knowledge and career information	2.73	1.286	**53**		.151	229	.00	.900	229	.00
	Lack of role models in my chosen career	2.73	1.237	**53**		.170	229	.00	.904	229	.00
	Lack of education and training	2.78	1.340	**52**		.173	229	.00	.892	229	.00
	Lack of opportunities in my chosen career	3.00	1.370	**47**		.159	229	.00	.892	229	.00
Gender Stereotypes	Because of my gender, people will believe I possess lesser abilities in my work	2.70	1.373	**54**	**5**	.205	229	.00	.882	229	.00

	Because of my gender, I will have to work twice as hard as my counterparts	2.68	1.376	**55**		.196	229	.00	.881	229	.00
	Because of my gender, I will have to occupy a junior position at work	2.18	1.207	**60**		.224	229	.00	.834	229	.00
	Because of my gender, I will be expected to do administrative work	2.21	1.252	**59**		.243	229	.00	.831	229	.00
	Because of my gender, I will be expected to have a lesser status in the society	2.13	1.239	**62**		.241	229	.00	.811	229	.00
	Because of my gender, I will be expected to possess domestic skills rather than technical skills	2.18	1.291	**60**		.248		.00	.794	229	.00
	Because of my gender, I will be expected to have a low level of education	1.93	1.203	**64**		.290	229	.00	.757	229	.00
	Because of my gender, I will be expected to choose a career different from the one I prefer	2.14	1.614	**61**		.254	229	.00	.687	229	.00
	Because of my gender, people will believe I will perform badly in mathematics and science subjects	1.96	1.215	**63**		.266	229	.00	.761	229	.00
	Because of my gender, I will earn a lower salary than my counterparts for similar work	1.90	1.179	**65**		.293	229	.00	.754	229	.00
Access to Opportunity Structures	I have access to information on organizations and jobs in my chosen career	3.48	.989	**36**	**8**	.223	229	.00	.888	229	.00
	I have attended various career orientation programs	3.15	1.138	**44**		.195	229	.00	.911	229	.00
	I have initiated conversations with knowledgeable individuals in my career area	3.36	1.152	**39**		.240	229	.00	.895	229	.00
	I have access to information on the labour market and general job opportunities in my career area	3.18	1.068	**42**		.210	229	.00	.905	229	.00
	I have access to information on specific areas of career interest	3.39	1.075	**38**		.239	229	.00	.894	229	.00

4. Discussion and Conclusions

The survey results presented the evaluation of the factors that predict women's career choices in construction. The findings revealed that the career choices of the respondents were mostly influenced by the interest in performing well, expectations of learning new skills and being able to use these skills and talents in their job, expectations to be successful in their career , expectations to achieve their career goals and the interest to make a lot of money . These findings are consistent with previous studies that expectations of achieving a certain outcome are a significant component of the career choice process of young adults and university students and is a strong predictor of their post-university pathways (Fouad and Guillen, 2006). The study found outcome expectations, perceived barriers, goal representations, social supports and gender stereotypes had the most influence on women's career choices in the construction industry.

The least-influence of learning experiences on the career choices of this population can be explained in several ways. A likely explanation for the results in this study is that the sample may be socio-economically homogenous, as a majority of the respondents are from low SES categories and may not have positive or access to any learning experiences at all. Betz (1989) argued that an environment with little or no information and experiences about some careers for young adults, and neither encourages nor discourages participation in these careers constitutes

a null environment. Further, such an environment with profound poverty due to its impact on learning experiences is unlikely to foster career aspirations and choice.
Another possible explanation can be related to the theory of locus of control (Layton, 1987). Trice et al. (1989) described locus of control as the extent to which a person believes they are in control of their choices and craft their future career plans. Studies argue that career choices are linked to a sense of taking control and taking responsibility for major events life events (Luzzo and Jenkins-Smith, 1998; Abdinoor, 2020). Therefore, people with a high internal locus of control tend to believe career-related occurrences in their lives such as career choices are because of their skills, abilities and internal factors that are within their control. It could be that the respondents in the current study perceive that their career choices re rarely influenced by their experiences.

Although this study sampled female students in the KwaZulu-Natal province of South Africa, a generalization of the findings to the entire South African population needs caution. Further, because the sample in this study was one of convenience, some limitations apply. Since the present sample may be described as unique due to the inclusion of only women enrolled in construction-related programmes at two universities, it is uncertain whether these results may not adequately represent the population of interest and be generalized to a general sample of students in other universities.

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Making the 'Available Desirable' Using Adaptive Reuse (AR) In Sustainable Construction: A Systematic Review and Directions from case studies

Oluwatobi Owojori[1], Chioma Okoro[1]

[1] Department of Finance and Investment Management
School of Management, College of Business and Economics
University of Johannesburg, South Africa
tobiowojori@gmail.com

Abstract
The future of construction will take a different look from the past considering that the conventional system of "take, make, and dispose of" appears more and more insecure in a resource-constrained future calling for more sustainable construction. Alternatively, the system becomes more attractive, in contrast to demolition and new construction projects given that the real estate resources are kept in use and their value retained resulting in increased efficiency. To guarantee resources for future generations, adaptive reuse and thus the reduction of waste, recycling, and efficient use of spaces is essential to ensure the prolonged life of developments. The study examined the role of adaptive reuse to identify critical indicators for sustainable development through adaptive reuse. A systematic review from the Scopus bibliographical database was used to identify the indicators of sustainable development. Subsequently, multi-case studies were used to explore the application of adaptive reuse in line with the sustainable development indicators. The progress made towards adaptive reuse as a tool for sustainable development in construction. Findings revealed that adaptive reuse can be applied to achieve economic, environmental, social, and cultural pillars of sustainable development. The paper recommends that practical actions and tools seem to be the optimal way of making sustainable construction more concrete and understandable for the construction sector, therefore it is of significance to look in the directions of the modeled cities and implements the lessons learned to promote sustainable development.

Keywords
Construction, Adaptive reuse, Systematic review, Sustainability, Sustainable development

1. Introduction

Over the years sustainability has been the core concern of various organisations including the construction industry and the topic has been gaining global spread in literature (Winans et al., 2017), involving also diverse industries and policymakers (Suarez-Eiroa et al., 2019). Building and construction generate close to half of all greenhouse gas emissions thus prompting the subject of sustainable construction as a major driver for adaptation. Researchers and various organisations try to find effective and efficient means of lowering the contribution of cities to climate change and building adaptation appears to offer a practical means of lowering building-associated emissions (Wilkinson & Reed, 2011).

Constructing a new building produces a lot more waste materials than modifying a pre-existing building for a new use, and thus Bullen (2011) suggests that existing building stock should be regarded as a recyclable source and not as a -product because most products become waste eventually after being utilised for consumption. With adaptive reuse, buildings are being environmentally responsible while integrating socio-economic factors as well enhancing the environment that the building is sited (Richardson, 2013).

In line with the United Nation's sustainable development goals (SDG11), Adaptive reuse is a vital tool that is important for guaranteeing resources for future generations, based on the 3 R (reuse, recirculation, recycling), and prolonging the lifecycle of products. Adaptive reuse (AR) in the construction sector is majorly characterised by the need to improve the use of available and existing resources, through the reduction of waste, recycling, and efficient use of spaces which is an important factor in the development of sustainable cities (Strumillo, 2016).

However, the concept of adaptive reuse has somewhat remained elusive in the building and construction industry as evidenced in the prioritisation of new construction over adaptively reusing existing constructions. There is a need to examine the concept of adaptive reuse as a major proponent of sustainability. Studies on adaptive reuse have focused on showing the potential of the adaptive reuse of buildings but not as a direct function of the pillars of sustainable development. For instance, Strumillo (2016) investigated adaptive reuse of Buildings as an important factor of sustainable development but did not relate the case studies based on the sustainable pillar (social, economic, environmental, and cultural).

Langston (2011) investigated the benefits associated with adaptive reuse and explored how to enhance those benefits while Langston et al. (2008) assessed the factors affecting local sustainable development but did not directly examine the case studies as a contributor to sustainable development. Further, Yung & Chan (2012) investigated implementation challenges focusing on carbon emissions in heritage buildings; while Yung et al. (2014) identified community initiatives in adaptive reuse of historic buildings but the relation of the initiative in terms of the socio-cultural, environmental, and economic contribution to the community was not incorporated. Although studies have been undertaken on adaptive reuse, few studies have related it to a wider range of sustainability outcomes. This study, therefore, reviews existing knowledge by identifying the indicator of sustainable development and analyses case studies to establish the critical role of the adaptively reused buildings in contributing to the pillars of sustainable development.

The paper maintains that adaptive reuse should be treasured and applied more practically beyond the theory in the construction industry as this corresponds to the idea of recycling and is a crucial step towards sustainable development. The paper adopts a qualitative and exploratory approach to identify adaptive reuse as a tool for sustainability using the lessons from case study examples to promote the sustainability vision using. Starting from these approaches, the paper identified from the literature the indicators of the four pillars of sustainable development and analysed the contribution of adaptive reuse from selected case studies to sustainable development.

1.1. Pillars of sustainable development in construction: Overview

The term sustainability (SD) is often used to signify projects, schemes, and activities targeted at the conservation of a specific resource. However, it comprises four distinct parts which are: human, social, economic, and environmental, referred to as the four pillars of sustainability (Kolk, 2016; Zhai & Chang, 2019). The principle of the four pillars of sustainability states that for complete sustainability, problems need to be solved and maintained concerning all four pillars of sustainability.

Schaefer and Crane (2005) define "Sustainable development as a development that meets the needs of the current generation without compromising the ability of future generations to meets their own needs". Evers (2018) further relays the notion to the organising principle for providing human development goals and also sustaining the capacity of natural systems to provide the natural resources and ecosystem services upon which the economy and society depend. Considered from this perspective, sustainable development aims at attaining social development, environmental stability, and economic development. The four pillars are briefly described below:

- Economic sustainability: this recognises that as a population increases, human needs such as food, clothing, and shelter also increase, but the available resources in the world cannot meet up with the requirements endlessly (Retchless & Brewer, 2016). Economic sustainability, therefore, requires that decisions be made in the most reasonable and economical possible way while taking into regard the other aspects of sustainability (Zhai & Chang, 2019)
- Social sustainability: this aims at delivering enabling conditions for everyone to have the capacity to realize their needs, ensuring that everyone's needs are met. Whatever impedes this capacity is deemed a barrier, and needs to be addressed for persons, organizations, or communities to be progressive (Kolk, 2016). It also comprises other issues such as human rights, gender justice and impartiality, community involvement, and the rule of law all of which are aimed at promoting harmony and societal stability for sustainable development (Zhai & Chang, 2019).
- Cultural sustainability: encompasses the sense of wellbeing, creativity, diversity, and innovation that should be treated as one of the basic requirements of a healthy society. It refers to a broader definition of culture that is not limited to arts and heritage but encompasses the whole complex of distinctive spiritual, material, intellectual and emotional features that characterize a society or social group (Zhai & Chang, 2019).

- The notion of environmental sustainability is about the natural environment and its ability to remain beneficial and resilient in supporting human life. Environmental sustainability relates to ecosystem integrity and the carrying capacity of the natural environment (Kolk, 2016).

This section has summarised the four pillars of sustainable development as reviewed from literature namely, economic, social, environmental, and cultural sustainability. These four pillars are an essential consideration for sustainable development and therefore construction projects must build on these pillars to deliver sustainability. This paper further identified indicators of adaptive reuse as a tool for sustainable development and reviewed case studies of adaptive reuse to show their contribution to sustainable development in the construction industry. The methodology adopted is as described in section 3.0.

2. Materials and Method

This study employs a systematic literature review. Search on Scopus database was conducted to review relevant articles. Denyer & Tranfield (2009) proposed a five-step process to a systematic literature review. This process involves formulating question(s), locating, and identifying relevant studies, selection, and evaluation of studies, analysis or synthesis, and results reporting. Denyer and Tranfield's (2009) procedure was adopted in this research.
The search question string used was TITLE-ABS-KEY ("adaptive reuse " AND "sustainable development" OR "sustainable construction") AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "cp")) AND (LIMIT-TO (EXACT KEYWORD, "Sustainable Development") OR LIMIT-TO (EXACT KEYWORD, "Adaptive Reuse") OR LIMIT-TO (EXACT KEYWORD, "Adaptive Re-Use") OR LIMIT-TO (EXACT KEYWORD, "Sustainability") OR LIMIT-TO (EXACT KEYWORD, "Buildings") OR LIMIT-TO (EXACT KEYWORD, "Circular Economy")) AND (LIMIT-TO (LANGUAGE, "English"))

No date restrictions were imposed on the search as priority was given to the relevance of the materials in terms of their substantial contribution to the ongoing discourse on adaptive reuse and sustainable development, irrespective of the age of the material. Attempts, however, were made to capture as much recent literature as possible to reflect the currency and increasing relevance of the topic. The initial search criteria identified a total of 109 references. However, applying the screening and eligibility processes stated above, 64 articles were identified for full-text retrieval, out of which 26 were identified as meeting the final inclusion criteria, more additional 14 materials were sourced using snowballing as shown in Figure 2.

Three case studies on adaptive reuse were also examined to provide practicality. The selection of the three cases is from countries considered as frontiers in circular economy and adaptive reuse of buildings. As a research approach, case studies offer insights along multiple fronts for exploratory stages of a project (Rowley, 2002). The study considered countries from both developed and developing countries who are frontiers in sustainable development and transition to circularity. The Netherlands is regarded as the World Capital of circular economy and adaptive reuse based on the move to become a circular city by 2050 through her government-wide program and projects, which makes it suitable for a model case, and the case selected was chosen because of its peculiarity in terms of size and the use of sustainable local materials through the construction. Also, France is recognised as one of the frontiers in circular economy and adaptive reuse, and the case study was selected based on the reuse of materials in the project. Egypt was also chosen in Africa based on its listing among the 6 "Grow countries" accelerating transition to a circular economy in the 2020 circularity gap report. Furthermore, Egypt is well known for its historical and heritage buildings which are suitable for adaptive reuse studies.

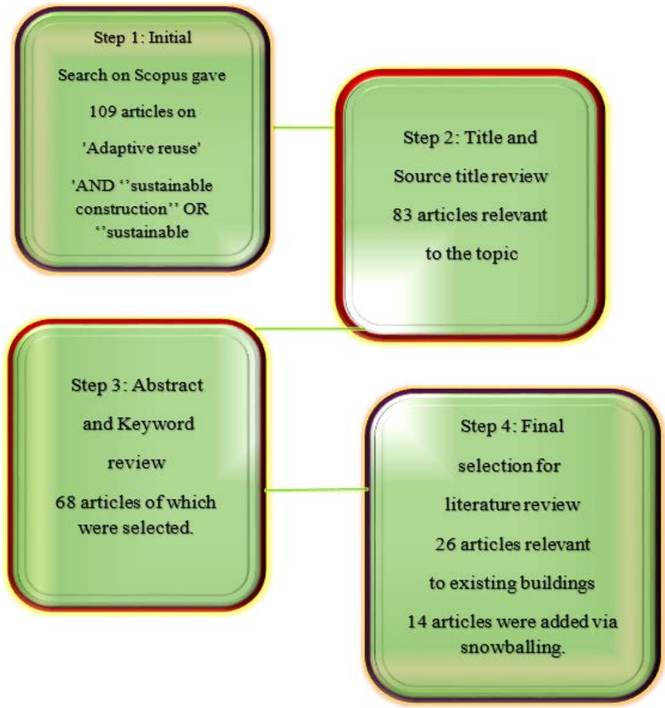

Fig. 2. The systematic review search procedure

3. Results

3.1 Adaptive reuse as a tool for sustainable development

Adaptive Reuse is 'to re-use a building or structure to give it new life through a new function' (Odasa, 2014) and it is described as developing the potential of further use for functionally obsolete buildings. It is fundamentally the recycling of a building (Ijla & Brostrom, 2015). Literature has shown that adaptive reuse can benefit both the local community and the existing built fabric as it possesses socio-economic, ecological/environmental, and cultural characteristics which are considered to constitute the pillars of sustainability, and so adaptive reuse is a potential tool for sustainability.

Furthermore, adaptive reuse can contribute to sustainable development, economically, environmentally, socially, and culturally, establishing values such as giving a sense of place and new income flows (Girard, 2019). Adaptive reuse of buildings has been successfully engaged in several places and thus played a key role in the sustainable development of many communities.

Adaptive reuse can pull new visitor attractions, which have an impact on economic development, this is for the reason that new use may inspire new public and private investors sponsoring the expansion of interrelated activities and the establishment of funding services in the zone in which the reuse project is carried out (Douglas, 2002). Therefore, economic benefits, comparable to all contributions, could exist at different scales (owner, community, urban scale). When adaptive reuse is considered more frequently in building construction, it presents numerous opportunities as a viable solution to achieving sustainable development. The next section presents the three case studies and their adaptive reuse scenarios.

3.2 Indicators of sustainable development in adaptive reuse in building projects

The results on the indicators of adaptive reuse as a tool for sustainable development and case studies of adaptive reuse as well as their contribution to sustainable development in the construction industry are presented in this section. Table 1 describes the indicators of sustainable development, indicators are necessary to assess the case studies against outcomes and performance rather than outputs (Ness & Xing, 2017). The indicators were identified based on the four pillars of sustainability, the indicators for social sustainability are social engagement, community empowerment, quality of life, and Improvement. The indicator for economic sustainability includes economic development and technological invention. Further, the indicators for environmental sustainability are mirrored in environmental control and land preservation, while the indicators for cultural sustainability are reflected in community environmental awareness, education and preservation of cultural heritage, local value enrichment, tourism, and economic development (Bullen & Love, 2011; Tam 2018). The next section presents the three case studies.

Table 1. The indicators of sustainable development in adaptive reuse of building project

Sustainable Pillars	Elements	Descriptors	Literature
Social	Social engagement And community empowerment	• Revenue Growth • Neighborhood/Environmental Quality • liveliness & Hospitable community	Bullen & Love (2011), Yung et al. (2014), Ijla & Broström (2015), Yung, Chan & Xu (2014), Langston et al. (2008), Mitoula et al. (2013)
	Quality of life Improvement	• Increased welfare • Increased vacation or leisure • Robust and resilient city	
Economy	Economic development	• increased investment/investors •Increased market /business opportunities • job opportunities • improved tax • increasing Property Values	Ijla & Broström (2015), Tam, Fung & Sing, (2016), Agaliotou (2015), Wang (2011), Mitoula et al. (2013)
	Technological invention	• Technical Invention Integration • Recovering Local Traditional Construction Methods • Aesthetically Smart Cities	
Environment	Environmental Control and Land preservation	• Climate Change Alleviation • Eco-Building • Energy Efficient building • building life cycle extension Reuse of Buildings, Materials and resources • Reduced landfill and demolition Waste •Decreased GHGs emissions • decreased consumption of resources • increased recycling • Decreased Urban Sprawl	Bullen & Love (2011), Langston et al. (2008), Vardopoulos (2018) Lewin & Goodman, (2013), Mitoula et al. (2013)
Culture	Community environmental awareness education	• Contribution to education, cultural skills, and knowledge • community environmental awareness	Bullen & Love (2011), Tam et al. (2016) Lewin & Goodman (2013), Papalou (2015), Plevoets & Cleempoel (2012), Tsilika (2014)
	Preservation of cultural heritage Local value Enrichment	• Preserve Local Memory and identity •Diversity and vitality • Aesthetic Enhancement	
	Tourism (cultural) Economic development	• Safeguard the words' cultural and natural heritage • • Promoting cultural and tourism	

3.3 Case studies from selected cities

The analysed case studies in Table 2 demonstrated the contribution of all the three case studies to the listed indicators of sustainable development. This has been reflected in the communities through increased revenue growth and technological innovations, promotion of eco-efficient buildings, and sustainable building materials. Increased culture and tourism also increased property values and investment (IJla & Bostrom, 2015).

Table 2: Contribution of the cases to sustainable development

Sustainable pillars	Elements	Descriptive contribution	Case study 1	Case study 2	Case study 3
Social	Social engagement and community empowerment	• Revenue growth	x	x	x
		• Neighbourhood/environmental quality	x	x	x
		• Liveliness & hospitable community	x	x	x
	Quality of life Improvement	• Increased welfare			x
		• Increased vacation or leisure		x	x
		• Robust and resilient city		x	x
Economy	Economic development	• Increased investment/investors	x	x	x
		• Increased market /business opportunities	x	x	x
		• Job opportunities	x	x	x
		• Improved tax		x	x
		• Increasing property values	x	x	x
	Technological invention	• Technical invention integration			
		• Recovering local traditional	x	x	x
		Construction methods	x	x	x
		• Aesthetically smart cities	x	x	x
Environmental	Environmental Control	• Climate change alleviation	x	x	x
		• Eco-Building	x	x	x
		• Energy efficient building	x	x	x
		• Building life cycle extension	x	x	x
		• Reduced landfill and demolition waste	x	x	x
		• Decreased GHGs emissions	x	x	x
		• Reuse of building materials	x	x	x
		• Increased recycling	x	x	
	Land preservation	• Decreased urban sprawl	x	x	x
Culture	Community environmental awareness and education	• Contribution to education, cultural skills, and knowledge	x	x	x
		• Community environmental awareness	x	x	x
	Preservation of cultural heritage	• Preserve Local Memory and identity		x	x
		•Diversity and vitality		x	x
	Local value enrichment	• Aesthetic Enhancement	x	x	x
	Tourism (cultural) Economic growth	• Preservation of cultural and natural heritage	x	x	x
		• Promoting culture and tourism		x	x

3.3.1 Case study 1: The Werkspoorkwartier project Netherlands

The city of Utrecht is close to 45 miles west of Arnhem and there lies a large ex-industrial area around its harbor area. During the 20th century, steam trains, railroad parts, and other large-scale fittings were manufactured there, but by the 1970s and '80s, those activities began to diminish and a collection of companies primarily auto repair and renovation workshops occupied the vacant buildings.

The adaptive reuse: By 2012, the municipality determined to convert the Werkspoorkwartier (named after the Werkspoor company, the former Dutch state company that built and maintained the train network) into a center for future-oriented cultural and creative industries. The two largest buildings were selected out to be rehabilitated into highly visible examples of the desired change. Thus, the Werkspoorkathedraal became a venue attracting up to 20,000 was to adapt light manufacturing, such as 3D printing.

The materials used in the project were all recycled and eco-efficient, for example, the use of traditional local materials in the project black and white walls mix with the new wooden structure, creating a lively and comfortable working environment, Photovoltaic elements on the roof and new insulation are further sustainable elements of the project, this also increased business and job opportunities.

3.3.2 Case Study 2: Bayt al-Kritliya, Cairo, Egypt

Bayt al-Kritliya is in Darb al-Asfar, Cairo, Egypt, is regarded as one of the most magnificent residential Ottoman edifices. The building was originally built in 1540 AD and was expanded afterward in 1632 AD. The building mirrors the social patterns of the Ottoman era with divided public and private areas referred to as salamlik and haramlik, respectively. Additionally, it comprises other features such as mashrabiyas and maq'ad. Bayt al-Kritliya is considered as a world heritage that combines both tangible and intangible heritage features. Aga Khan Award for Architecture (2007). The adaptive reuse: The house was contracted for reuse into a museum in 1999 and followed by many phases. The museum was named "The Gayer-Anderson Museum" after his last declared name and is considered as a well-preserved example of the domestic architecture of Cairo during the seventeenth century. The house comprises an array of furniture, carpets, and other collections. The project was directed at protecting the house and its various collections as well as its exceptional setting of having two houses connected. Thus, the building was adaptively converted into a museum. The project involved the construction of new preservation, establishing new display spaces, and landscaping the gardens to produce an open-air area for cultural events and other amenities (Othman & Elsay, 2018).

3.3.3 Case study 3: The Rehafutur Engineer's House (France)

Rehafutur Engineer's house is an ancient mining house in the Northern France UNESCO heritage site and is among the sites incorporated in the EU's project CAPEM (Cycle Assessment Procedure for Eco-impacts of Materials) targeted at evaluating the efficacy of renewable materials for insulation. The major intervention realised in the course of adaptive reuse comprised of enhancing the building thermal insulation.
The adaptive reuse: now transformed into offices, due to its heritage significance, making use of bio-based (e.g., wood fiber, sheep wool), and recycled (e.g., recycled textiles) insulating materials, high standards of energy efficiency were achieved. Furthermore, to preserve the heritage value of the original construction, materials were reused. For example, marble fireplaces were used as adornments in public rooms, and cement tiles were also reused. Rehafutur Engineer's House is an important illustration of the application of circular economy principles (adaptive reuse) in the construction industry for the use of renewable insulation materials, high energy efficiency standards, and recycling of materials (Mangialardo & Micelli, 2018). The study approaches the selected case studies in adaptive reuse of buildings to examine their contributions to the pillars of sustainable development (economic, social, cultural, and environmental) identified as a system of interconnected relationships. It is however necessary to specify that all three cases have been analysed through a desk exploration.

4. Summary and suggestions for the construction industry

Literature review and analysis of the case studies showed the importance of adaptive reuse of buildings to achieving sustainable development. The three case studies showed that the various adaptive reuses contributed to the four pillars of sustainable development reviewed in their respective applications. Re-using existing built materials provides several environmental benefits. These include decreased demolition waste, decreased utilisation of resources as against the demolish-and-rebuild development, and the preservation of the initial building's embodied energy. It also maintains the uniqueness and cultural identity of the building, creating further jobs than new construction and providing significant tourism pull and attracting and investment. The research comes to the following recommendations for the construction sector for sustainable development:

- The adaptive reuse of buildings should be used as an essential approach to achieve sustainable construction.
- Leverage on expanding the life cycle of buildings to increase cost-effectiveness.
- Seek to prioritise reuse of existing stock before new construction.
- Embrace technological innovations for building adaptability and sustainable construction.

With the foregoing, through practical and applied adaptive reuse of buildings, the global building and construction sustainability is achievable.

5. Conclusions

Adaptive reuse as a tool for sustainable construction has gained recognition in literature over the years. Nonetheless, practice and application in achieving sustainable development have not measured par with theory. The construction industry has continuously focused on new constructions which is a good development but contradictory to the principles of sustainable development and waste hierarchy. Notwithstanding, the time to act towards sustainable construction is now. This study provides an adapted, systematic literature review cum case study review to provide evidence of adaptive reuse as a tool for sustainable development in the construction industry. Based on the review, despite recent advancements in literature, much more practicality is needed about adaptive reuse in construction projects.

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Success Factors for Effectively Implementing Lean Practices in the Construction Industry: A Case of North West Province, South Africa

Khotso Dithebe[1], Wellington Didibhuku Thwala[2], Clinton Aigbavboa[1] and Kamohelo Sello[1]

[1] SARChl in Sustainable Construction Management and Leadership in the Built Environment, Faculty of Engineering and the Built Environment, University of Johannesburg, Johannesburg, South Africa
[2]Department of Civil Engineering, College of Science, Engineering and Technology (CSET), University of South Africa, South Africa
khdithebe@gmail.com

Abstract
The construction industry is and continues to struggle with productivity, in terms of waste generated, environmental issues and lack of improvement during the construction process, mainly because of limited employee autonomy, longer construction cycles as well as reoccurring time and cost overruns. The purpose of the study was to assess and rank important success factors for effectively implementing lean practices in the construction industry to respond to the challenges encountered. A survey design was adopted in the form of a closed-ended questionnaire. Seventy-two questionnaires were analysed using descriptive analysis. A Cronbach alpha value of 0.93. The results indicated that compatibility and suitability of lean techniques in relation to the existing conventional techniques/processes, commitment to lean culture and availability of resources were the top three important success factors for effectively implementing practices in the construction industry in the North West Province, South Africa. From the results appropriateness and suitability of integrating new and innovative (lean) methods with conventional construction processes supersedes any other factor, along with commitment to lean culture. Therefore, increased emphasis and focus must be placed at the design stage to determine compatibility and suitability. The small sample size of this research limited the study from making generalisable and definite conclusion on important success factors for effectively implementing lean practices in the construction industry, however the findings of the study can form the basis of future studies whose aim is to establish the level of effectiveness of the identified factors in the implementation of lean practices.

Keywords
Construction Industry, Sustainability, Lean Practices, Waste Minimisation, Employee Autonomy

1. Introduction

Studies of lean construction and implementation of lean practices in the construction industry have been widely undertaken overtime. Aslam et al. (2020a) asserts that the study of success factors for effective implementation of lean construction has been extensively explored (Kim and Park, 2006; Kawish, 2017; Sarhan et al., 2018; Ballard and Kim, 2007), however the identified factors are broadly explained and have not been consolidated in a framework to be more realistic and practical. Blijleven et al. (2019) postulate that to implement lean practices organisations must invest in co-location, management leadership, lean workshops, utilising and measuring performance of lean tools and techniques. The study categorised the factors mentioned above as success factors required to implement lean practices. Other factors within the success factors domain include employment empowerment. Employee empowerment has been identified amongst the success factors of lean implementation in the construction industry by Bashir et al. (2015) and Kawish (2017). In addition to empowerment employees must be involved in the process, from the initial phase to the close out phase. Other than employee empowerment Aslam et al. (2020a) highlights the importance of selecting appropriate lean tools and methods (Shou et al., 2016), high commitment from project participants (Enshassi et al., 2019), early involvement of participants (Kawish, 2017), integrated project delivery (Ayarkwa et al., 2011) and understanding standardisation and flexibility during the implementation of lean practices. As much as it is paramount to standardise processes after implementing them it is always key to exercise flexibility to situations that may deviate from the standardised processes.

Based on the above deliberations it is identifiable that consensus has not been reached on important success factors for effectively implementing lean practices in the construction industry. Furthermore, Alinaitwe (2009) and Sarhan et al. (2018) elucidate that legislation in the form of lean practices policy and regulation is important when it comes to implementing lean practices, while Sarhan et al. (2018) emphasises on the role of lean consultant support and top management and their commitment towards effective implementation of lean practices in the construction industry. More so, while the role and technical skills of employees in the implementation process is recorded as one of the success factors (Asri and Nawi, 2015; Ahmed and Sobuz, 2019), it is still not clear whether it is important. Therefore, the purpose of this study is to determine important success factors for effectively implementing lean practices in the construction industry in the North West Province, South Africa.

2. Implementation of lean practices in the construction industry

2.1 Motivations, why must organisation implement lean practices

The implementation of lean practices by the construction industry for the benefit of promoting sustainable construction as indicated by Aslam et al. (2020a) and Gao et al. (2020) has an impact both on the competitive advantage of the organisation as well as the firm's image. Firms that constantly implement lean practices in their day-to-day activities without fail are more than likely to improve their project performance margins (schedule, cost, quality, safety, productivity) compared to firms that do not. The more the firm improves its operations and productivity the more the image of the firm is improved (Tezel et al., 2018), which also results in the services of the firm being more preferred by clients. Ellis (2018) added that greater productivity is amongst the benefits of implementing lean practices in the construction industry.

However, it is crucial to note that the organisations implementing lean must first partially unsubscribe to their orthodox methods and processes of delivering projects and subscribe more to lean practices to realise competitive advantage and improved image. The integration of orthodox methods and lean practices is encouraged to allow for smooth transitioning. Alarcon and Sequel (2002) explicates on the drivers for change in the organisation. Ayarkwa et al. (2012) concurs that changing the current culture in the organisation to lean culture is prevalent in the implementation of lean practices, indicating that management must take a leading role in advocating and committing to lean culture in the organisation not only through policy (Devaki and Jayanthi, 2014) but also through training and education. Leadership and commitment from management is thus a requirement to shift the culture and minimise resistance to change in the organisation.

2.2 Role of top management and commitment

The implementation of lean practices has been mainly attributed to top management commitment (Warcup, 2015), not realising that the effective implementation of the concept is the responsibility and requires commitment from each participant involved. Commitment from top management only is not adequate to effectively implement lean practices. Committed participants ensure that there are less conflicts in the implementation proceedings, Aslam et al. (2020a) however indicates that commitment from subcontractors, suppliers and employees is always lacking. To further avoid conflicts and keep participants committed and engaged in the process of implementing lean practices mutual communication and relationships must be prioritised (Ahmed and Sobuz, 2019). Lack of effective communication channels between participants and poor working relationships in the organisation have increased the quantities of waste instead of eliminating them during the construction supply chain.

While each participant has a duty to fulfil in the implementation process, top management amongst other duties must provide leadership in terms of encouraging participants and aligning organisational strategy to the lean goals. Leadership and commitment from management are needed to align the aims of the lean program with the goals of the organisation, for the purpose of ensuring the availability of the resources during the execution of the program (McCall et al., 2009).

2.3 Employee involvement and empowerment

In addition to top management commitment the involvement of employees in the implementation of lean practices is critical. Allan et al. (2013) concurs on the significance of involving employees not only at the operations phase of executing construction processes but also at key phases of the project where lean has an impact. The continuous improvement on the involvement of employees is undertaken using the kaizen method and frequent training. Allan et al. (2013) shares that kaizen method advocates for small continuous efforts required to identify problems and opportunities in the construction processes. The method is mostly suitable at the operations level where employees are confronted with daily operations of the organisation, at the operations level employees determine gaps in the performance of the asset and find solutions to them (Allan et al., 2013).

In addition, emphasis must be placed on empowering employees in the implementation of lean practices. Empowered employees are encouraged to adopt new techniques and create better working culture that is aligned to lean philosophy. Peng and Pheng (2011) and Itua and Shamuganathan (2015) recommended training and coaching to prepare and empower employees with the required knowledge and skills to participate in lean initiatives. These actions are particularly important if employees do not have prior knowledge of lean concept and process improvement methodologies. Training allows employees to understand the true essence of the lean concept, which is not restricted to merely cost reductions or staff trimming policies but also includes principles to enhance process efficiencies (Allan et al.,2013; Mostafa et al., 2013; Shang and Sui Pheng, 2014) during the construction processes. Training further helps employees develop a better understanding of the processes in which they participate (Guerrero and Barraud-Didier, 2004). External facilitators or trainers' services for lean must be considered for effective implementation of the concept. On job training was the most preferred method to learn lean skills Warcup (2015), however a multiple training technique (lectures, workshops and including on job training) was suggested for this study. Practice without theoretical underpinning always produces unsatisfactory results in the workplace.

2.4 Collaboration and partnering between lean stakeholders

The collaboration of the participants in the implementation of lean is one of the key attributes to a successful implementation process (Gao et al., 2020). Creating an environment where participants can collaborate has a beneficial impact on the outputs of implementing lean. Collaborations must not only happen between construction professionals, subcontractors, and suppliers but also between the identified stakeholders and the lean instigator.

Jayaram et al. (2008) highlighted supplier development and supplier partnering as elements for relationship building with contractors/suppliers. Supplier development involves educating suppliers about quality standards and procedures and training them on the ongoing process/continuous improvement program. The purpose is to integrate suppliers into the continuous improvement process and to facilitate effective and efficient value creation across the supply chain (Jayaram et al., 2008; Ellis, et al., 2021; Oluwabukunmi, et al., 2019). Supplier partnering treats suppliers/contractors as strategic collaborators by emphasizing long-term commitment, open communication, information, sharing and mutual trust (Jayaram et al., 2008; Olatunji, 2008). Supplier partnering further entail techniques such as early involvement of contractors/suppliers, gain/pain share contracts, team collocation and cross-functional teams. Supplier partnering recognizes that the strategic linking of activities and sharing of benefits between companies result in competitive advantage (Jayaram et al., 2008; Ghosh, et al., 2020).

2.5 Lean techniques and construction process compatibility

Aslam et al. (2020a) shares that as much as the adoption of the lean concept in the construction industry is key, the compatibility of the construction processes to allow lean philosophy is a challenging phenomenon that requires extensive investigation. It is thus paramount to identify and determine compatibility between lean philosophy and traditional construction processes, a criterion must be developed to cross check similarities, differences and overlapping concepts. Suitable lean tools and techniques must be selected and adopted based on the compatibility of the construction processes, not every lean technique will be suitable for every aspect of the construction process (Aslam et al., 2020b). According to Aslam et al. (2020a) the most suitable lean technique for material management and supply chain is 5S, whilst Last Planner System (LPS) is used for planning and pull approach. In addition, Gao et al. (2020) advice organisations to follow a smooth and gradual process of integrating lean tools and techniques into the existing processes, and frequently measure the performance of the implementation process.

3. Methodology

This study adopted a quantitative approach to assess success factors for effectively implementing lean practices in the construction industry. The study took a positivist approach, where a survey was conducted to determine the reality of the phenomenon objectively and quantifiably (Taylor, 2008). The structured questionnaire was administered to willing and available construction professionals that were selected using convenience sampling technique. Convenience sampling compared to other techniques involves selecting participants based on convenience, these are participants readily available and accessible (Etikan et al., 2016; Nazir, et al., 2020; Newman, et al., 2020; Ahmed, et al., 2021) to partake in the study. The readily available construction professionals sampled using a defined criterion were inclusive of construction project managers, architects, quantity surveyors, construction managers, civil engineers, site agents, foreman, SHE representatives, structural engineers, electrical engineers and mechanical engineers. The professionals were conveniently sampled from a total of ten projects. The questionnaire had two parts, Part A elaborating on the background of the participants and Part B expounding on success factors for effectively implementing lean. Part B of the questionnaire used a 5-point scale to enable participants to respond to the importance of the factors identified: 1 = Not Important (NI); 2 = Slightly Important (SI); 3= Moderately Important (MI); 4 = Important (I); 5 = Very Important (VI). Prior to formulating the questionnaire face validity was carried out with the assistance of ten experts who were asked to ensure that the questionnaire was accurate and ready for distribution (Sushil and Verma, 2010). From a total of 80 readily available participants only 72 of them filled and returned the questionnaire, representing a 90% response rate. According to Moser and Kalton (1971) response rate between 20-30% is considered biased and insignificant. Prior to data collection the reliability of the questionnaire determined using Cronbach's alpha was 0.933. According to George and Mallery (2003) values closer to one indicate that the research instrument achieved internal consistency. Descriptive statistics analysis was conducted. The use of descriptive statistics was critical for measuring frequency, central tendency (mean item score) and dispersion (standard deviation) (Marshall and Jonker, 2010).

4. Findings and discussion

4. 1 Background information

Table 1 shows participants background information. The participants were extracted from 10 construction projects in Northwest Province in South Africa. From the table only 74% of the participants held post-matric qualification, while only 5% pursued postgraduate qualification. The results indicate that the participants had adequate knowledge to understand and reply to the questions of the research. In terms of participants' profession there was no major difference between quantity surveyors, construction managers, civil engineers, site agents, foreman and safety officers. Most of the professionals came from the main contractor while 5% were part of the client representatives. On the other hand, 46% of the participants had more than 15 years of experience, indicating that the participants have adequate knowledge and expertise of the construction industry. In terms of implementing lean practices in the construction projects 83% of the participants did not know or were not sure whether lean practices were implemented in the projects, this can be attributed to participants at lower levels not knowing what lean practices are, and how they are implemented thereof.

4.2 Descriptive Analysis

The results in Table 1 reveal that compatibility and suitability of lean techniques, commitment to lean culture and availability of resources were the top three success factors for implementing lean practices in the construction industry in the Northwest Province, South Africa. The success factors had a mean item score of 3.46, 3.33 and 3.28, respectively. However, interpreting the results holistically it is clear that all fourteen factors have an average above 3.0, indicating that all the success factors investigated for effective implementation of lean practices in the construction industry were important. However, Bashir et al. (2015) and Kawish (2017) in their studies outlined employee involvement as a success factor for effective implementation of lean practices. In this current study early employee involvement was ranked eight, indicating that it was not one of the highly preferred factors to induce effective implementation of lean practices. The results of this current study concur with Shou et al (2016) that determining the suitability of the lean tools and methods should be a priority in the implementation of lean practices. Without assessing whether lean tools and techniques are suitable and compatible to be integrated in the existing construction processes it is not clear how employees and other stakeholders can commit and advocate for their integration in the construction projects. It is the responsibility of top management to ensure an integrated project delivery (Ayarkwa et al., 2011), during the process it is also key to train and educate involved stakeholders about lean concepts.

In this current study investing in training and education was ranked third, along with integrating conventional and lean practices together (MIS=3.28) and advocating for change (MIS=3.28). Ayarkwa et al. (2012) asserts that changing the current orthodox culture of completing construction projects must be advocated for in the construction firms. Committing to lean culture is more beneficial and provides greater productivity (Devaki and Jayanthi, 2014; Ellis, 2018). It is also true that training and education requires budget, it is for this reason that this factor is ranked with the same mean item score with availability of funds (Bajjou and Chafi, 2018). More so, the integration of conventional and lean practices is ranked before compatibility and suitability, clear indicating that organisations must first verify suitability of lean concepts with the existing construction processes and techniques before they can be integrated. Successful implementation of lean practices in the construction industry provides organisations with a competitive advantage and improves the image of the firms by construction process, soliciting feedback from suppliers and advocating for extended employee autonomy (Tezel et al., 2018; Aslam et al., 2020a; Gao et al., 2020). Additionally, construction firms are enabled to complete their projects without time and cost overruns and with minimal wastage. Construction firms that can complete their projects within the predefined standards are better preferred (for their reputation) by clients. According to this study's results top management leadership and commitment (MIS=3.15), effective communication and engagement (MIS=3.15) and lean consultant support (MIS=3.15) were the least preferred success factors for effective implementation of lean practices in the construction industry. These results disagreed with Warcup (2015) and Ahmed and Sobuz (2019).

Table 1. Mean and rank results of success factors for effectively implementing lean practices

Success factors for effectively implementing lean practices	Overall	
	MIS	Rank
Compatibility and suitability of lean techniques	3.46	1
Commitment to lean culture	3.33	2
Availability of resources	3.28	3
Integrate conventional and lean practices	3.28	3
Advocate change	3.28	3
Invest in training and education	3.28	3
Extend employee autonomy	3.25	4
Subcontractor and supplier buy-in	3.22	5
Lean practices policy	3.22	6
Teamwork and collective system thinking	3.21	7
Early employee involvement	3.19	8
Top management leadership and commitment	3.15	9
Effective communication and engagement	3.15	10
Lean consultant support	3.13	11

5. Conclusion and recommendations

The study assessed and ranked success factors for effectively implementing lean practises in the construction industry in the North West Province, South Africa according to their importance. From the results compatibility and suitability of lean techniques, commitment to lean culture and availability of resources were ranked as the top three success factors important for effectively implementing lean practices, respectively. It can be asserted then that more than anything it is key that top management places focus on verifying the implementation of lean practices in the existing construction processes before they can be integrated. The verification and suitability processes must further ensure that organisations do not waste or spend resources on adventures that are not going to produce desirable outcomes to the organisation. It was further noted that raising awareness in relation to adopting lean culture in the construction firms was not enough, but that top management needed to advocate and commit to relinquishing resistance to change and committing to new and innovative ways of eliminating waste, reducing construction processes, soliciting customer feedback and extending employee autonomy. The results of this current study further highlighted that top management leadership and commitment, effective communication and engagement and lean consultant support were least important according to the ranking system adopted. However, in relation to the mean item scores all the identified factors were important and pivotal towards effectively implementing success factors lean practices in the construction industry. The results of this study can be used as a foundation for future studies whose aim is to establish the level of effectiveness of the identified factors in the implementation of lean practices, and whether there is a link between the established association and the performance of the construction projects.

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ID 7

Learning from Construction Accidents: Input, Process and Context

Albert P.C. Chan[1,2], Tracy, N.Y. Choi[2], Yang Yang[1,2] and Zhang Qingwen[1]
[1] The Hong Kong Polytechnic University Shenzhen Research Institute, Shenzhen, China.
[2] The Hong Kong Polytechnic University, Hong Kong, China
bsnychoi@polyu.edu.hk

Abstract
Learning from past accidents has long been an important way to prevent similar accidents from happening again. However, given that accidents continue to plague the construction industry, learning is far from being an effective practice. Previous research indicated that failure to learn from safety incidents could result in repeat of similar incidents. To prevent the recurrence of similar construction accidents in the future, there is a pressing need of enhancing the incident learning system within the organisations. The aim of this study is to offer a research framework that examines the relationship between the three key components of the organization's learning system, namely, learning input, learning process and learning context. In the proposed research framework, the study will develop the instruments to measure the organization's learning process, resilient safety culture (learning context) and incident information flow (learning input) through a comprehensive literature review. A large-scale questionnaire survey will be administered among management staff and frontline workers to examine the relationship between learning process, resilient safety culture, and information flow. Several analytical tools, i.e. principal component analysis (PCA) and Bayesian network (BN) modeling, will be adopted to analyze the aforementioned relationships. The results will not only strengthen the current knowledge in safety but also enhance the learning system of organizations and individuals to avoid the recurrence of similar accidents in the future.

Keywords: Construction project organizations, Learning from accidents, Recurrence, Resilient safety culture, Incident information flow

1. Introduction
The construction industry has long been one of the industries with the highest accident rate among other industry in the world. For example, in United States, the number of fatal accidents in the construction industry reached 1013 (Bureau of Labor Statistics, 2019) in 2017. In the same year, fatal accident cases occurred in the construction industry accounted for 76% of all industries in Hong Kong (Hong Kong Special Administrative Region Labour Department, 2018). In 2016, there were 734 construction works related accidents in China, an increase of 32.5% over 2015 (Zhang et al., 2019). Frequent construction accidents not only bring irreparable loss of life, but also cause a great economic burden on families and enterprises, and a negative image of the industry, which is not conducive to social harmony and stability.

Due to the complexity of construction projects, environmental, technical and human-related factors influence each other, which brings unforeseen safety risks to construction personnel (Harvey et al., 2018). These dynamic tasks and complex working environment are considered as potential causes of the continuous occurrence of accidents in construction projects (Manu et al., 2010). In addition, the continuous occurrence of similar safety accidents is also reflected in accident statistics in various countries and regions. For example, in the United States, 39.2% of construction worker fatalities are related to "fall of person from height" (Occupational Safety and Health Administration, 2019). Fall accidents accounted for 30% in among all types of accidents in Hong Kong (Hong Kong Special Administrative Region Legislative Council, 2017), and 26% in the United Kingdom (Health and Safety Executive, 2018). Based on the warnings of these data, it is urgent to find the root cause of the repeated occurrence of similar construction accidents, so as to effectively protect the safety of workers and improve the ability of project organizations to respond to safety risks.

2. Research Background

Some descriptive studies have investigated the characteristics of similar accidents, including the time of the accident, the source and environment of the accident, the degree of personal injury, and the characteristics of the project involved (Chan et al.,2008). Although these studies can summarize the characteristics of similar accidents, the hidden factors behind the recurrence of similar accidents such as whether they occurred in the same project or in the same construction company were rarely explored. Existing research mainly considers similar accidents as one-off cases and lacks of exploration on the inter-connection between similar accidents. On the other hand, various accident causation models have been developed by the scholars to reveal the root causes of the same type of accidents (Wong et al., 2016; Harvey et al.,2018). Although these studies can summarize the general causes of similar accidents, they failed to explain the "recurrence" of these accidents.

The failure to successfully learn from past accidents is one of the reasons for the repeated occurrence of construction accidents (Kirwan, 2001). Some scholars even believed that the root cause of repeated accidents is learning failure. “Learning from accidents” is the main method of existing safety research. Its purpose is to learn from the data and information of past construction accidents, learn lessons, and to find effective methods and measures to avoid similar accidents in the future (Bond, 2002). However, few studies have examined how construction company and construction personnel can enhance their safety perceptions and behaviors, safety culture and safety management systems for effectively learning from past accidents. In the field of non-construction safety research, studies have pointed out that the reasons for the failure of accident learning include: accident underreporting (Sanne,2008), insufficient learning ability (Jacobsson et al., 2009), evasion or shirk responsibility (Rose, 2004), and administrative decision-making problems (Hovden et al., 2011), etc. However, they have not examined thoroughly in construction safety research.

3. Research aim and objective

The aim of this study is twofold. First, the study aims to initiate a theoretical model that explores the relationship between learning culture, learning capability and safety performance. Second, the study aims to validate the theoretical model by applying an empirical approach to investigate the effects of learning culture and learning capability on safety performance. This paper contributes to the body of knowledge in safety learning both theoretically and practically, as such literature is deemed lacking. Theoretically, it offers a holistic insight into how safety learning contributes to safety performance. Practically, it develops an integrated LFI approach for guiding construction practitioners and companies to engage various LFI activities and improve their learning capability and culture. The ultimate goal of applying such an LFI approach in construction organizations is to prevent multiple future incidents through effective learning from past errors and experiences.

4. Methodology

4. 1 Research Design

The study was based on research hypotheses regarding the integration of learning components by examining their inter-relationship. A total of two hypotheses were originally proposed.

H1: The learning culture significantly affects safety performance

Organizational culture acts as an essential contextual condition that significantly affects the learning process. A blame culture can discourage employees from reporting incidents and/or self-made errors and from taking safety corrective actions, resulting in a learning failure (Cannon and Edmondson 2005; Stemn et al. 2018). The action and judgement of an investigator may be influenced by fear caused by criticism from management (Manuele, 2003). In the LFI system, learning participants are crucial for facilitating the learning process, drawing the lessons learned, and disseminating and implementing them (Koornneef, 2000). How they participate in learning closely relates to their knowledge and beliefs about incident causation (Stemn et al. 2018). In turn, organizational culture can influence the beliefs and attitudes of the learning participants. When only direct causal factors of the incidents are emphasized, the learning participants including the investigators may not look for the root causes arising from organizational and management weakness. Unfavorable organizational culture, such as adopting punishment as a corrective control in response to an incident, can decrease the safety commitment of the workforce, affect their safety awareness, and eventually decrease their willingness to participate in learning (Geller 2014; Stemn et al. 2018). “What is worthy of reporting” heavily relies on the definition and scope of reportable events described by an organization (Lindberg et al. 2010). In other words, the content of reporting depends on whether the organizational culture appreciates minor events and near misses as important learning sources. Resilient safety culture is considered as an essential dimension of the learning culture in the conceptual model because of the following: (1) safety culture is an important subset of organizational culture and is one of the underlying causal factors of construction accidents (Behm and Schneller 2013); (2) safety culture has complex inter-relationships with learning culture (Littlejohn et al. 2017); (3) resilient safety culture stresses organizational learning and reflects whether organizations have the capabilities to learn from safety hazards and respond to the changing risks (Trinh et al. 2018). This dimension, however, has received scant attention in the LFI studies (e.g., Catino and Patriotta 2013).

H2: The learning capability of individuals affects their safety performance
Following the axioms "What-You-Look-For-Is-What-You-Find" (Lundberg et al. 2009) and "What-You-Find-Can-Determine-What-You-Can-Fix" (Stemn et al. 2018), what lessons employees can learn and apply can be determined by individual's learning capability. It is assumed that individuals have better learning capability may have better safety performance since they will be able to learn errors and good practices from past and continuously improve their knowledge and skills to take safe actions. The quality of the lessons received will be determined by the individuals' capability, skill, beliefs and knowledge (Stemn et al, 2018). All workers and management play important roles in the process of learning from accidents because they learn from accidents on behalf of their organization (Baumard and Starbuck, 2005). In the process of learning from accident, the employees need to identify and report accidents, investigate the accidents, analysis and identify lessons from the accident, store and share lessons obtained through the distribution of safety information (Lindberg et al., 2010; Chevreau et al., 2006). Thus, frontline workers are highly encouraged to participate in the learning procedures. High learning capability of employees ensures that lessons knowledge gained are effectively implanted across the organization and are properly retrieved and utilized (Manuele, 2003).

4.2 Survey Questionnaire
The design of the questionnaire started from a review of existing literature that was introduced in Section of literature review. According to the literature review, the measurements of each learning components were defined for compiling the questionnaire (Table 1). The draft questionnaires were peer-reviewed by academics and construction professionals and frontline workers. A total of 22 reviewers were invited to provide feedback to the questionnaire designed to ensure that the statements of the questions were clear and could be easily understood by construction employees, especially frontline workers. These reviewers included five scholars in the U.S., Australia, and Mainland China, four construction professionals engaged from Chinese construction projects, and 13 frontline workers in Wuhan and Hong Kong. Among these reviewers, four Chinese scholars understand English and Chinese (either Cantonese or Mandarin) very well. They were further requested to advise the consistency of the questionnaire in bilingual language. The feedback of all reviewers was collected from April to June 2021 to refine the questionnaires. Note that only a part of the questionnaire was used in this paper.

Table 1: List of learning factors and indicators

Latent factors	Indicators	References
Learning culture	At my workplace, there is an atmosphere of trust and openness	Reason (1997)
	My company treats incidents as learning opportunities	Cooke and Rohleder (2006)
	My company implements a reward system that encourages implementation of safety corrective actions.	Cooke and Rohleder (2006)
	My work group discusses whether safety recommendations from previous incidents are appropriate for our work before implementation.	Littlejohn et al. (2017)
	Managerial and supervisory staff conduct sufficient site inspections to check changes in work conditions	Feng and Trinh (2019; Trinh et al. (2019); Trinh and Feng (2020)
	Management and supervisory staff implement appropriate corrective measures immediately following any changes to working conditions (i.e., new hazards identified, hazardous events occurring).	Trinh et al. (2019); Trinh and Feng (2020)
Learning capability	I participate in incident learning through specialised training programs.	Canno and Edmondson (2005)
	I am able to understand incident information based on my knowledge and technical capability.	Littlejohn et al. (2017); Fruhen et al. (2014); Wu and Huang (2019); Deng et al. (2020)
	I am able to identify my workmate on my unsafe behaviours for incident information.	Fang et al. (2015)

	I modify my unsafe behaviours based on incident information.	Wu and Huang (2019); Zhang et al. (2015)
	At my workplace, I learn from accidents and near misses.	Cooke et al. (2007); Carroll and Fahlbruch (2011); Drupsteen and Hales (2014); Littlejohn et al. (2017)
	I not only learn from previous internal incident experience but also acquire lessons from external sources.	Stemn et al. (2018)
	I make sure that important information about incident is shared with others who might benefit from it.	Littlejohn et al. (2017)
Safety performance	I use all the necessary safety equipment to do my job.	Griffin and Hu (2013)
	I use the correct safety procedures for carrying out my job.	
	I ensure the highest levels of safety when I carry out my job.	
	I promote the safety program within the organization.	
	I put in extra effort to improve the safety of the workplace.	
	I voluntarily carry out tasks or activities that help to improve workplace safety.	

4.3 Data Collection

The questionnaire survey was administered among construction workers in Chinese construction projects between July and October 2021. Each questionnaire consists of five sections. The first three sections contain the measurements of learning culture, learning capability, and safety performance. Respondents were asked to rank each parameter with a Likert-scale score from 1 (strongly disagree) to 5 (strongly agree). The fourth section is to measure the safety performance. The last section is about the demographic information of respondents. Electronic surveys were conducted using a Quick-Response code link. The questionnaires were distributed to managerial staff through the research team's network. Management personnel were then requested to help invite their frontline workers to participate in the survey. A Chinese version of the questionnaire was used for the survey. A total of 210 frontline workers returned their responses.

4.4 Data Analysis

Prior to further statistical analysis, the reliability of the measurements was checked using Cronbach's alpha analysis. A Cronbach's alpha value above 0.70 is considered reliable (George and Mallery, 2003). Structural equation modeling (SEM) was then applied in this study to examine the effects of learning culture and learning capability on safety performance. To implement a SEM analysis, the sample size for SEM is suggested to be no lower than 10 times the number of variables (Han et al. 2020). In the present study, a total of 18 factors were presented and 210 valid questions were obtained, meeting the aforementioned criteria. Structural equation modelling (SEM) using Amos 22.0 was used to delineate the relationship among learning culture, learning capability, and safety performance. The composite reliability (CR) and average variance extracted (AVE) of each construct were examined. A CR greater than 0.7 suggests an acceptable level of internal consistency reliability. An AVE greater than 0.5 shows a satisfactory level of construct convergent validity.

5. Results and discussion

5.1 Demographic information of respondents

The demographic information of respondents was summarized in Table 2. Over 33 percent of the respondents were in the age group of 31-40. Only 23 out of 210 respondents were female. Most of the survey participants were building professionals with years of experience who should be able to provide reliable data and genuine opinions to the research. 60 percent of respondents had acquired more than 5 years of working experience and nearly 40% had worked for more 10 years within the construction industry. 48% of the respondents worked for main contractors while 40% worked for subcontractors. More than half of the respondents have a diploma or above. It was observed that 59% of the respondents had over one year of work experience on that construction site. The respondents were worked in various types of projects included residential, commercial, industrial, etc. Among them, most of the respondent (81%) worked in resident building projects. The survey was conducted in different regions of China. The majority of respondents, over 75%, worked at construction site in Shandong.

Table 2: Demographic information of respondents

Items	Frequency	Percent %	Cumulative Percent %
Age			
<=20	4	1.9	1.9
21-30	61	29.0	31.0
31-40	71	33.8	64.8
41-50	60	28.6	93.3
>=51	14	6.7	100.0
Total	210	100.0	100.0
Working Experience			
<1 yr	20	9.5	9.5
1-5 yrs	61	29.0	38.6
6-10 yrs	47	22.4	61.0
>=11	82	39.1	100.0
Total	210	100.0	100.0
Employer			
Main contractor	101	48.1	48.1
Subcontractor	84	40.0	88.1
Developer	7	3.3	91.4
Others	18	8.6	100.0
Total	210	100.0	100.0
Year of experience on that job site			
<1 yr	86	41.0	41.0
1-3 yrs	91	43.3	84.3
>=3 yrs	33	15.7	100.0
Total	210	100.0	100.0
Project Type			
Residential	170	81.0	81.0
Commercial	15	7.1	88.1
Industrial	6	2.9	91.0
Infrastructure	7	3.3	94.3
Other	14	5.7	100.0
Total	210	100.0	100.0

5.2 Effects of learning culture and learning capability on safety performance

The Cronbach's alpha for scale of learning culture, learning capability, and safety performance was larger than 0.7, indicating good to excellent scale reliability. Also, the CR and AVE values for each construct were larger than 0.7 and 0.5, respectively, suggesting the acceptable levels of internal consistency reliability and construct convergent validity. The results of goodness-of-fit indices indicated that the measurement model appeared to fit the data reasonably well: $\chi 2=766.538$ with df=133, $p<0.001$, and CFI=0.826. The SEM results showed that learning culture and learning capability significantly influenced safety performance: learning culture → safety performance (ß=0.740, $p<0.001$); and learning capability → safety performance (ß=0.286, $p<0.001$) (Table 3). The hypothesises are considered to be acceptable for interpretation. All the standardized path coefficients are positive. As shown in Figure 1, the greater the path coefficient, the more significant the attributes can be interpreted as a major indicator of the latent factors. The factor Learning Culture (LCu) is considered as the most important factor that significant direct relationship with safety performance. This factor covers five indicator variables. Good learning culture in the organization is the key to achieve a good safety performance. Cooke and Rohleder (2006) suggested that safety performance can be improved by creating a positive safety culture. In an atmosphere strong safety culture, employees discuss their safety concerns freely and take remedial actions properly. Demonstrating strong commitment of senior management to safety is crucial to facilitate the safety improvements. As a result, a lack of such safety commitment may hinder learning from incidents and reduce motivation for learning (Zwetsloot et al., 2013).

Learning Capability (LCa) received a path coefficient of 0.286 and seven attributes were under this factor. Individual learning ability has a strong correlation with safety performance. The findings from this study suggest that organizations should make a greater effort to enhance the learning capability of employees. Improving employees' learning ability to learn from workplace accidents may help organizations reduce the occurrence of accidents. However, many organisations place a greater emphasis on learning lessons from accidents rather than enhancing individuals' learning capability. By actively and systematically investigation of worker learning, more latent conditions might be identified and indicators for a successful learning process may be determined (Stemn et al. (2018). Workers with strong learning capability may be able to assist in prioritizing of actions, achieve better allocation of time and resources and facilitate improvements of safety performance (Drupteen and Hasle, 2014).

Table 3. Latent factors and their attributes

Latent factors	Indicators	Cronbach's alpha	Composite reliability	Average variance extracted	Coefficient
Learning culture (LCu)	LCu1: At my workplace, there is an atmosphere of trust and openness	0.819	0.765	0.545	1.000
	LCu2: My company treats incidents as learning opportunities				0.940***
	LCu3: My company implements a reward system that encourages implementation of safety corrective actions				0.801***
	LCu4: Managerial and supervisory staff conduct sufficient site inspections to check changes in work conditions				0.939***
	LCu5: Management and supervisory staff implement appropriate corrective measures immediately following any changes to working conditions (i.e., new hazards identified, hazardous events occurring)				0.801***
Learning capability (LCa)	LCa1: I participate in incident learning through specialised training programs	0.897	0.839	0.746	0.777***
	LCa2: I am able to understand incident information based on my knowledge and technical capability				0.926***
	LCa3: I am able to identify my workmate on my unsafe behaviours for incident information				1.000
	LCa4: I modify my unsafe behaviours based on incident information				0.966***
	LCa5: At my workplace, I learn from accidents and near misses				0.728***
	LCa6: I not only learn from previous internal incident experience but also acquire lessons from external sources				0.753***
	LCa7: I make sure that important information about incident is shared with others who might benefit from it				0.743***
Safety performance (SP)	SP1: I use all the necessary safety equipment to do my job.	0.967	0.947	0.791	0.857***
	SP2: I use the correct safety procedures for carrying out my job.				0.850***
	SP3: I ensure the highest levels of safety when I carry out my job.				0.900***
	SP4: I promote the safety program within the organization.				1.000
	SP5: I put in extra effort to improve the safety of the workplace.				0.900***
	SP6: I voluntarily carry out tasks or activities that help to improve workplace safety.				0.971***

***$p<0.001$

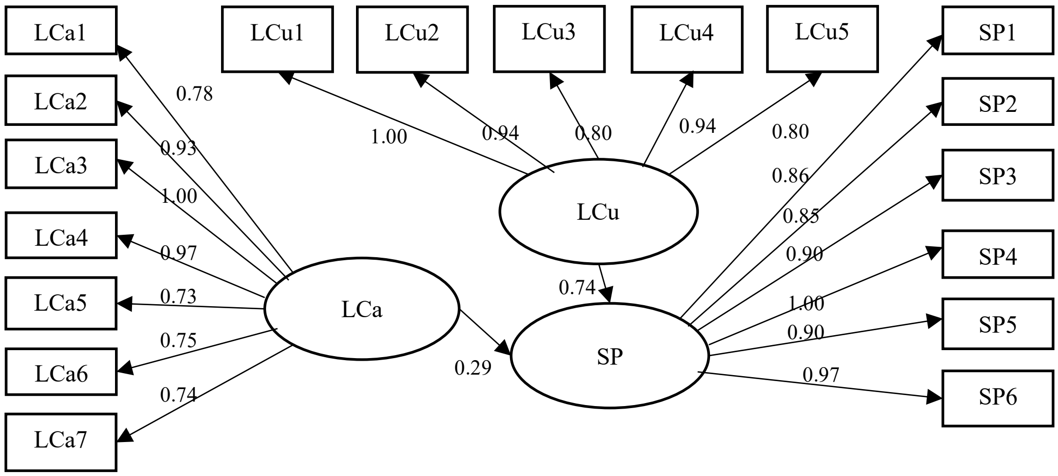

Figure 1. Effects of learning culture and learning capability on safety performance

6. Conclusions

Failure of organizational learning from accidents has been argued as one of the underlying causes leading to recurrence of similar accidents. In view of this, a questionnaire survey and the SEM approach were adopted for the study to analyze the causal relationship between the learning culture and learning capability on safety performance. The SEM supports the hypothesized positive interrelationships between learning culture and safety performance with a strong path coefficient of 0.74 at a 0.001 significance level. The findings indicate to a clear implication for an organization's top management to obtain a better knowledge so that an appropriate strategy can be developed and suitable resources can be utilized to improve construction project safety performance.

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A Theoretical Assessment of Causes for Deferred Maintenance of Public Buildings in developing countries-The Kingdom of Eswatini

Matse Ncamiso1, Mashwama Nokulunga1 and Aigbavboa Clinton1 and Thwala Didibhuku2

[1] Department of Construction Management and Quantity Surveying, University of Johannesburg, Johannesburg, South Africa.
[2] SARChI in Sustainable Construction Management and Leadership in the Built Environment, Faculty of Engineering and the Built Environment, University of Johannesburg, Johannesburg, South Africa
nomiso01investment@gmail.com

Abstract
The study examines previous literature on causes of deferred maintenance in public buildings. Deferred maintenance refers to routine maintenance, and structural part replacements required to prolong the facility life to meet its expected life expectancy but delayed past the scheduled service period. Maintenance technology is concerned with all factors influencing and triggering requirements for maintenance work. The event in a building's fabric can lead from numerous unrelated design decisions, inappropriate materials, inaccurate load evaluation, insufficient usage evaluation and insufficient exposure assessment. Previous researchers have identified problems and issues influencing the execution of feasible maintenance of buildings. These challenges have become a prevalent issue encountered in building maintenance by the building manager. The study is conducted with reference to existing theoretical literature, published and unpublished research. The study is mainly a literature review on the causes of public buildings maintenance to be deferred. Previous research' findings will be applied to the situation in Eswatini. Budget restrictions make it difficult to organize building maintenance tasks and lack of maintenance software tools has a negative impact on maintenance. The objective of the study is to identify the causes from literature review for deferred maintenance in public buildings. This study will assist the public facility management and the government at large to avoid the challenges affecting maintenance of public infrastructure.

Keywords
Theoretical Assessment, Causes, Deferred Maintenance, Public Buildings, Developing Countries

1.0 Introduction

Preserving public buildings and ensuring that they stay in a high notch serviceable condition is a challenge faced by most developing countries in the world (Yasin et al., 2017). Moreover, proper maintenance of public buildings is critical for a building to be in good condition. Hence, priority has to be given to public buildings, because they are key assets in delivering welfare service to the public (Hopland & Kvamsdal, 2019). In addition, maintenance of public buildings in developing countries usually loses the budgetary battle when government budgets are to be reduced (Borge and Hopland, 2016). According to the Council of the Great City Schools (2014), deferred maintenance is a measure of preventive and routine maintenance, including minor and major improvements, and structural system to prolong the life of the facility to meet its expected life expectancy. Deferred public building maintenance contribute to poor public services and is influenced by different factors such as the inappropriate materials, inaccurate load evaluation, insufficient exposure assessment (Okosun and Olagunju (2017).

2.0 Research Methodology

The study is part of the researcher dissertation which is still in progress hence, literature review at this moment. The research was carried out with reference to the published and unpublished theoretical literature from online journals, Conferences, Proceedings dissertations. Again, articles from Google scholar, Emerald, Science direct which were all related to the causes of public buildings maintenance to be deferred were also used. Moreover, the study is mainly a theoretical literature review. A theory triangulation qualitative research has been adopted for this study whereby more than one theoretical framework has been used to ensure the research is affluent, robust, comprehensive and well developed. However, the results of this studies are rigorously discussed and produce rewarding conclusions. According to Turner and Turner (2009) triangulation is the process of using a different point of view to confirm, dispute, or extend previous discoveries. Furthermore, triangulation is utilized often in presence research, with examples of explicit use occurring mostly in studies focusing on social presence. Creswell (2014) and Muijs (2004) explained that qualitative approaches to data collection, analysis, interpretation, and report writing differ from the traditional, quantitative approaches. Qualitative data usually not numerical therefore it cannot be statistically analyzed.

3.0 Causes for Deferred Maintenance

This paper has discussed a number of factors affecting maintenance of public building in developing countries like the kingdom of Eswatini. The focus of this paper was on top management challenges and technical problems.

3.1 Top Management Problems

According to Ali et al. (2016) and Lee and Scott (2009), top management encounters challenges when it comes to maintenance of public buildings and normally they don't have any maintenance procedure or they don't follow it at all. Following are factors that contribute to poor maintenance within top management.

3.1.1 Financial constraints due to lack of budget allocation for building maintenance.

Maintenance management (MM) team is often hindered by finances when it comes to maintenance activities of a building (Zakaria et al., 2012). Maintenance budget is always a major challenge in either planned or unplanned maintenance due to the fact that evaluation for maintenance is not carefully done before allocating funds for undertaking the work (Mohd-Noora et al., 2011). Budget for maintenance is commonly allocated based on previous budget plus a certain percentage. Top management is also facing technical challenges in accurately estimating maintenance work, which results in underestimates or cost overruns (Alshehri et al., 2015 & Mydin 2015). Olanrewaju et al., (2015) and Chua et al. (2018), claim that it is common with building owners to put the maintenance budget last in their list not considering the long term consequences.

3.1.2 Poor procurement management systems

In construction in general the lowest tender always gets the contract, same goes with maintenance works the same procedure is normally followed. The lowest bidder normally is awarded the project, moreover, the lowest bidder will try to make profit and take short cut and therefore compromising quality. In-addition, maintenance contractors (MC) normally employ cheap labour to perform the maintenance work as they are paid low salaries to maximize the contractor's profit and these results in time wastage and poor workmanship (Ali et al. 2016). The government strategy of awarding work to the lowest bidder brings a negative influence to the top management when selecting a suitable maintenance approach. Cost estimates for maintenance works should incorporate the age of the building and economic fluctuations, so selecting the lowest bidder who did not consider these items well would be a disadvantage to the project. Old building maintenance is more complicated compared to newly built structure and the material and expertise cost will accumulate with the rising standard of living (Alshehri et al., 2015).

3.1.3 Lack of knowledge in maintenance scope

Poor commitment and support for the maintenance personnel makes it difficult for the maintenance management team to deliver good quality work. Tools for measuring the maintenance personnel performance is lacking in most government organizations (Alshehri et al., 2015). Hence, education level and work experience for the maintenance personnel in the maintenance field plays a major role to influence the building management system.

3.2 Technical Problems

The challenges faced by building managers while undertaking maintenance works that are related to technical aspect in prolonging the life span of the building from the day it was constructed until the end of its life cycle are referred as technical problems (Rahman et al, 2012). The challenges can be separated as follows:

3.2.1 Greediness of the maintenance contractor
Greediness of the maintenance contractor can be a major cause of maintenance works to be deferred for example building material diversion, particularly cement. Therefore, production on the client site would be hindered as material is being stolen or transferred to the contractor's own developments. Again, use of substandard materials to achieve more profit can also lead to early decay of the buildings which would cause the maintenance of the structure to be deferred for years (Ayodeji, 2011)

3.2.2 Lack of maintenance planning software tool
In order for the maintenance department to deliver a high-profile service an effective software system is needed that contains operation, maintenance and renovation so that it helps in making budget allocation decision. The software system helps the building managers during maintenance planning by distributing the allocated budget accordingly (Alshehri et al., 2015). Awol et al., (2016) claimed that maintenance can be deferred due to lack of condition-assessment program for all existing public buildings, setting minimum requirements for the maintenance of different facilities.

3.2.3 Poor designs and poor workmanship during the construction stage
Ogunmakinde et al. (2013) argued that poor designs and poor workmanship during the construction stage of the buildings will increase the amount of maintenance needed by the structures during its lifetime.

3.2.4 Shortage of spare material in the local markets
Alshehri et al. (2015) argued that maintenance work done in old buildings is quite difficult, since it is difficult to get the exact same spare part from the local market which will call for replacement with a new item, which might be costly. Therefore, sourcing the spare part from outside market will escalate the maintenance cost and the maintenance process will also be delayed (Ali et al. 2016). (Rahman et al, 2012). Ordering spare part is sometimes delayed by the procurement system of government whereby the building managers are expected to get three quotations and compiled justification then forward to the top management for approval before purchasing. Hence such processes will affect the maintenance department productivity.

4.0 Lesson Learnt

This research work assisted to reveal the causes of public buildings maintenance to be deferred. Deferred maintenance generates a backlog of expenditure which will be covered either by major rehabilitations to existing properties or investments in new ones in the future. Maintenance management is often hindered by budget restrictions in organizing building maintenance activities. Maintenance budget is always a major challenge in either planned or unplanned maintenance due to the fact that maintenance evaluation is not carefully done before allocating funds for undertaking the work. Again, maintenance usually loses the budgetary battle and when government budgets are to be reduced can be an easy target in general as short-sighted politicians focus primarily on winning the following election and pay little attention to maintenance projects that can save costs in the long run.
Furthermore, it is noted on the study that lack of maintenance software tools brings a negative effect on maintenance. Hence, in order for the maintenance department to deliver a high-profile service an effective software system is needed that contains operation, maintenance and renovation so that it helps in making appropriate budget allocation decision.

5. Conclusion

The literature revealed factors that contribute to the cause for deferred maintenance on public buildings. Most of these challenges are encountered by building managers in public buildings (PB) were: lack of knowledge in maintenance scope, awarding tenders to lowest bidders (compromises quality of works), unqualified maintenance contractor (MC), government regulations and rules affecting the selection of suitable maintenance approaches, budget restrictions on maintenance, lack of supervision from the maintenance team, unavailability of skilled labourers, lack of maintenance training and motivation to engineers, lack of maintenance software tools, shortage of materials in the local markets, lack of awareness on the importance of maintenance and vandalism of facilities by users. The study is part of the researcher master's dissertation which is still in progress and it's on the verge of questionnaire distribution and the researcher is hoping for robust respond.

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Experimental Analysis of Aggregate Densities and Deflections for Compaction Quality Control with Light Weight Deflectometer

Yi Jiang[1], Shuo Li[2], Guangyuan Zhao[3]

[1] School of Construction Management, Purdue University, West Lafayette, IN 47907, USA
jiang2@purdue.edu
[2] R&D Office, Indiana Department of Transportation, 1205 Montgomery Street, West Lafayette, IN 47906, USA
sli@indot.in.gov
[3] Department of Civil & Environmental Engineering, University of Waterloo, Waterloo, Canada
luke.zhao@uwaterloo.ca

Abstract
Nuclear gauge has been widely used to determine the in-place dry densities of pavement layers in compaction quality control. However, there is a trend for transportation agencies to use light weight deflectometer (LWD) to measure compaction sufficiency of pavement construction. LWD measurement can provide the in-situ modulus of geomaterials that is one of the key parameters used to characterize the properties of pavement structural layers. Since the measurements of nuclear gauge (density) and LWD (deflection) are different, it is necessary to analyze their relationships with compaction properties, such as moisture content, layer thickness, and construction condition. This study performed intensive laboratory experiments on the aggregate materials to evaluate the effects. Extensive experiments were also performed in the test pits with LWD to determine the effect of aggregate layers on pavement structure. Proctor tests were conducted on selected pavement base materials to establish the moisture-density relationships. Material deflections were also measured on the compacted materials in the Proctor molds to reveal the moisture-deflection relationships. Through the test pits experiments, the contribution of each aggregate layer to the pavement structure capacity was analyzed and quantitated. It was concluded that moisture content has a significant effect on LWD deflection or modulus. Aggregates compacted near the optimum moisture are capable of providing a stable deflection value. After compaction, LWD measured deflection decreases as the moisture content decreases.

Keywords
LWD, Compaction, Moisture Content, Dry Density, Deflection

1. Introduction

Light weight deflectometer (LWD) is designed to measure the compaction quality of a structural layer (Umashankar et al., 2016; Kavussi et al., 2019). However, the measured deflection and modulus are affected by the underlying structural materials. The measured modulus is the modulus of the entire structural system, rather than the modulus of the compacted top layer. Therefore, the effects of the materials below the compacted top layer should first be analyzed to accurately measure the modulus of the compacted material in the top layer with LWD. In this study, Proctor tests were conducted on selected pavement base materials to establish the moisture-density relationships. Material deflections were also measured on the compacted materials in the Proctor molds to reveal the moisture-deflection relationships. According to the pavement engineers of the Indiana Department of Transportation (INDOT), the No. 53 aggregate has been the major type of granular materials with specified gradations for subgrade treatment, and granular base and subbase for Portland cement concrete pavement and hot mix asphalt (HMA) pavement in Indiana. Therefore, the main effort of the laboratory experiments was focused on the properties of the No. 53 aggregates related to the construction quality, including gradation, optimum moisture content, maximum dry density, deflection, and modulus. In addition, some other materials recently used for road construction, such as No. 43 aggregate, steel slag, and recycled asphalt pavement (RAP), were also tested to provide first-hand data and baseline information. In addition to the indoor Proctor-LWD experiments, outdoor test pits were designed and constructed to simulate the real pavement structures. Through the test pits experiments, the contribution of each aggregate layer to the pavement structure capacity was analyzed and quantitated.

2. Laboratory Experiments of Material Modulus

2.1. Gradations of the Sample Materials

No. 53 aggregates samples, denoted as No. 53A and No. 53B, were obtained from two different suppliers for this study as shown in Figure 1. The information on the materials from the suppliers includes gradations, optimum moisture contents, and maximum dry densities. Table 1 presents the gradations provided by the suppliers of the two samples along with the INDOT gradation specifications (INDOT, 2017). The given gradations of the material samples were within the INDOT specified ranges and, therefore, satisfied the requirements of the gradation specifications. Sieve analyses were conducted with the two material samples. The results of the sieve analyses as well as the gradations given by the suppliers are also presented in Table 1. It is shown that the actual gradations were very close to those provided by the suppliers. Therefore, both No. 53A and No. 53B aggregates meet the standard specifications.

(a) No. 53A (b) No. 53B

Fig. 1. Two Samples of No. 53 Material

Table 1. Gradations and Specifications for No. 53 Aggregates

Sieve Size	% Passing Sieve Size				
	No. 53A		No. 53B		INDOT Specification
	Supplier	Test	Supplier	Test	
1½" (37.5mm)	100.0	100.0	100.0	100.0	100
1" (25 mm)	90.9	90.7	91.3	94.0	80 - 100
¾" (19 mm)	79.2	79.7	80.7	84.3	70 - 90
½" (12.5 mm)	66.0	66.0	64.0	66.5	55 - 80
3/8" (9.5 mm)	58.7	60.6		59.4	
#4 (4.75 mm)	47.1	51.6	39.6	39.4	35 - 60
#8 (2.36 mm)	33.1	35.4	29.5	29.4	25 - 50
#30 (0.6 mm)	14.5	14.0	16.0	17.7	12 - 30
#200 (0.075 mm)	8.9	8.1	10.0	10.0	5 - 10

2.2 Maximum Dry Density and Optimum Moisture Content

The optimum moisture content and the corresponding maximum dry density of a soil mixture are the most important values for achieving the desired compaction. These values provided by the suppliers of No. 53A and No. 53B are shown in Table 2. The given optimum moisture content and maximum dry density for No. 53A are 8.9% and 134.2 pcf, and those for No. 53B are 10.9% and 127.8 pcf. To analyze the relationships between the degree of compaction and LWD measurements, Proctor tests were performed to establish the moisture-density relationships for No. 53A and No. 53B materials. Notice that the AASHTO Designation T 99 Method D (AASHTO, 2017) was chosen for the

Proctor tests. This method is applicable to the materials with a maximum of 30% of the particles retained on the 19.0 mm (3/4 in.) sieve. As illustrated in Table 1, the No. 53A aggregate sample contained 20.3% of the particles greater than the sieve size of 19.0 mm (3/4 in.) according to the lab sieve analysis. The No. 53B aggregate sample had 15.7% of the particles greater than the sieve size of 19.0 mm (3/4 in.).

Table 2. Proctor Test Results for No. 53 Aggregates by Suppliers

Proctor Test Value	**Aggregate Sample**	
	No. 53A	**No. 53B**
Optimum Moisture Content	8.9%	10.9%
Maximal Dry Density	134.2 pcf	127.8 pcf

With Method D of the AASHTO Designation T 99, all aggregate particles larger than the sieve size of 19.0 mm (3/4 in.) is defined as oversized material. Therefore, a correction may be necessary if the oversize material is above a certain percentage specified by the agency. If the agency does not specify such a percentage, it is recommended that a correction be made when more than 5 percent by weight of oversize particles is present (NDDOT, 2015). Since INDOT did not have the specified the percentage of oversize material, according to the recommended 5 percent criteria, corrections were necessary for both No. 53A and No. 53B materials. The correction method for Method D of the AASHTO Designation T 99 is specified as the AASHTO Designation T 224 (AASHTO, 2010). Correction tests were conducted for the two No. 53 aggregate samples to adjust the densities to compensate for oversize coarse particles that were greater than the sieve size of 19.0 mm (3/4 in.). Presented in Figures 2 and 3 are the original and corrected Proctor curves for both the No. 53A and No. 53B aggregate samples, respectively.

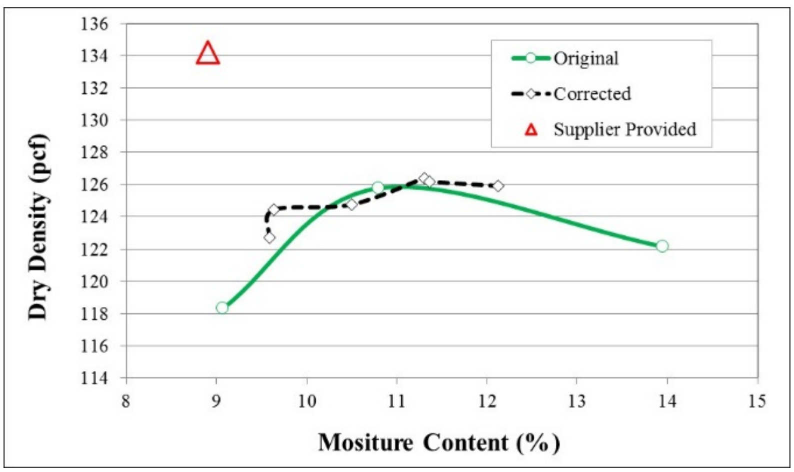


Fig. 2. Original and Corrected Moisture-Density Curves for No. 53A

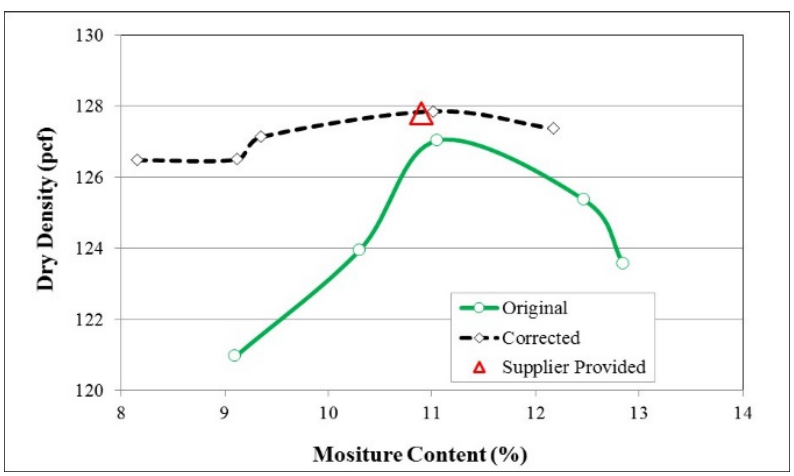


Fig. 3. Original and Corrected Moisture-Density Curves for No. 53B

It is shown that for No. 53A aggregates, the original maximum dry density and optimum moisture content were 125.8 pcf and 11.2%, while the corrected maximum dry density was 126.3 pcf and the corrected optimum moisture content was 11.4%. The corrected values were both slightly higher than their corresponding original values. For No. 53B aggregates, the original maximum dry density and optimum moisture content were 127.0 pcf and 11.1%, while the corrected maximum dry density was 127.9 pcf and the corrected optimum moisture content was 11.0%. The corrected values were very close to the original values. Therefore, the differences between the original and corrected maximum densities and between the original and corrected optimum moisture contents for both materials were not significant for practical applications. For comparison, the moisture contents and dry densities provided by the two suppliers are also presented in Figures 2 and 3. It is apparent that the laboratory results and the supplier provided values are quite different for No. 53A aggregates. For No. 53B aggregates, however, the optimum moisture content and the maximum dry density from the supplier are very close to those from the laboratory tests.

Table 3 summarizes all the moisture and density values from the suppliers and from the laboratory tests for both No. 53A and No. 53B aggregates. Comparing No. 53A and No. 53B aggregates, the laboratory tests, original or corrected, yielded very similar values of optimum moisture contents and maximum dry densities of the two material samples. Also, as presented in the sieve analysis results, the gradations of No. 53A and No. 53B aggregates were also similar. It was therefore justified to use either No. 53A or No. 53B to represent No. 53 material in the experiments and analysis. Therefore, only No. 53A was utilized to perform other experiments and analysis henceforth. The material would then be denoted as No. 53, rather than No. 53A, as presented in the remaining sections of this chapter.

Table 3. Supplier Provided and Laboratory Moisture-Density Values

Sample	**Optimum Moisture Content**			**Maximum Dry Density**		
	Supplier Provided	**Original (T 99-D)**	**Corrected (T 224)**	**Supplier Provided**	**Original (T 99-D)**	**Corrected (T 224)**
No. 53A	8.9%	11.2%	11.4%	134.2 pcf	125.8 pcf	126.3 pcf
No. 53B	10.9%	11.1%	11.0%	127.8 pcf	127.0 pcf	127.9 pcf

2.3 Laboratory Testing of Material Densities and Deflections

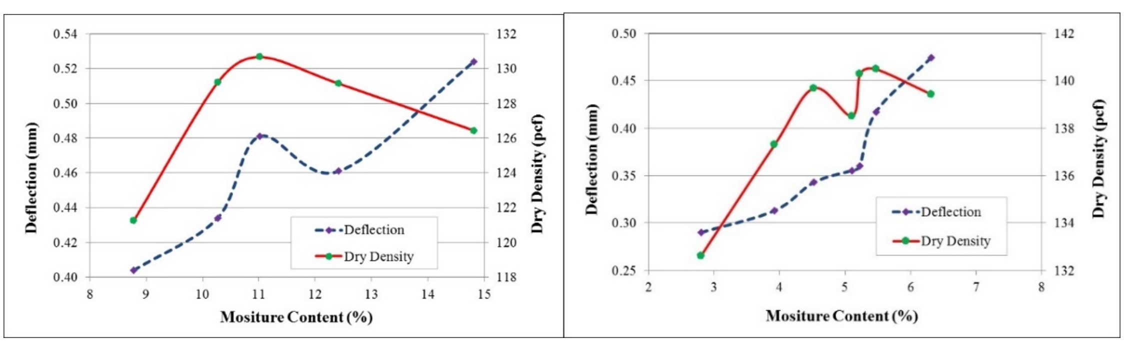
To establish the relationship between optimum moisture content and LWD measurement, a series of laboratory tests were conducted. In addition to No. 53 aggregates, some other types of materials, including No. 43 material, steel slag aggregate, and reclaimed asphalt pavement (RAP), have also been utilized in pavement bases in Indiana. The samples of these materials were obtained and used in the laboratory experiments for modulus analysis. As it is well known, for a given compaction effort, a soil's dry density will increase to a peak point as the moisture content of the soil increases and then the dry density will decrease if the moisture content further increases beyond the peak point of the dry density. A moisture-density curve of a soil from the Proctor test is typically a bell-shaped curve. The bell shape of the moisture-density curve is usually more apparent for clayey soils. Therefore, a clay sample was also included in the laboratory tests because of its typical plastic moisture-density relationship and its widespread existence in pavement subgrade in Indiana.

Like the study by Schwartz, et al. (2017), an aggregate sample was first compacted confirming to the AASHTO standard Proctor method, and then, the LWD measurements were made directly on the compacted sample in the Proctor mold. Figures 4 demonstrates the Proctor compaction and LWD measurement during the laboratory experiment. The deflections were measured six times on the material sample in the mold with the LWD. The first three deflection values were discarded and the average of the last three of the six deflection values were calculated as the measured deflection. The device was a Zorn LWD with a 5 kg drop weight and a 150 mm diameter base plate.

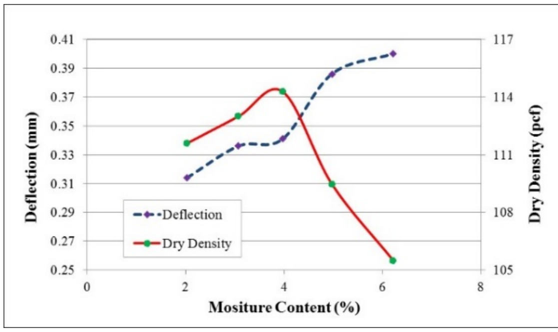
(a) Proctor Compaction (b) LWD Test in Mold

Fig. 4. Photos of laboratory LWD testing

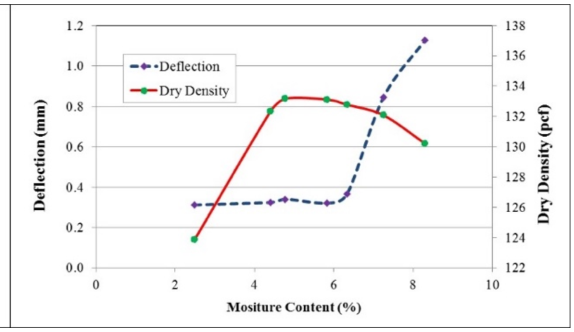
The main purpose of the LWD measurements over Proctor compacted materials was to reveal the change patterns of deflections and moisture contents in comparison with the moisture and density relationships. Plotted in Figure 5 are the moisture-density curve and the moisture-deflection curve for No. 53, No. 43, steel slag, RAP, and clay samples. It was expected that the changes of deflections and densities would have an inverse relationship so that as density increases the deflection decreases and vice versa. As shown in Figure 5, however, the materials do not demonstrate the inverse correlations between density and deflection. Only RAP and clay materials show slight deflection declines and reached a minimum deflection value as density increases within a limited range. In general, the materials exhibited a common pattern that as moisture content increases the deflection increases. It is indicated that the moisture content plays important but different roles in densities and deflections. Different from the well-known bell-shaped moisture-density relationship, the moisture-deflection relationships do not commonly show an optimum moisture content at which the deflection would be at a turning point. Therefore, the results of the laboratory experiments imply that a minimum deflection might not exist in terms of different moisture contents. This is because aggregate modulus increases as density increases, moisture content decreases, and aggregate interlocking increases. Compaction increases soil density and interlocking by reducing the voids in a soil with permanent deformation, while deflection is induced by an instant LWD impact with recoverable deformation.



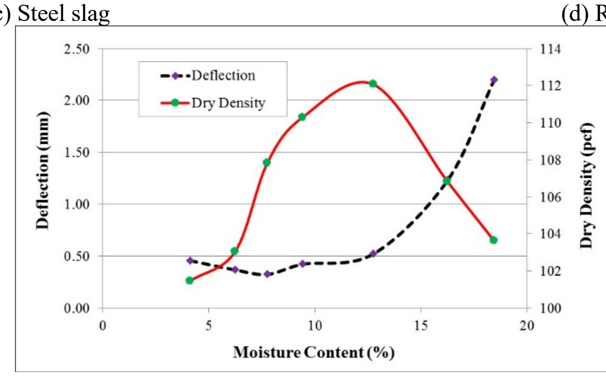
(a) No. 53 aggregate (b) No. 43 aggregate



(c) Steel slag



(d) RAP



(e) Clay soil

Fig. 5. Moisture, dry density, and deflection relationships for different materials

An important implication of the moisture-density and moisture-deflection relationships is that a range of moisture contents must be specified when establishing the maximum allowed LWD deflection value to effectively control compaction quality. Therefore, during construction, compaction should be performed when the moisture content is at or close to the optimum moisture content and the LWD deflections should be made as soon as the compaction is completed or before the moisture content decreases beyond the specified range. That is, it should not be allowed to measure LWD deflections on compacted layer after the moisture content has dropped below the specified range of moisture contents.

2.4 Effect of Moisture Content on Modulus

Moisture content is one of the important factors affecting the degree of compaction of geomaterials. In the traditional moisture-density controlled compaction process, a layer of pavement material is compacted at the optimum moisture content until the dry density of the material has reached the specified value. To examine the effect of moisture content on the modulus of geomaterial, laboratory tests were conducted to measure LWD deflections on the compacted materials at different moisture contents.

Two sets of the laboratory experiments were performed to reveal the change patterns of modulus at different moisture contents under compaction. The first set of the laboratory experiments was to compact the material specimen in Proctor mold at the optimum moisture content and to measure the deflection of the compacted specimen immediately after the compaction. After the first measurement with LWD, the specimen was placed in an oven at 230°F for 30 minutes and then deflection was measured, and the moisture content was determined. This process was repeated until the specimen was completely dried. The second set of the laboratory was to compact material at a moisture content in Proctor mold and to measure the deflection on the compacted specimen. This laboratory was conducted on six material specimens of different moisture contents to obtain the corresponding deflections. The measured deflections were all converted to moduli with the following equation.

$$E = \frac{Hq}{d}\left(1 - \frac{2\mu^2}{1-\mu}\right) \quad (1)$$

Where, E = material modulus; H = specimen height; q = LWD measured pressure; d = LWD measured vertical deflections; μ = Poisson's ratio.

Because a range of Poisson's ratio μ=0.1 to 0.4 is recommended in the Mechanistic-Empirical Pavement Design Guide (MEPDG) (AASHTO, 2015), μ=0.3 was selected to calcuate the modului from the LWD measured deflections. Plotted in Figures 6 and 7 are the results of the laboratory experiments for No. 53 and No. 43 aggregates, respectively. The first observation from the two charts is that, for both No. 53 and No. 43 materials, after the material was compacted at the optimum moisture content the modulus increased considerably as the moisture content was reduced each time. This phenomenon may have some significant practical implications in compaction quality control with LWD devices. The practical meanings of compaction quality control with LWD would include: 1) Compaction must be performed at the optimum moisture content to achieve sufficient dry density; and 2) LWD deflection or modulus must be measured within a limited time window after compaction to obtain meaningful deflection values pertinent to the degree of compaction. The second observation from the laboratory results is that No. 53 and No. 43 reflected differently to the changes of moisture contents in terms of moduli when the materials were compacted at different moisture contents. The modulus of No. 53 remained relatively stable at different moisture contents. On the other hand, the modulus of No. 43 material increased noticeably as the moisture content decreased. The different patterns of the two materials indicate that the coarser material (No. 43) was more sensitive to the moisture content than the finer material (No. 53) with respect to LWD measured deflections or moduli.

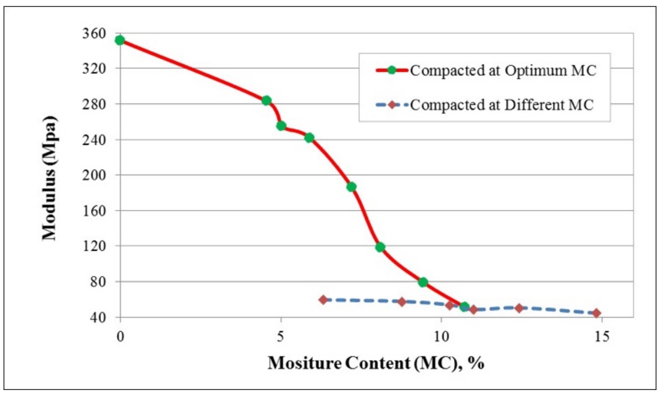


Fig. 6. Variation of Modulus with Moisture Content for No. 53 Aggregates

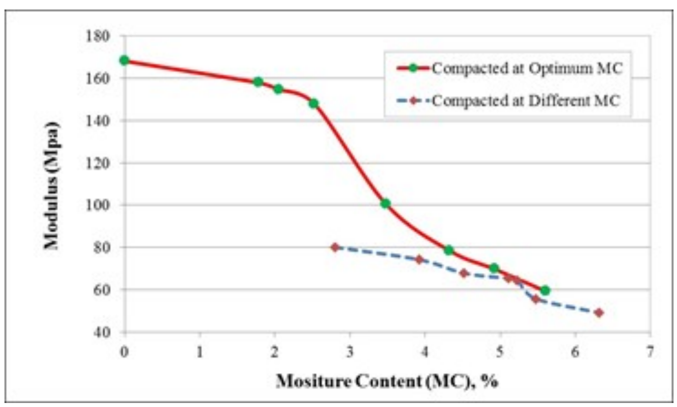


Fig. 7. Variation of Modulus with Moisture Content for No. 43 Aggregates

3. Test Pits Experiments of material deflections

Two 1m×1m×1m test pits were constructed to test the No. 53 and No. 43 aggregate materials. The soil in the bottom of the pit was first compacted before placing aggregates. The process of the experiment included the following steps (Figure 8): mixing water with the material, placing a layer of the material and compacting the layer with a jumping jack, leveling the layer, and measuring deflection at the center of the pit with LWD. To assure sufficient compaction at each layer, the moisture content of the material must be at or close to the optimum value and the material must be compacted at least two times and deflection must be measured after each compaction. If the difference between the two deflections is less than 0.01 mm, the compaction is considered satisfactory. Otherwise, additional compaction will be performed until the difference between deflections of two adjacent compactions is below 0.01 mm.

(a) Adding Water (b) Compaction

(c) Leveling (d) LWD Measurement

Fig. 8. Test Pit Experiment Process

The thickness of each layer was 6 inches for the No. 53 material and was 4 inches for the No. 43 material. The compaction and measurement process at each test pit was repeated until the test pit was full. The test results are illustrated in Figure 9. The two curves in the figure demonstrates different effects of the materials on the deflections or moduli as more materials were added to the structures. For No. 53, the deflection decreases as the structure thickness increases. It is apparent that the No. 53 material improves the overall stiffness of the structure. However, for No. 43, the deflection remains stable when as much as 8 inches of the material are added to the structure. That is, the No. 43 material would not contribute to the structural capacity during construction when the thickness of the material is less than 8 inches.

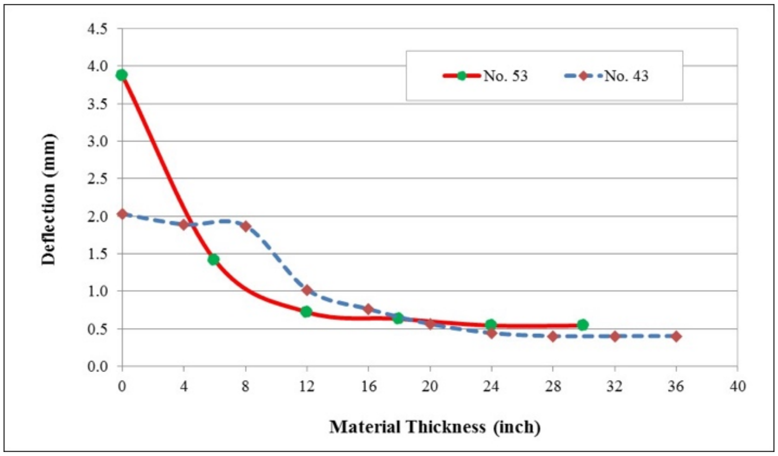


Fig. 9. Variation of Deflection with Layer Thickness in Test Pits

4. Conclusions

The Proctor test for aggregates was performed in accordance with the AASHTO Designation: T 99 by INDOT. Corrections may be necessary if the oversize material is above a certain percentage. However, the laboratory test results indicate that the differences between the original and corrected maximum densities and between the original and corrected optimum moisture contents for both materials were not significant for practical applications. Different from the well-known bell-shaped moisture-density relationship, the moisture-deflection relationships for aggregates did not show an optimum moisture content at which the deflection would be at a turning point. The results of the laboratory experiments imply that a minimum deflection may not exist in terms of different moisture contents. When compacted at the optimum moisture content, the modulus of aggregates increased considerably as the moisture content decreased. When compacted at a random moisture content, the modulus of No. 53 aggregates remained relatively unchanged, but the modulus of No. 43 aggregates increased noticeably as the moisture content decreased. Coarser aggregates are more sensitive to the moisture content than finer aggregates with respect to deflection or modulus. The results of LWD tests in the test pits indicate that No. 53 aggregates can contribute to the structural capacity, but No. 43 aggregates can only contribute to the structural capacity when its thickness is eight inches or more. The deflection decreased as the thickness of aggregate layer increased. As the layer thickness increased to a certain level, the deflection became stable.

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Critical Success Factors for Human Resource Management Practices in the Nigerian Construction Industry: A Delphi Approach

Helen Babalola[1,2] and Clinton Aigbavboa[2]

[1]Department of Project Management Technology. The Federal University of Technology Akure, Nigeria
[2]SARChi in Sustainable Construction Management and Leadership in the Built Environment, Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa
hibabalola@futa.edu.ng

Abstract
Different practices influence the construction industry. One of such is the human resource management practices (HRMPs) that enhance the performance and productivity of the human resource (HR). The choice of HRMPs is influenced by varied factors which are unknown in the Nigerian construction industry. Based on this contextual setting, the study assessed the critical success factors by establishing the influence of the different critical success factors (CSF) on HRMPs and determined the impact of each of the factors in the Nigerian construction industry. The study adopted the Delphi survey method of data collection that involves a structured questionnaire to solicit views of fifteen (15) experts, including professionals in the built environment, academics, and human resource/ personnel managers. The evaluation of the success factors was done by identifying the influence of each CSF on HRMPs; these factors were measured from no impact to very high impact. Mean, median, and standard deviation was utilized to analyze the data. The study findings indicate that out of all the nineteen (19) critical success factors evaluated, priorities of top management and the required working capital were ranked 1st among the CSF for HRMPs in the Nigerian construction industry. The Delphi study approach recommended that firms should prioritize management priorities and working capital availability since they are influential factors and have a very high impact in determining the choice of HRMPs in the construction industry. The study contributes to the body of knowledge on CSF for HRMPs in a developing country, especially the Nigerian construction industry.

Keywords
Construction Industry, Human Resource Management Practices, Critical Success Factors, Top Management Priorities, Working Capital.

1. Introduction

Human resource management practices (HRMPs) are a combination of practices "that are espoused to be internally consistent and reinforcing to achieve overarching results" (Lepak, Liao, Chung & Harden, 2006:221). These combinations of practices are referred to as bundles of HR practices utilized by organizations to achieve strategic goals (Boon, Den Hartog & Lepak, 2019). Combining practices rather than single practice helps to achieve performance in an organization, including the construction industry (Osibanjo & Adeniji, 2011; Wright & Boswell, 2002).

Evidence from literature suggested that the utilization of bundles of HR practices rather than individual HR practices brings about a strong relationship with performance (Combs, Liu, Hall & Ketchen, 2006). The bundle of HR practices promotes overarching goals (Jiang, Lepak, Han, Hang, Kim & Winkler, 2012); creates firms' synergy (Garg, Jiang & Lepak, 2020); helps to achieve a high system score (Becker & Huselid, 1998). Also, as noted by (Smith, Fischer & Fister, 2003; Garg et al., 2020), HRM practices of an organization include essential dimensions of the constructs that bring about accurate prediction. However, what exactly makes up the elements that will bring about bundles of HR practices has varied significantly over the years. In this study, these elements are the critical success factors (CSF) of HRMPs. Some known elements for HRMPs include company culture and structure, satisfactory working environment, state-of-the-art availability of equipment, quality and timeliness of feedback, appraisal structure of the employee, health and safety of employees in the workplace (Chew, 2004; Elrehail, Harazneh, Abuhjeeleh, Alzghoul, Alnajdawi & Ibrahim, 2019). It could also be attributed to internal and external factors such as management priorities, required working capital, high turnover rate, and organisation size (Ozutku & Ozturkler, 2009; Kokkaew & Koompai, 2012; Andalib, Darun & Azizan, 2015; Prajapati, Pitroda & Vyas, 2015). These elements, among others, have been recognized and mentioned in literature as a set of elements for HRMPs. Previous studies, including (Ozutku & Ozturkler, 2009; Kokkaew & Koompai, 2012; Andalib et al., 2015; Prajapati et al., 2015), established that the required working capital and management priorities were most mentioned among the set of elements for HRMPs. However, in relation to the Nigerian construction industry, minimal research has identified HRMPs critical success factors. Based on this, the present research seeks to: identify the CSFs influencing the choice of HRMPs; and determine the impact of each of the factors in the Nigerian construction industry, which informs the objectives of the current study. This paper is structured as follows: first, previous studies on HRMPs CSF. Next, the research method is outlined and summarized. The results of the stated objectives, as well as the discussion, are reported. The final section of the study discusses the conclusion and recommendations for future research.

2. Literature on Human Resource Management Practices Critical Success Factors

HRMPs are activities that a consistent and coherent system utilized to recruit, develop, motivate, retain, and secure the most valued asset, the people, for organizational goals. However, the choice of these activities varies from one firm to another and is influenced by different factors. (Hofstede, 1993) observed that HRMPs are influenced by economic system, and political-legal system (government policies). The study of (Hofstede, 1993; Cantarello, Filippini & Nosella, 2012; Al-Sarayrah, Tarhini, Obeidat, Al-Salti & Kattoua, 2016; Obeidat, Al-Sarayrah, Tarhini, Al-Dmour, Al-Salti & Sweis, 2016) showed that national dimensions such as power distance, uncertainty avoidance, individualism, collectivism, masculinity, and femininity were factors influencing the choice of HRMPs. In their study, (Kane & Palmer, 1995) concluded that industry/sector characteristics, top management priorities, changes in technology, organizational mission, power and politics, and changes in the national economy are CSF that determine HRMPs. Previous studies mentioned internal and external factors as factors influencing HRMPs, which vary from industry to industry. For instance, (Ozutku & Ozturkler, 2009) noted that HRMP is influenced by internal and external factors such as top management priorities, corporate headquarter actions, and the sector or industry characteristics. Furthermore, (Andalib et al., 2015; Prajapati et al., 2015) classified top and line managers' priorities as an internal factor influencing the choice of HRMPs. Moreover, Kokkaew and Koompai (2012) informed that external factors influencing HRM practices in Thai construction companies are project size, structure and complexity of the project, and required working capital. Accordingly, in explaining the HRMPs CSF, (Sikora & Ferris, 2011) utilized the social context theory and the theory of planned behaviour. They posited that contextual/organizational and individual factors such as quality of HR and line manager competencies significantly impacted HRMPs.

Therefore, the literature reviewed showed that varied factors influence the choice of HRMPs. These factors are needed to ensure that organizations utilize bundles of practices that enhance the HR's performance and productivity in the construction industry. Also, the construction industry with a long-term plan needs to prepare HR for future changing business conditions. Finally, the disconnected studies reviewed were insufficient to explain CSF influencing the choice of a firm's human resource management practices holistically. However, a combination of the literature reviewed will give an all-inclusive view for investigating the key CSF for HRMPs in developing countries, a case of the Nigerian construction industry.

3. Methodology

In this study, both the literature review and Delphi method was utilized. The literature review assisted in identifying the CSF. At the same time, the latter was employed to seek panelists view on the CSF influencing the choice of HRMPs in the Nigerian construction industry. Also, the impact of the CSF on the Nigerian construction industry was determined in the present study.

The Delphi survey was conducted among fifteen (15) experts, including professionals such as engineers (4), builders (2), project managers (2), architects (2), quantity surveyors (2) in the built environment, and the HR/personnel managers (3) in the Nigerian construction industry. The experts were selected from across Southwest cities in Nigeria; Lagos (5), Osun (1), Ogun (2), Ondo (4), Oyo (1) states including the Federal Capital Territory (2). This assist in enriching the study by seeking varied opinions and knowledge across these cities in Nigeria. The Delphi method is an approach that involves the use of a copy of sets of questionnaires to gain consensus and produce feedback to participants who are experts in key areas (Habibi, Sarafrazi & Izadyar, 2014; Mazzucca, Weatherly, Morshed & Tabak, 2018). It is also based on a group rather than individual judgment (Ameyaw, Hu, Shan, Chan & Le, 2016). These experts are selected based on the following requirements: Knowledge: Must be knowledgeable in the field of construction/ project management, HRM and its practices; Academic qualification: Should possess at least a national diploma, a higher national diploma, a postgraduate diploma, a bachelor's degree, a master's degree or doctorate; Employment: Should have previously served or currently serve in a professional capacity or at a place of employment such as an agency, institution, company as an engineer, personnel manager/HR, project manager, architect, quantity surveyor, builder, an officer of an establishment that is involved in employee selection or the execution of construction contracts in Nigeria; Experience: The expert should possess a high level of theoretical and practical experience over the years in the subject area; Willingness: Selected members of the panel must be willing to participate fully in the entire Delphi study; Must be a member of a professional body.

In the first round, only close-ended questions were used in the Delphi study. The responses from round one of the study were analyzed, and the results formed the basis of round two. In the second round, the Delphi questions allowed the expert panelists to review and comment on CSF influencing the choice of HRMPs in the Nigerian construction industry, which the expert panelists proposed in round one of the Delphi study. Open-ended questions were used in the second round of the Delphi study to investigate the expert panelists' comments expressing agreement, disagreement, or clarification concerning proposed attributes that determine HRMPs in the Nigeria construction industry. In both rounds, frequencies and interquartile deviation (IQD) were used to measure the degree of consensus reached in the responses of the expert panelists. For each response, the group median was calculated. The group median was the appropriate measure of central tendency utilized in this study because it was found to be more suitable for the type of information collected. The results from the first round Delphi survey formed the second and final survey round questions. Hence, in the second round of the survey, the group median for each element was computed and sent back to expert panelists; they were asked to maintain the first-round response/ change it as informed by the group median of the first round. In all, fifteen (15) experts completed two rounds of the Delphi process as against nineteen (19) that started the Delphi survey. The size of the experts was sufficient based on the recommendations from scholars who have previously employed the Delphi techniques in previous studies. It was cited that 10 to 15 panelists could be adequate if the background of the panelists is homogenous (Delbecq, Van de Ven & Gustafson, 1975). Also, (Aigbavboa, 2013) utilized 15 expert panelists for a Delphi study on residential satisfaction. This makes a panel of 15 experts considered adequate, as seen in the present study.

The experts' opinions was analyzed using Microsoft Excel and calculated using the median, mean, standard deviation, and interquartile deviation with the adopted scale for measuring consensus (Table1). The adopted scale was based on a 10-point impact scale ranging from no impact to very high impact, where 1 and 2 represent no impact; 3 and 4 represent low impact; 5 and 6 represent medium impact; 7 and 8 represent high impact; 9 and 10 represent very high impact (Aigbavboa, 2013). The experts' credentials were kept confidential throughout the study.

Table 1: Adapted scales of consensus

Consensus	Median	Mean	Interquartile deviation (IQD)

Strong	9-10	8-10	≤ 1 and ≥ 80% (8-10)
Good	7-8.99	6-7.99	≥ 1.1≤ 2 and ≥ 60% ≤ 79% (6-7.99)
Weak	≤ 6.99	≤ 5.99	≥ 2.1≤ 3 and ≤ 59% (5.99)

4. Results and Discussions

The Delphi results give a summary of how consensus were achieved in both rounds as below:

The first objective identifies the critical success factors influencing the choice of HRMPs in the Nigerian construction industry. Based on this objective, the experts recognized nineteen (19) critical success variables to influence the choice of human resource management practices in the Nigerian construction industry. When evaluated, findings revealed that each identified factor had a median value falling within the very high impact (VHI: 9-10) and a high impact (HI: 7-8.99). Also, it was revealed that all nineteen (19) variables achieved consensus with IQD cut off (IQD ≤ 1) score (See Table 2). This suggests strong consensus in the view of the expert panelists towards HRM practices CSF. The acknowledged critical factors comprised: firm top management priorities, working capital of the firm, masculinity (…achievement, courage, persistence, and material success), quality of HR in the firm, femininity (…relationships, humility, concern for others, and quality of life), adaptation to changes in technology, power distance (…extent to which employee accept that power in firms is unequally distributed), having organization mission/purpose, avoidance of uncertainty (…extent to which HR is uncomfortable with the uncertainty and vagueness), sustaining manager's competence**,** effective actions of corporate headquarters, project complexity of the firm, firm characteristics, the structure of the project**,** individualism (…workers who take care of themselves and direct families only)**,** collectivism (…belief that group comes first and good of group should be ahead of individual), firm project size, adapting to politics and power issues, and economic situation of the country.

Further, the second objective determines the impact of each success factor of HRM practices in the Nigerian construction industry. Table 2 depicted the outcome of the analysis. It revealed that, out of the 19 CSF influencing HRM practices in the Nigerian construction industry, seven (7) had very high impact (VHI: 9.00–10.00) on HRMPs, while twelve (12) had high impact (HI: 7.00–8.99) based on the 10-point impact scale this study employed. However, none of the success factors was found not to have impacted HRMPs in the Nigerian construction industry. Also, the study revealed that strong consensus was achieved for all the nineteen (19) success factors as they obtained scores ranging from 0.00 to 1.00 based on their respective IQD scores.

Table 2: Critical success factors attributes

Sub-attributes	(M)	($\bar{x}$)	(σx)	(IQD)	(R)
Priorities of top management	9	9.00	0.76	1.00	1
Required working capital	9	8.73	1.33	0.50	2
Masculinity *(...achievement, courage, persistence, and material success)*	9	8.73	1.39	0.50	2
Quality of HR in the firm	9	8.67	1.45	0.50	4
Femininity *(...relationships, humility, concern for others, and quality of life)*	9	8.47	1.36	1.00	5
Changes in technology	9	8.40	1.30	1.00	6
Power distance *(...extent to which employees accept that power in firms is unequally distributed)*	9	8.40	1.35	1.00	6
Organisation mission/purpose	8	8.33	1.11	1.00	8
Uncertainty avoidance *(...extent to which HR is uncomfortable with the uncertainty and vagueness)*	8	8.33	0.90	1.00	8
Manager's competence	8	8.27	1.28	1.00	10
Actions of corporate headquarters	8	8.20	1.52	1.00	11
Project complexity	8	8.13	1.13	0.00	12

Firm characteristics	8	8.00	1.41	1.00	13
Structure of the project	8	7.60	1.76	1.00	14
Individualism (*…workers who take care of themselves and direct families only)*	8	7.60	0.91	1.00	14
Collectivism *(...belief that group comes first and good of group should be ahead of individual interest and success)*	8	7.33	1.84	1.00	16
Project size	8	7.33	1.29	1.00	16
Politics and issues of power	7	7.13	1.30	0.50	18
Economic situation	7	7.07	0.00	0.00	19

M = Median, $\bar{x}$ = Mean, σx = Standard deviation, IQD = interquartile deviation, R = $\bar{x}$ ranking

Specifically, the required working capital had a mean value of 8.73, indicating a high impact on HRMPs. This supports (Kokkaew & Koompai, 2012) assertion that external factors such as the availability of working capital influence HRM practices. Similarly, top management priorities with a mean value of 9.00 were scored to have a very high impact among the factors influencing the choice of firms' HRMPs. This is in line with (Kane & Palmer, 1995; Ozutku & Ozturkler, 2009) studies that top management priorities significantly influence HRMP. Further, changes in technology with a mean value of 8.40 scored a very high impact among the critical success factors. The finding is consistent with the finding of (Kane & Palmer, 1995) that variations in technology significantly impact the choice of HRMPs.

Moreover, the quality of HR attained a mean value of 8.67. This was found to be consistent with the views of Sikora and Ferris (2011), whose earlier study found this factor to have a significant impact on the choice of HRMPs. Furthermore, owing to the result of the finding of power distance with a mean value of 8.40, masculinity with a mean score of 8.73, and femininity with a value of 8.47 in influencing the choice of HRMPs in this study, which corroborates the previous studies of Hofstede (1993); Al-Sarayrah et al. (2016); Obeidat et al. (2016). In addition, the majority (12) of the factors also attained high impact (HI: 7.00-8.99) among the success factors influencing the choice of HRMPs. In contrast, none of the factors was found not to have had an impact among the success factors influencing the choice of HRMPs. It is noteworthy that the experts expressed no variability in views among the nineteen (19) factors concerning the economic situation. This factor had a standard deviation value of 0.00. This finding is consistent and corroborates most of the previous studies on HRMPs such as (Hofstede, 1993; Kane & Palmer, 1995; Andalib et al., 2015; Al-Sarayrah et al., 2016; Obeidat et al., 2016). To this end, factors identified from existing literature to have an impact on the choice of firms HRMP in other cultural contexts were found to have affected the Nigerian construction industry. Further, though none of the factors had been identified to not influence the success factors influencing the choice of HRMPs. Required working capital and priorities of top management were found to have had a very high impact among the success factors that influence the choice of HRMPs in the Nigerian construction industry. Others include quality of HR, motivation, changes in technology, power distance, masculinity, and femininity.

Moreover, the present economic condition in Nigeria could have affected HRM practices, especially in the construction industry. From the above discussions, it is evident that the findings of this study are largely consistent with the findings of previous studies on human resource management practices as mentioned above. Still, the relative impact values recorded for each factor differ. Thus, it is empirically proven that the experts' views on the CSF for HRMPs in other industries impact HRMPs in the Nigerian construction industry. Noteworthy, required working capital and top management priorities emerged first among the nineteen CSF for HRMPs in the Nigerian construction industry. While the economic situation of the country emerged 19th among the CSF influencing the choice of HRMPs.

5. Conclusion and Recommendations

This study assessed the critical success factors influencing the choice of HRMPs in the Nigerian construction industry. This was done using the Delphi technique. The study concludes that nineteen (19) critical success factors influence HRMPs based on objective one. Also, based on the second objective, the study concludes that, relatively, priorities of top management and the required working capital of the organisation jointly emerged 1st among the CSF for HRMPs in the Nigerian construction industry. In contrast, the economic situation of the country emerged 19th among the CSF. The study shows that CSF has a high level of impact on HRMPs. From the study, it is important to note that the top two of the nineteen "CSF" could be grouped together as management-related factors. The study findings theoretically provide a solid platform for future researchers seeking to discover the "CSF" for HRMPs in the built environment.

The study recommended management priorities and availability of working capital as an influential factor that have a very high impact in determining bundles of HRMPs to be utilized in the construction industry. The results of the study could be recommended for other developing economies that share similar characteristics with Nigeria. It is also recommended that future studies should be carried out to validate the current qualitative study.

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ID 12

An Evaluation on the Implement of Artificial Intelligence Technology on South African Construction Projects

Mokgaetji Gift Phaladi[1], Xolile Nokulunga Mashwama[2], Clinton Ohio Aigbavboa[3]
[1-3]Department of Construction Management and Quantity Surveying, University of Johannesburg, Johannesburg, 2028, South Africa
phaladimg@gmail.com

Abstract
Artificial Intelligence(AI) technology has the power to unlock the industry's greatest challenges faced such as poor efficiency issues, design errors, low productivity, and accidents on site. Therefore, the study is a literature review on the assessment of the implementation of AI technology on construction projects in South Africa. The study was carried out with reference to existing theoretical literature, published research, and internet sources. The study has adopted a quantitative research approach. The study has revealed the positive impact of implementing AI technology on construction projects and how it can transform the construction sector. This includes timeous delivery of the construction project(s), enhanced profitability, increased productivity, enhanced efficiency, and reduction of construction accidents. However, the adoption of AI technology in South Africa is still at an early development stage. The study would contribute to the existing body of knowledge of AI technology, particularly to developing countries where literature is lacking. Again, it will assist and enlighten the construction inclusive of consultant company owners to advance their firms and construction projects.

Keywords
Automation, Artificial Intelligence Technology, Fourth Industrial Revolution, Construction Sector, Robotics.

1. Introduction

Over the past years, the construction sector was considered to be a less digitalized sector with poor productivity issues when compared to others (Barbosa *et al.,* 2017). Currently, most construction firms are forced to shift from the old traditional ways of carrying out tasks on-site to a more advance digital shift. This transition is moving at an exponential rate where the construction sector is struggling to keep up (Harty *et al.,* 2015). However, the usage of digital technologies such as Artificial Intelligence(AI) on construction projects means they would be an increase in efficiency (Gotthardt *et al.,* 2019). Again, construction projects would be successfully delivered timeously. Past studies have indicated that developing African countries especially South Africa are still lacking behind with the usage of AI technology. Therefore, the purpose of this study is to investigate the implementation of Artificial Intelligence on construction projects in South Africa as a technological tool for Increasing productivity.

To achieve this purpose, the study aims to assess how the adoption of AI technology can transform construction projects. This study will enlighten the construction firms about the importance of adopting AI on construction projects. Again, will provide light to the author's main dissertation research. The paper is structured as follows; section Two will present a literature review, section Three will present the research methodology, whilst section Four presents research findings and discussions. Lastly, section Five will state the conclusion and recommendation(s) of areas for further future studies.

2. Theoretical Overview of Artificial Intelligence

2.1 Artificial Intelligence and its Role in the Construction Sector

Artificial Intelligence(AI) can be defined as "an interdisciplinary branch of computer science which deals with the development of machines, software and algorithms that mimic the cognitive functions of humans to solve complex information processing problems" (Salehi & Burgueno, 2018). Past studies have been conducted on Artificial Intelligence technology regarding the benefits and challenges on both construction projects and organizations on how they can be improved or affected through the usage. Researchers such as (Salehi & Burgueno, 2018; Jesuthasan, 2018; Blanco *et al.,* 2018; Gotthardt *et al.,* 2019; Jariwala, 2015; Bolton *et al.,* 2018; Nickerson, 2019) have all done studies on AI technology. Again, Thirgood & Johal (2017); Boyd & Holton (2017) researched the impact of adopting AI on the construction sector where it will affect human laborers negatively. Since it is claimed that AI machines will cause human beings to lose their employment. Previous studies have again indicated that if AI is properly exposed and exploited would see timeous delivery of the construction projects.

On the other hand, AI technology can be used in most of the sectors such as on Controlling difficult systems (Kiela *et al.,* 2016), transportation (Tango & Bott, 2013), fixing hardware and software issues (Gordon *et al.,* 1993), for controlling safety concerns on construction projects (Ticket *et al.,* 2016). Advantages of using AI technology on construction projects include; managing the building effectively (Klashanov, 2016), prevention of injuries that occurs on construction site (Sarka *et al.,* 2019), enhancement of efficiency on a construction project(s), and can make an effective decision (Klashanov, 2016), can monitor the health conditions of a human beings (Zitnik *et al.,* 2019), can improve productivity growth on construction projects (Jesuthasan, 2018), improves profitability, eliminates design errors made by a human, and reduces construction waste. AI technology can reach a lucid conclusion with the capabilities of surpassing human intelligence. Because the tasks which were normally requiring human intelligence will now be completed by intelligent machines. However, the usage of AI technology on South African construction projects is not fully exposed and exploited. Hasegawa (2006) claims that it is still at an early development stage. According to Blanco *et al.* (2018), further said the implementation of Artificial Intelligence in the construction sector would eliminate the industry's greatest problems faced such as safety issues, time, and cost overruns. Below is a summary of how AI can be adopted on construction projects.

Some of the benefits of implementing Artificial Intelligence(AI) technology on construction projects include the following;

2.1.1 Reduction of Construction Risks
Normally, when the construction site is busy with certain activities the chances of risks occurring would likely be higher. In contrast, the implementation of technological software such as AI systems is capable of monitoring construction site risks so that they can be prevented from occurring again. This is because the implemented intelligent machines on-site can perform the tasks used to be done by human beings (Boyd and Holton, 2017).

2.1.2 Improvement of Quality on Work Done
The AI technology can also be used after the completion of constructing a building structure or anything for identification and checking of errors. According to Roubini (2014), postulated that intelligent machines are capable of detecting any problems on the completed structure that can lead to a collapse of the building. The majority of the project team are still using Building Information Modelling (BIM) which is capable of storing important information of the constructed structure and does not provide solutions to the discovered problem during the construction stage (Frey and Osborne, 2013).

2.1.3 Enhanced Health and Safety of the Construction Projects
Some of the projects have been closed due to accidents and incidents constantly occurring as a result of the mismanagement of the funds, improper construction methods adopted by contractors (Lamb, 2016). However, the adoption of AI technology on projects is capable of assessing safety hazards, especially for the workers who enter the construction site(s) without pre-requirements of the protective clothing and equipment (Lawson, 2016). Most importantly, AI offers prevention of accidents through the analysis of Artificial intelligent machines. Safety officers can use those intelligent systems to monitor construction site safety as this will ensure a good health and safety standard on the construction projects.

2.1.4 Time and Cost-Saving
The adoption of Artificial Intelligence (AI) technology on construction projects would save time such as on reducing plaster wastages and eliminating design errors. However, if less time was taken to construct the designed structure more costs would be saved. The adoption of intelligent machines would save the contractors funds which would result in more profit made from the contract awarded (Adriaanse and Voordijk, 2005).

2.2 Artificial Intelligence and Human Collaboration
The introduction of digital transformation in the construction sector forces humans and technology to be used simultaneously. According to Carpenter *et al.* (2018), opines that human and AI technology are two things that are different in terms of capabilities. Abbass (2019), further said that the usage of AI on construction projects is more effective than a human being. Moreover, AI can analyze more data accurately within seconds,

whilst human intelligence cannot match with the intelligence of smart technology (Carpenter *et al.,* 2018). Human beings are capable of making good decisions during project life-span with limited intelligence (Abbass, 2019), AI can reach a lucid conclusion which leads to increased productivity and efficiency. Construction projects were or are still delivered longer than expected as a result of the limited decision-making of human beings. On the other hand, AI technology has been playing an active role in other parts of the world such as countries like Japan, China, and Malaysia. However, in developing countries majority of the human being is still ambiguous about the positive impact AI has on construction projects. Hence, the implementation of AI technology in developing countries particularly in African nations is relatively low (Chui *et al.,* 2018). Abbass (2019), further said that teaching human being about how AI technology works can bring trust to AI technology. Fox *et al.* (2017), noted the human capacity and understanding of analyzing data would be improved. For the successful implementation of government institutions together with the professional regulatory bodies must work together in encouraging the organizations to start adopting the AI technology on construction projects to advance the sector and their firms to be more competitive with the other industries who are already using this Fourth Industrial Revolution feature on their daily activities.

3. Research Methodology

The study has adopted a quantitative research approach. Studies of Cresswell (2014); Fellows & Liu (2015) further justified that the usage of quantitative research approach is suitable where the research study topic is still new in the field of study. The study will collect data from the targeted participants through a structured interview to gain an understanding and knowledge of adopting AI technology on construction projects. The targeted participants for the study include; Architects, Construction Project managers, Quantity Surveyors, and Engineers who are registered with the various professional statutory regulatory bodies such as ECSA, SACPCMP, SACAP, and SACQSP. The participants for the study will be contacted and selected from the database list provided by the professional statutory regulatory bodies. Due to Covid-19 pandemic restrictions, online questionnaire surveys were disseminated to the above-mentioned targeted participants to ease the coronavirus infection on construction projects.

The study has adopted a non-probability purposive sampling technique to select the participants. On the other hand, Cresswell & Plano Clark (2011), further added that purposive sampling is used to select individuals or groups of people who have sound knowledge and extensive experience. 260 online questionnaire surveys were distributed and 223 were returned back with an 86% response rate. A 5-point Likert scale was used to determine the benefits of implementing Artificial Intelligence on construction projects. The scale adopted was as follows; 1= Strongly Disagree, 2= Disagree, 3= Neutral, 4= Agree, 5= Strongly Agree. A 5-point Likert scale was further transformed to Mean Item Score(MIS) and Standard Deviation(SD). In addition, were ranked from highest to lowest based on the highest MIS values. The Cronbach alpha value for the benefits of implementing AI was 0.702 which is assumed to be acceptable.

4. Research Findings and Discussions

4.1 Respondent's rating on the Usefulness of Artificial Intelligence on stages of Project Life Cycles
Figure 1 below represents the use of Artificial Intelligence (AI) technology on stages of the project life cycle. The findings reveal that 21% of the respondents think the usage of AI would be useful, 72% of the respondents think AI

technology would be most useful on stage three, 44% of the respondents think AI technology would be most useful on stage four. Whilst, 90% think would be useful on stage five, whereas 84% think would be useful on stage six.

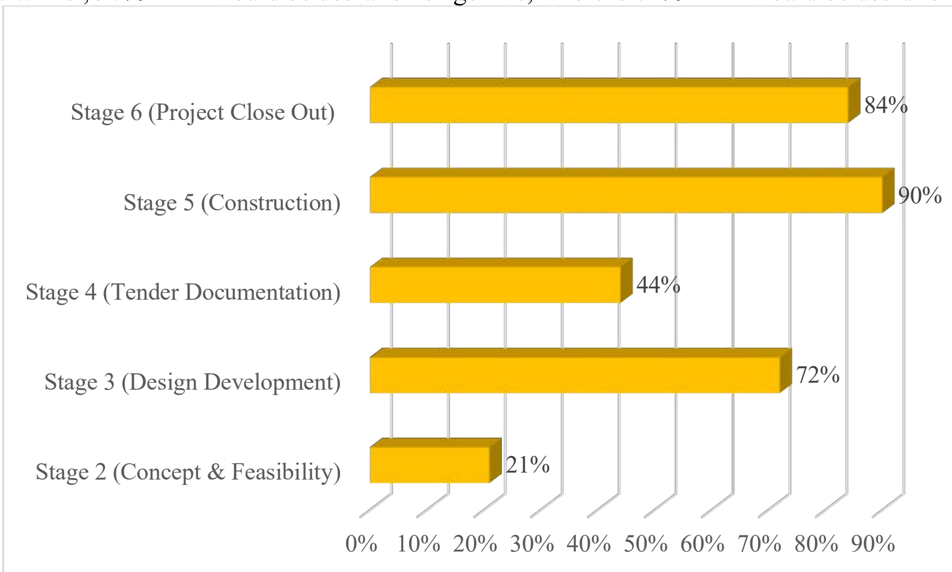

Figure 1. Respondent's rating on the usefulness of Artificial Intelligence technology

4.2 Respondents on Benefits of Implementing Artificial Intelligence

Table 1 below represents respondent response on the benefits of implementing Artificial Intelligence (AI) on construction projects. The top Five results for the benefits of implementing of AI are: 'improves quality of work post-construction' with (MIS= 4.19, SD= 0.510, R= 1), 'reduces budget overruns' with (MIS= 4.08, SD= 0.545, R=2), 'saves time' with (MIS= 4.01, 0.724, R=3), 'overcome shortage of experienced labors' with (MIS= 3.95, SD= 0.701, R=4), 'improves performance on construction work' with (MIS=3.93, SD= 0.666, R= 5), 'improves the health and safety of the construction projects' with (MIS= 3.950, SD= 0.697, R=5).

Table 1. Benefits of implementing Artificial Intelligence on construction projects

Factors	MIS	SD	Rank
Improves quality of work post-construction	4.17	0.510	1
Reduces budget overruns	4.08	0.545	2
Saves time	4.01	0.724	3
Overcomes shortages of experienced labors	3.95	0.701	4
Improves performance on construction work	3.93	0.666	5
Improves the health and safety of the construction projects	3.93	0.699	5
Elicits faster information exchange	3.91	0.697	6
Improves productivity	3.84	0.377	7
Reduces construction risks such as accidents on-site	3.83	0.643	8
Reduces construction errors	3.81	0.655	9
Improves customer relations	3.78	0.615	10
Improves profitability	3.76	0.477	11
Saves cost	3.75	0.456	12
Improves communication amongst the project team	3.73	0.531	13
Improves tracking and security	3.71	0.571	14
Facilitates improved decision making	3.58	0.556	15

The top five least results which were ranked by respondents are: 'improves profitability' with (MIS= 3.67, SD= 0.477, R=11), 'saves cost' with (MIS=3.75, SD= 0.456, R=12), 'improves communication amongst the project team' with (MIS= 3.73, SD= 0.531, R=13), 'improves tracking and security' with (MIS= 3.71, SD= 0.571, R=14), 'facilitates improved decision making' with (MIS= 3.58, SD= 0.556, R=15). The findings of the study are in agreement with Thirgood and Johal (2017) and Decker *et al.* (2017) that the benefits of implementing Artificial Intelligence (AI) on construction projects add a significant value such as reduction of budget overruns, reduced construction errors, and improvement of productivity. However, Qureshi and Syed (2014), agreed that productivity and performance on construction will be improved through the usage of AI technology. Further benefits include cost and time saving (Adriaanse and Voordijk, 2005). The issue of health and safety on construction projects has been part of the reasons why the projects were delivered late. Lawson (2016), argued that the usage of AI technology would massively improve construction projects.

5. Conclusion and Recommendations

The study has successfully revealed the benefits of implementing Artificial Intelligence(AI) technology on construction projects. Moreover, the study has further pointed out that the adoption of AI technology on construction projects has the capability of making adequate effective decisions than human labor. Also, the benefits of implementing AI technology were highlighted. Further research has to be conducted to encourage South African construction firms on the importance of using AI technology to advance their works on a construction project(s). Again, further research has to be conducted on where specifically during project phases should AI technology be mostly used for improving productivity and efficiency. The study recommends that the South African government institutions must invest more in infrastructural development and also, to financially support the construction firm owners to start using AI technology on construction projects.

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ID 13

Challenges of Public-Private Partnerships in Low-Income Housing Provision in Nigeria

Babatunde Ogunbayo[1*] Clinton Aigbavboa[1], and Opeoluwa Akinradewo[1]

[1]cidb Centre of Excellence & Sustainable Human Settlement and Construction Research Centre, Faculty of Engineering and the Built Environment, University of Johannesburg.
tundeogunbayo7@gmail.com

Abstract
Low-income housing provisions through a public-private partnership with a quality facility, good services, and access to social amenities, among others, encountered different challenges through its process. This study considered the major challenges of Public-Private Partnerships (PPPs) in low-income housing provisions in Nigeria. A field survey was carried out among professionals involved in the provisions of low-income housing within Lagos state Nigeria to determine major challenges they encounter in the delivery of PPPs housing for low-income earners. A systematic random sampling method was used, and 84 questionnaires were retrieved from professionals that participated in the PPPs housing delivery system for low-income housing. The result shows that inadequate project funding, high cost of building material, faulty design, access to land, and problems of land grabbers were some of the challenges encountered by PPPs in low-income housing provision. The study, therefore, suggested that funding, existing land laws, and users' financial capacity need to be considered in the planning stage of PPPs low-income housing to avoid challenges that could create neglect of the project.

Keywords
Nigeria, Public-Public Partnership, Security of Tenure

1. Introduction
Housing is a major economic asset recognized universally (Olatubara, 2007). Housing is a right because it embraces other utilities and social services that make a community livable (Ebie, 2009; Ogunbayo & Aigbavboa, 2021). It determines the general well-being of society at large (Ajanlekoko, 2002; Ogunbayo & Aigbavboa, 2019). Kabir (2004) opined that the major challenges faced by most developing countries are provisions of housing that are affordable for low-income earners. Adedeji and Olotuah (2012) and Ogunbayo et al.(2022) postulated that housing provision in most developing countries, especially Nigeria is fraught with an excess of problems for low-income earners who constitute most of the country's population. Nigeria, as a developing country, needs over fifty-six trillion naira (₦56 trillion) to support its housing deficit, projected to be around sixteen (16) million housing units; this excludes the cost of the provision of land (Mabogunje, 2007; World Bank 2013). On average, this shows that about 3.5million (₦3,500,000) is required for the provisions of housing units. The World Bank (2013) concluded that 75% of this housing deficit is needed by low-income earners minimum wage within the poverty range.

Despite the contribution of PPPs to housing development, the level of accessibility of low-income earners to housing in Nigeria is still very low (Adedeji et al., 2012). Olotuah and Aiyetan (2006) observed that the cost at which housing provided through PPPs reaches the market goes a long way to determining its affordability, which is abnormally high such that only few can afford it (Olotuah et al. 2006; Adedeji et al. 2012). This has widened the gap between income and housing in Nigeria, especially among low-income earners (Okupe, & Windapo, 2000). Low-income earners have more or less disappeared from the housing market because of this in Nigeria. Cairo, the Egyptian capital, with an estimated population of 12 million low-income earners and as many as 20.5 million people in the wider metropolitan area, has been struggling with a lack of affordable housing for several years (Oxford Business Group, 2018). Across the country, the housing deficit stands at approximately 3 million units, with Cairo, the capital city, responsible for the largest share of this shortfall (UN-HABITAT, 2006/7; Oxford Business Group, 2018).

However, Ibem (2010) posited that the strategic means of solving low-income earner housing challenges is through the engagement of the private sector in addressing housing inadequacies together with its affordability (Ibem, 2010; Akinradewo, Oke, Aigbavboa & Mashangoane, 2018). Ogunbayo et al. (2018) stated that proper design and good planning, based on established governments and professionals' laws and regulations, are essential in the planning stage of PPPs housing to avoid errors during the project's execution. However, PPPs in housing projects provide an efficient and productive platform for housing provisions (Ibem, 2010; Ogunbayo et al., 2021). Olotuah and Bobadoye (2009) observed that there are managerial and logistic challenges with PPPs housing provision, especially in its planning and production process. The study of Ogunbayo et al. (2016) showed that change in design, non-financial visibility, and unstable economy were challenges in PPP housing. In their study, Osei-Kyei, and Chan (2017) concluded that in bidding for PPPs low-income housing projects, an elaborate risk management plan and proper legislation should be provided to avoid challenges during the execution of the PPPs housing project. This challenge includes access to housing input together with access to land and funding (Ibem & Amole 2014). Olotuah et al. (2009) further stated that the lack of standard assessment of public housing programs, policies, and proper monitoring is a challenge that affects the success of PPPs low-income housing provision. Ibem et al. (2014) observed that funding, access to land, government policy, and others have an adverse effect on the perfect execution of PPPs housing production and provision.

These challenges deprive PPPs housing providers in Nigeria of meeting the demand for housing by low-income earners. Given the importance of PPPs in affordable low-income housing provision (Olotuah et al., 2009; Ibem et al., 2014; Ogunbayo et al., 2018). Therefore, it is a rewarding research goal to appraise the challenges of PPPs in low-income housing provision.

2. Research Methodology

This study was carried out among professionals who have previously participated in the PPPs housing delivery system for low-income housing projects. They include government officials, registered quantity surveyors, builders, architects, civil engineers, and consultants involved in different government PPPs projects within Lagos state and its environs. The respondents for the study were selected for this study because of their experience and involvement in PPPs projects. The study was limited to Lagos because it has many PPPs low-income housing completed or ongoing in the Nigeria housing provisions. Through a systematic random sampling method, 100 copies of structured questionnaires were administered to the respondents, and eighty-four (84) were retrieved from the respondents. The systematic random sampling method was used for this study because it is easier and more direct and tends to eliminate the possibility of clustering that could occur when the random sampling is adopted. The method also tends to cover all the elements evenly. The questionnaire was designed on a 5-point Likert scale, and it recorded an 84% response rate. This helped this study identify challenges encountered during the planning and execution stages of PPPs low-income housing provisions within the study area. Data were analysed using frequency and percentage and presented using charts.

3. Result and Findings

Figure 1 shows the respondent's profession as a PPPs contributor. The result shows that 22.62% (19) of the respondent are builders, 15.48% (13) of the respondents are quantity surveyors, 17.86% (15) are Architect, 14.29% (12) are consultants, while 16.66% (14) are government official and 13.09% (11) are civil engineers.

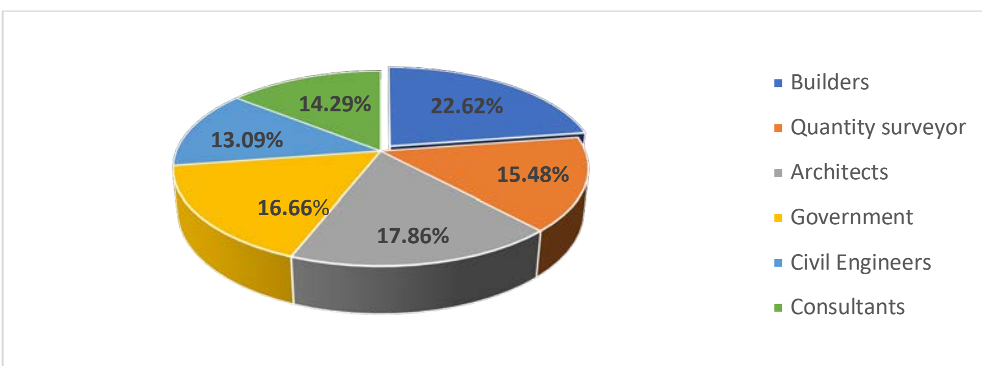


Figure 1. Respondents' profession

Figure 2 revealed respondents' years of experience in PPPs low-income housing provision. The result shows that 9.53% (8) of respondents have 0-5years of experience, 27.38% (23) have 6-10 years of experience, 46.43% (39) have 11-25years of experience, while 16.66% (14) of the respondents have above 25 years of experience.

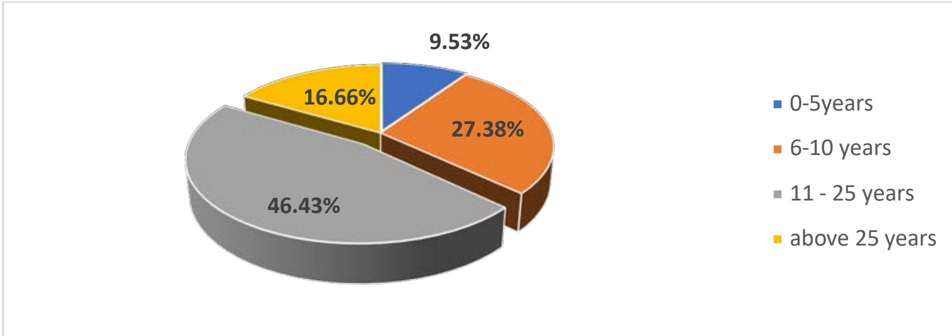


Figure 2. Respondents' years of experience

Figure 3 revealed respondents' opinions on challenges faced in accessing land for the PPPs project. The result indicated that 48.81% (41) of the respondents stated that the challenges of accessing land for PPPs low-income housing are very high, 32.14% (27) indicated that it is high, while 13.1% (11) said that it is of average and 5.95% (5) stated that challenges of accessing land for low-income housing projects are on a very low trend.

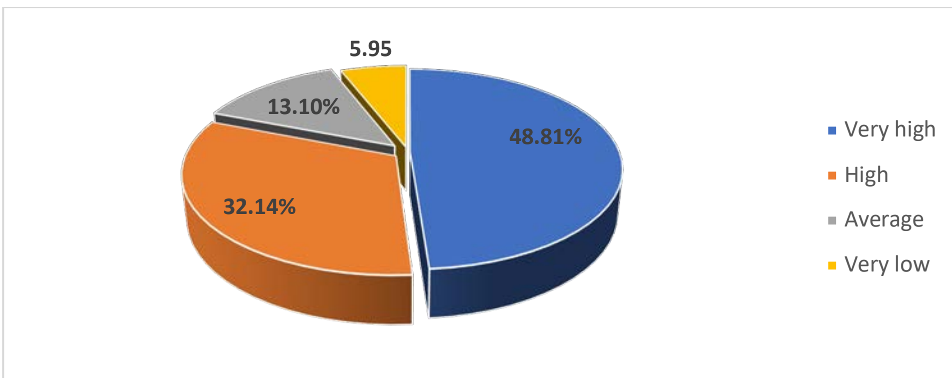


Figure 3. Response to challenges in accessing land for PPPs low-income housing provision

Figure 4 shows the challenges in the security of title and tenure documents required for PPPs' low-income housing project documentation. Respondents with 22.62% (19) stated that the challenges of the process are very high, 45.24% (38) of the respondents noted that the challenges of processing the document are high, 17.86% (15) stated that it is, on average, while 14.28% (12) said that the challenges of processing the security of title and for low-income housing project are on a very low side.

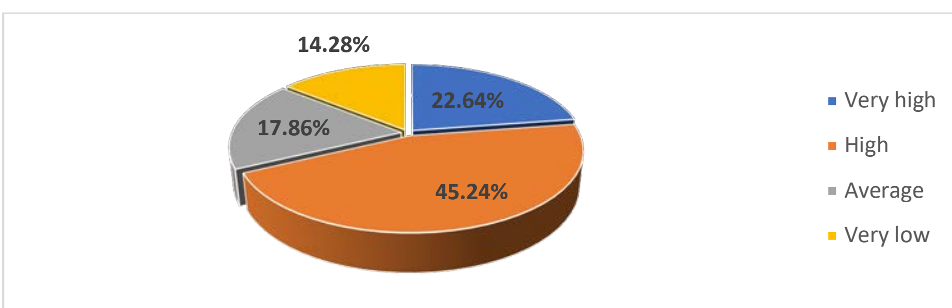


Figure 4. Response on challenges in the process of security of title and tenure

Figure 5 shows challenges due to faulty design in PPPs' low-income housing provision. The result indicated that respondents with 50% (42) agreed that the challenges of faulty design are very high, 27.38% (23) stated that the challenges of error in design for PPPs low-income housing are high, while 13.10% (11) said the challenges of faulty design are on the average level and 9.52% (8) of the respondents believed that challenges are very low.

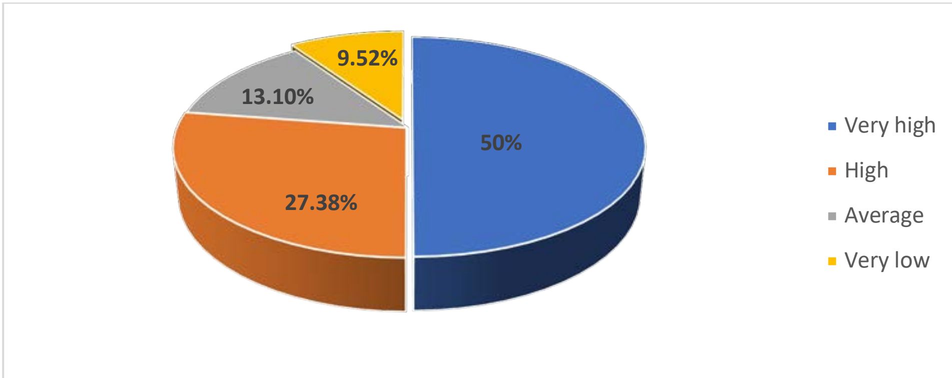


Figure 5. Response to challenges due to faulty design in PPPs low-income housing project

Figure 6 revealed the challenges of scarce and high building material costs in PPPs' low-income housing provision. Respondents with 48.81% (41) stated that the challenges of the scarce and high price of building materials required for low-income housing production are very high, 34.52% (29) of the respondents stated that the challenges are very high, 13.1% (11) indicated that it is of average, while 3.57% (12) said that the scares and high cost of building material challenges for low-income housing project are on a very low side.

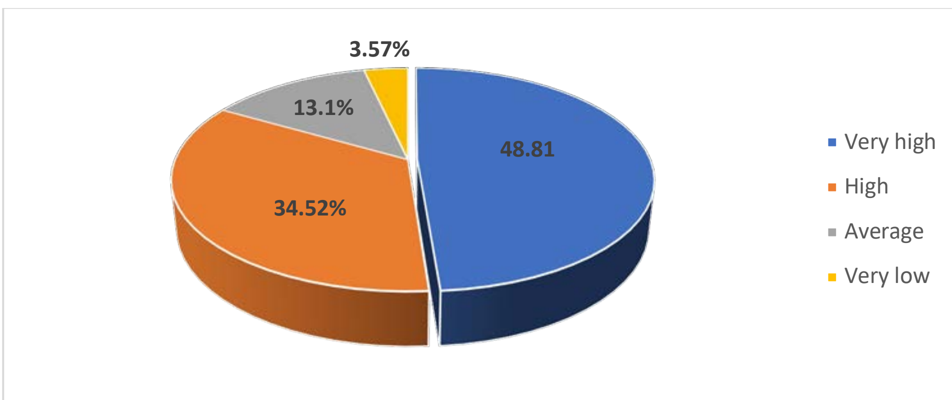


Figure 6. Response to challenges on scarcity and high cost of material for PPPs low-income housing provision

Figure 7 revealed the challenges of skilled labour required in the execution of PPPs low-income housing provision. The result showed that respondents with 22.62% (19) agreed that the challenges of skilled labour required for low-income housing production are very high, 32.14% (27) stated that the challenges are high, while 23.81% (20) said the challenges are of average and 21.43% (8) of the respondents said that the challenge is very low.

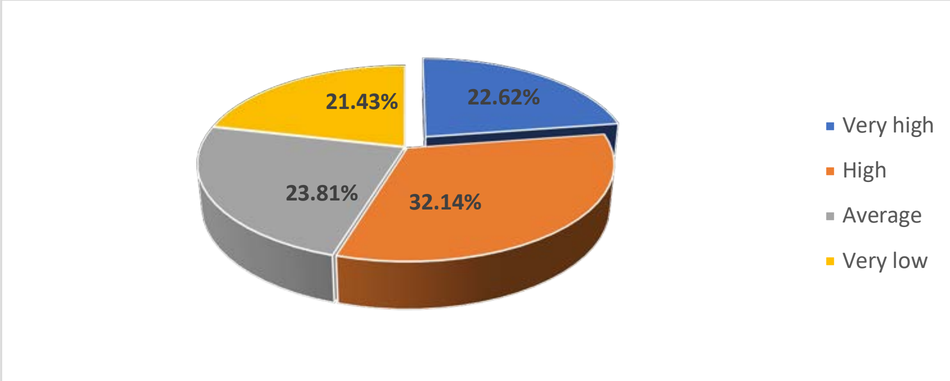


Figure 7. Response on challenges of skilled labour required for PPPs low-income housing provision

Figure 8 shows the challenges of accessing low-interest funds for PPPs' low-income housing provision. The result indicated that respondents with 55.95% (47) agreed that the challenges of accessing low-interest funds are very high, 25% (21) said that the challenges are high, while 16.67% (14) stated that the challenges of the low-interest fund are of an average and 2.38% (2) of the respondents believed that challenges are very low.

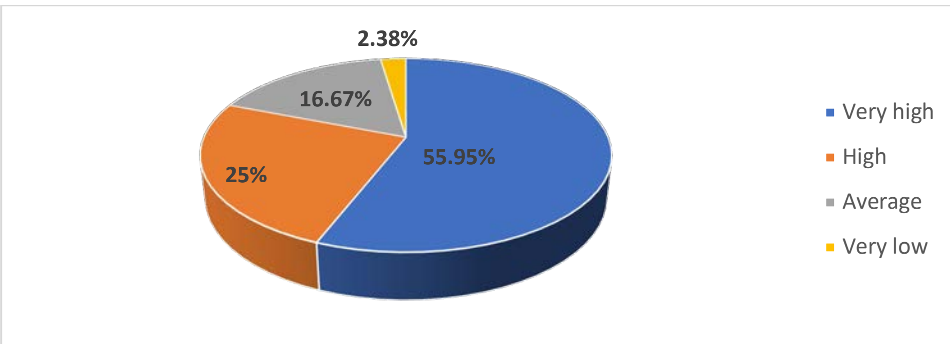
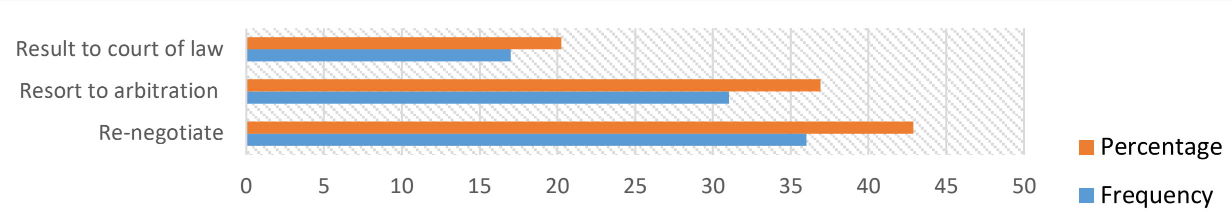


Figure 8. Response to challenges of accessing funds with low interest for PPPs low-income housing project

Figure 9 revealed the method of recouping invested funds in case of unanticipated challenges during the planning or execution of the PPPs low-income housing project. 42.86% (36) of the respondent stated that re-negotiation is the best method of recouping the investment in case of unanticipated challenges, 36.9% (31) said that resorting to arbitration is the best method, while 20.24% (17) stated that going to the court of law is the best method of recouping of an investment fund in PPPs low-income housing Project in case of unexpected challenges.



	Re-negotiate	Resort to arbitration	Result to court of law
Percentage	42.86	36.9	20.24
Frequency	36	31	17

Figure 9. Response on the method of recouping the investment in case of unanticipated challenges

4. Discussion of Findings

The study examined the major challenges of PPPs in low-income housing provision in Nigeria. The result of the study indicated that access to land is a serious challenge to PPPs' low-income housing provision because the government controls the land and the process of accessing it is cumbersome. With another menace of land grabbers that violently attacked most PPPs sites claiming to be the landowners. This affirms the finding of Kabir (2004), Ibem (2010), and Ogunbayo et al. (2018) that factors such as funding, access to land, government policy, and others have an adverse effect on the perfect execution of PPPs housing production and provision. The study also showed that the security of title and tenure is another challenge hindering PPPs' low-income housing provision. This supports Olotuah et al. (2010) and Osei-Kyei et al. (2017) that processing of security of title and tenure documents is a challenge because it involves different processes that usually delay the collection of necessary documents required for low-income housing project documentation. This finding also aligned with Ajanlekoko (2002) and Ogunbayo et al. (2016) that there are managerial and logistical challenges with PPPs' low-income housing provision, especially in its planning and production process. Another major challenge in PPPs' low-income housing provision, as discovered through the finding of this study, was the issue of faulty building designs, which is part of the challenges thwarting PPPs' low-income housing provision. The finding aligned with Ibem (2010) and Akinradewo et al. (2018).

Additionally, the result of the study affirmed Ebie (2009), Kabir (2004), and Mabogunje (2007), which showed that scarce and unstable prices of building materials are part of the major threats to the success and execution of PPPs low-income housing provisions. This study's finding is also similar to Ogunbayo et al. (2016), and Ibem et al. (2014), that change in design, non-financial visibility, and unstable economy were challenges in PPP low-income housing provision. This study also showed that the skilled labour required for the PPPs low-income housing project is challenging to its execution. The finding of the study conforms with Mabogunje (2007), Osei-Kyei et al. (2017), and Akinradewo et al. (2018), which states that the lack of skilled and trained professionals in the built environment is a challenge that is hindering the process of PPPs low-income housing production. Based on the finding of this work, the result further shows that accessing low-interest funding for PPPs low-income housing is an enormous challenge, which most times leads to abandonment and delays in delivery schedules for its provisions. The result is similar to Ibem (2010) and Osei-Kyei (2016) finding that the lack of standard assessment of public housing programs, financial policies, and proper monitoring is a challenge that affects PPPs' successful housing provisions. Finally, the study result also conforms with UN-HABITAT (2006/7), Kabir (2004), and Olotuah et al. (2009) that invested funds in PPPs low-income housing in case of unanticipated challenges during its planning or execution were recouped through neither re-negotiation, resort to arbitration nor through a court of law.

5. Conclusion and Recommendation

The study appraises the challenges of PPPs in low-income housing provisions in Nigeria. The study identified access to land, faulty design, the security of title and tenure, the high cost of building materials, and access to funding with low interest as major challenges that affect the low-income housing process and eventual provisions. The study, therefore, suggested that funding, existing land laws, and users' financial capacity need to be considered in the planning stage of PPPs low-income housing to avoid challenges that could create neglect of the provided low-income housing projects. Finally, the study concluded that housing provision for low-income earners should not be based on political gain but the political will of both the public and private sectors involved. A proper administrative housing system should guide this to meet low-income housing needs and reduce homelessness. The study contributes to the body of knowledge by making the government and private institutions involved in the PPPs project identify challenges anticipated in providing affordable PPPs low-income housing toward reducing homelessness.

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Assessment of Maintenance Needs in Public Educational Institutions Residential Facility

Babatunde Ogunbayo[1*], Clinton Aigbavboa[1], Didibhuku *Thwala[2], Opeoluwa Akinradewo and Olusegun Oguntona[3]*

[1]cidb Centre of Excellence & Sustainable Human Settlement and Construction Research Centre, Faculty of Engineering and the Built Environment, University of Johannesburg.
[2]Department of Civil Engineering, College of Science, Engineering and Technology, University of South Africa (UNISA), Pretoria, South Africa)
[3]Department of Built Environment, Walter Sisulu University, Butterworth Campus, South Africa
tundeogunbayo7@gmail.com

Abstract

Residential facilities of Public Educational Institutions (PEIs) encompass the immediate environment of the PEI, such as housing, recreational facility, sanitation, and others that provide shelter and make life worthwhile for its users. This study assessed the maintenance needs of residents of the PEI residential facilities. To collect data on their maintenance needs, structured questionnaires were distributed to ninety-eight (98) respondents within the PEI residential facilities in the study area through systematic random sampling techniques. Information gathered from secondary and primary data was used to analyse residents' maintenance needs of the PEI residential facilities assessed. The result showed that the major maintenance need of the residents of the PEI residential facilities is on services, especially toilet and water distributions facilities. It indicates further that most materials used to maintain toilet amenities and water distribution channels were substandard. There is a slow response to repairs on maintenance needs as requested by the residents on damaged components of the facility. The study suggested that in meeting the maintenance needs of residents of the PEI facilities, the maintenance unit should have a quality assurance unit that will certify materials required for maintenance activities before usage within the PEI residential facility.

Keywords

Building Services, Maintenance Need, Public Educational Institutions, Quality Standard, Quality Assurance.

7. Introduction

The need to provide better management of PEI facilities is a matter of importance (Idrus, Khamidi, & Olanrewaju, 2009). Maintenance management (MM) should be innovative, strategically 98nstandar, and have positive planned maintenance activities (Karia, Asaari, & Saleh,2014; Ogunbayo et al., 2022). Ogunbayo and Aigbavboa (2021) and Arditi and Nawakorawit (1999) state that the moment a building is being erected, its maintenance should start immediately to avoid early deterioration. Pļaviņa and Geipele (2013) and Ogunbayo and Aigbavboa (2019) opine that keeping every part of the building to an acceptable standard should be maintained to sustain its value. However, Puķīte and Geipele (2017) state that the aim of sustaining the value of any facility through a stable maintenance arrangement is to upgrade, improve, and refurbish the existing facilities constantly. Alsyouf (2009) states that a viable maintenance policy is required in an institution to guide decision-making on managing resources toward keeping available facilities in good shape. Karia et al. (2014) state that the maintenance unit of an organization is responsible for maintaining and operating its physical facilities. Ogunde et al. (2018) observed that the maintenance unit of an institution deals with issues related to up keeping of institutional facilities and its component to meet the end-users needs. Owolabi et al. (2014) posit that the maintenance management of an institution is responsible for boosting residents' productivity and satisfaction through stable maintenance service delivery. Uma, Obidike, and Ihezukwu (2014) and Ogundipe et al. (2012) opine that the benefits of a well-maintained building to residents are overwhelming; it brings about utmost performance at a minimal cost and provides decency and comfort to the users. However, Nduka et al. (2018) posit that the lack of proper planning of maintenance assignments can lead to inefficient maintenance management practice. In increasing public facilities' economic value, including educational buildings, attention should be given to maintenance tasks (Ogunde et al., 2018; Ogunbayo et al., 2019). Miller (2007) argues that supporting services through contracting or an in-house staff system to develop a quality maintenance approach for public institutions, including PEIs, could not be excluded. Asiyai (2012) posit that the standard of educational institutions depends on the quality of academics and the standard of its buildings. The responsibilities of managing PEI facilities effectively with minimum challenges depend primarily on the management of the educational institutions (Oluwunmi & Izobo-Martins, 2012). However, Okolie (2011) observed that overpopulation and expansion in student intake have increased pressure on the available PEI facilities. Kotzé and Nkado (2003) suggested that for PEI to meet its maximum output, in-house maintenance management staff should be trained on the technicality of their job. Asyai (2012) and Ogunbayo, Aigbavboa, and Akinradewo (2019) opined that the repair and maintenance work backlog has brought the building stock of different PEIs to an unacceptable level. Ogundipe et al. (2018) observed that a lack of on-job training for maintenance personnel on safety policies development and workable hazard management system within the axis of their duties affects the response time to the maintenance needs of the maintained buildings. Owolabi et al. (2014) asserted that governments worldwide had committed considerable expenditure to maintain their PEI and facilities. But Aina (2007) opined that the dwindling resources in the PEIs affect both academic and residential facilities of the PEIs due to cuts in maintenance budgets. Besides, Ogunbayo et al. (2018) state that in respect of construction design and method used, PEI facilities deteriorate with age due to delayed maintenance, vandalism, poor workmanship, and use of low-quality materials. However, Ajayi and Ekundayo (2008) assert that the challenge of satisfying the maintenance needs of the residents of PEI residential facilities are constrained by dwindling resources, lack of funding, and inadequate physical infrastructure. While Ojogwu and Alutu (2009) state that the challenges include overpopulation, poor workmanship, use of low-quality materials, and poor management. Based on this fact, this study assessed the maintenance needs of residents of the PEI residential facilities.

2. Research Methodology

To achieve the set objectives for this study, a quantitative research design was employed. In carrying out this, a systematic random sampling technique was adopted. The technique was used because it is more direct and evenly covers all the study elements. The technique was also used because there will be a low risk of data manipulation. The study used the residential facility of a public educational institution in Ota Ogun state Nigeria. The sampled residential facility of the educational institution consists of a total of 132 residents. Out of the number, 80 academic staff and 52 administrative staff reside within the study area. The choice of choosing this area for this study was based on respondents' knowledge, experience, and usage of available PEI facilities over the years within the study area. To ensure consistency of the data, 98 structured questionnaires were administered to both academic and administrative staff residing within PEI residential facilities. 50 of the questionnaires were administered to residents of academic staff blocks, while 48 were administered to administrative staff blocks. Out of all the administered questionnaires, only 90 copies were retrieved, representing 91.84% of the total questionnaire administered. This was found appropriate to achieve the study aim. The retrieved data were analysed using descriptive statistics, and the results were represented in figures.

3. Result and Findings

Figure 1 shows that 54.44% (49) of respondents are academic staff, while 45.56 % (41) of the respondents are the administrative staff of the PEI sampled.

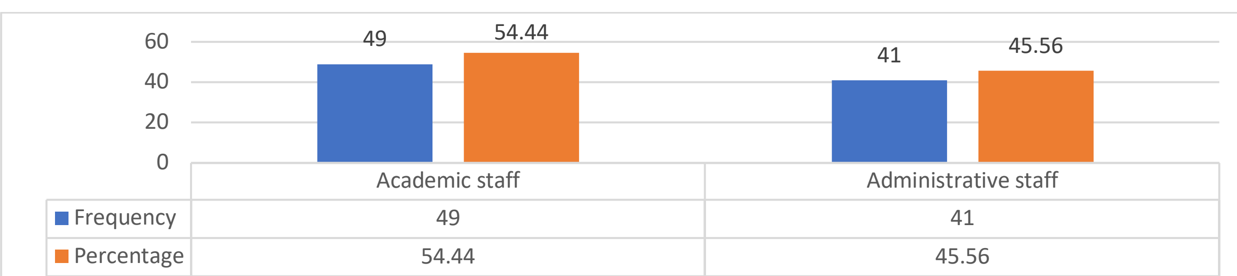
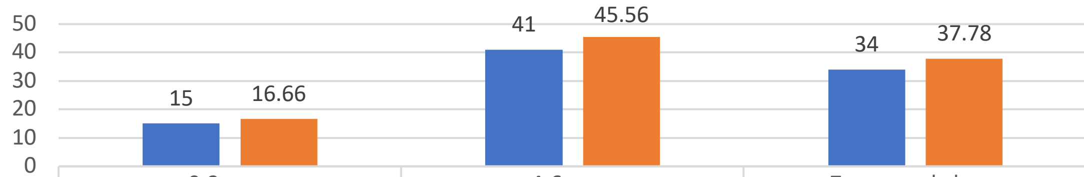


Figure 1. Designation of respondents

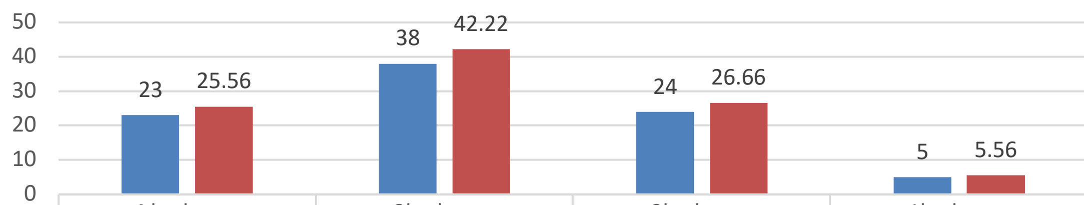
Figure 2 reveals the year of tenancy of the respondents. The result indicated that 16.66% (15) of the respondents have been residing within the residential facilities between 0-3years, while 45.56% (41) have been residing within the PEI residential facility for between 4-6years, while 37.78% (34) have a tenancy of seven years and above.



	0-3years	4-6years	7years and above
Frequency	15	41	34
Percentage	16.66	45.56	37.78

Figure 2. Respondent year of tenancy

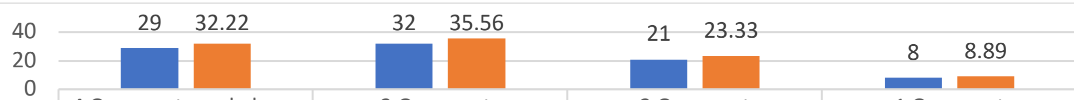
Figure 3 indicates the type of apartment respondent resides within the residential facilities. The result shows that 25.56% (23) of the respondent lives in a four-bedroom apartment, 42.22% (38) resides in a three-bedroom apartment, and 26.66% (24) resides in a two-bedroom apartment, while 5.56% (5) resides in a one-bedroom apartment.



	4 bedroom	3bedroom	2bedroom	1bedroom
Frequency	23	38	24	5
Percentage	25.56	42.22	26.66	5.56

Figure 3. Response on challenges in the process of security of title and tenure

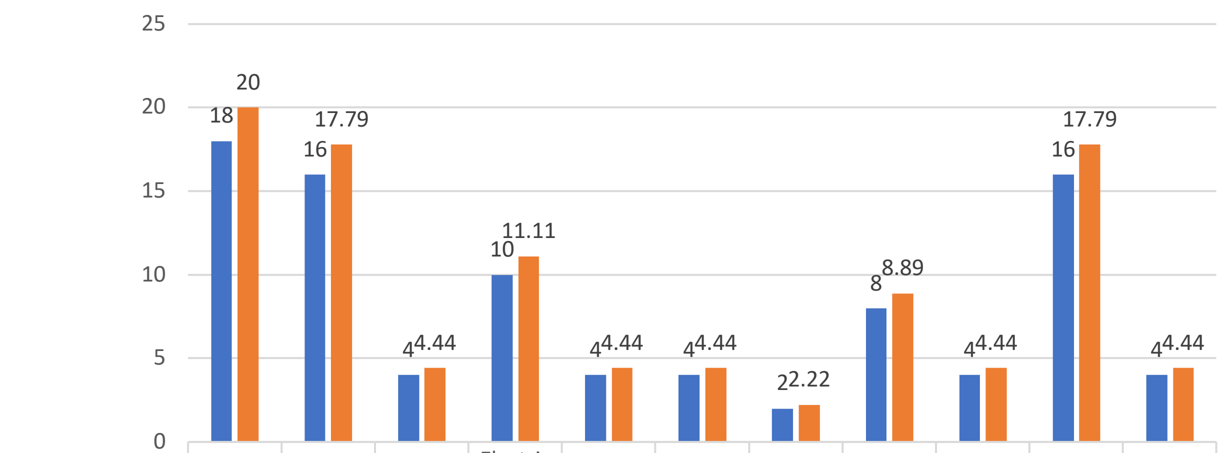
Figure 4 revealed the number of occupants per apartment within the residential facilities. The result indicated that respondent residing in an apartment with four occupants and above is 32.22% (29), respondents living in an apartment with three occupants is 35.56% (32), while respondents residing in an apartment with a minimum of two occupants is 23.33% (21). Respondents living within an apartment occupied by a single occupant are 8.89% (8).



	4 Occupants and above	3 Occupants	2 Occupant	1 Occupant
Frequency	29	32	21	8
Percentage	32.22	35.56	23.33	8.89

Figure 4. Number of Occupants in an apartment within the PEI residential facilities

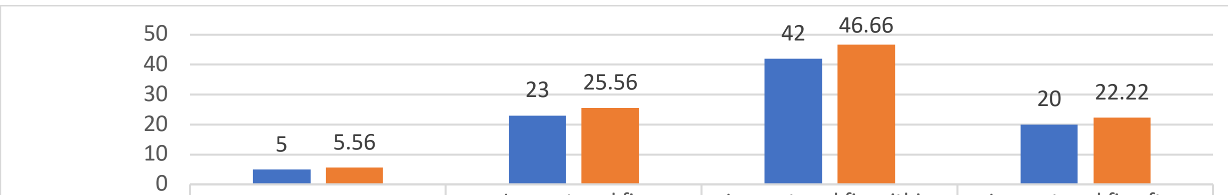
Table 5 indicated facilities that often need maintenance within the residential facilities. The result shows that toilet and its fittings 20% (18), water distribution pipe 17.79% (16) together with sewage system and pipe 17.79% (16) as the highest result in terms of facilities that often need repairs within the PEI residence, and it is followed closely by electrical installation and fittings 11.11% (10) and door and window locks 8.89% (8), while others such as floor and walls 4.44% (4), ward drop 4.44% (4), doors and windows 4.44% (4) roofing system 4.44% (4) together with furniture and bedding have the least result.



	Toilet and it fittings	Water distribution pipe	Floor and walls	Electrical installation and fittings	ward drop	Door and windows	Painting and aesthetic	Door and window locks	Roofing system	Sewage system and pipe	Furniture and bedding
Frequency	18	16	4	10	4	4	2	8	4	16	4
Percentage	20	17.79	4.44	11.11	4.44	4.44	2.22	8.89	4.44	17.79	4.44

Figure 5. Facilities that need maintenance often

Figure 6 indicates the response to the maintenance needs of residents of PEI residential facilities. 5.56% (5) of the respondents indicated that inspect and abandoned were only carried out on reported faulty components, 25.56% (23) stated that the maintenance personnel inspected and fixed it immediately, while 46.66% (42) said that within two weeks, maintenance personnel inspects and fix it, and 22.22% (20) stated that it takes more than a month for the maintenance personnel to inspect and fix the faulty components.



	Inspect and abandoned	Inspect and fix immediately	Inspect and fix within two weeks	Inspect and fix after more than a month
Frequency	5	23	42	20
Percentage	5.56	25.56	46.66	22.22

Figure 6. Response on challenges of skilled labour required for PPPs housing provision

Figure 7 shows the main maintenance period within the PEI residential facilities. 5.56% (5) of the respondent stated that the main maintenance is carried out daily, while respondent result with 7.78% (7) indicated that the main maintenance is carried out weekly, respondents 54.44% (42) agreed that main maintenance is carried out monthly, others with 15.56% (20) and 16.66% (15) stated that main maintenance is carried out within the PEI residential facilities on quarterly and yearly bases.

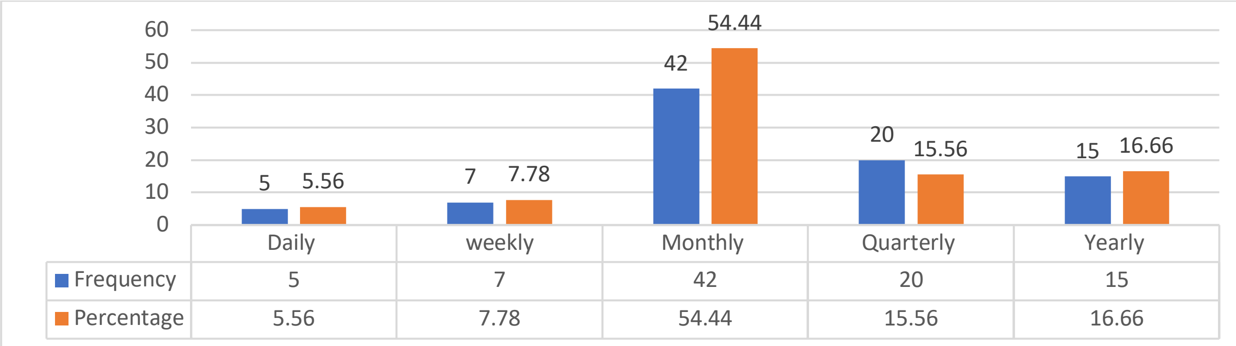


Figure 7. Main Maintenance period within the PEI residential facilities

Figure 8 shows the quality of material used for general maintenance work within the PEI residential facilities. 28.89% (26) stated that the material used is of high quality, 51.11(46) said the material is of low quality, while 20% (18) indicated that damaged material or component is repaired and reused for maintenance work within their residential facilities.

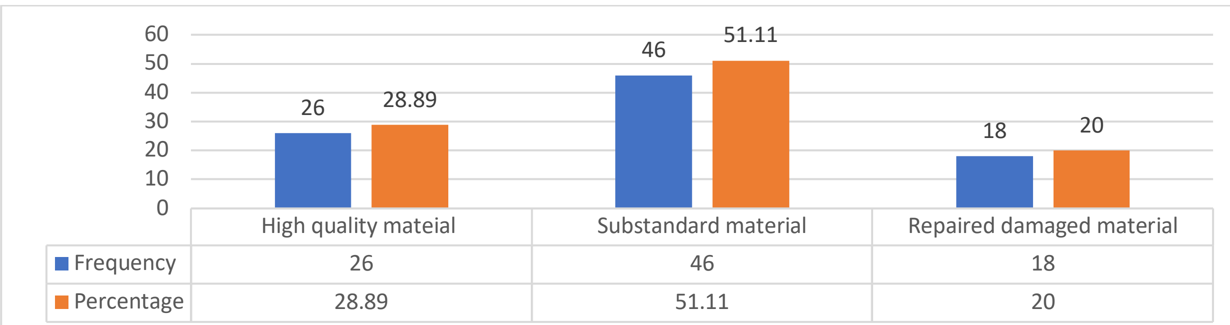


Figure 8. Quality of material used for maintenance work within the PEI residential facilities

4. Discussion of Findings

The study assessed the maintenance needs of residents of the PEI residential facility. Findings from the survey indicate that the PEI residential facility residents in the study area were academic and administrative staff, with over eighty percent of them having above four years of tenancy. Also, the result shows that high numbers of the respondents reside in four-bedroom, three-bedroom, and two-bedroom apartments with an average of 3-4 occupants per apartment. Also, the finding indicates that the residents' maintenance needs are mainly on the toilet and its fittings, water distribution pipes, electrical installation and fittings, sewage system, and pipes. The finding is similar to the studies of Alsyouf (2009), Pļaviņa et al. (2013), Karia et al. (2014), and Ogunbayo et al. (2019) that showed that the majority of maintenance works carried out in residential buildings are on services, especially toilet and water distributions facilities. Likewise, the finding signifies that response to repairs on maintenance needs reported on damaged facilities within the PEI residence is slow and delayed. The result aligned with the studies of Uma et al. (2014), Ogunde et al. (2018), Owolabi et al. (2018), Nduka (2018), and Ogunbayo et al. (2018) that showed that a lack of proper planning of maintenance and technical personnel assignments together with the shortage of human resources and inexperience personnel could give rise to inefficient maintenance management practice.

Similarly, the finding shows that main maintenance activities are on a monthly schedule-based (corrective) maintenance plan. The finding is comparable to the studies of Kotzé et al. (2003), Okolie (2011), and Asyai (2012) that indicated that delay in carrying out maintenance activities through corrective measures as against proactive measures has led to backlogs of repair and maintenance work that has brought building stocks including PEI buildings to an unacceptable level. Equally, the finding from the study shows that low-quality materials were used in substantial maintenance work or replacement, while some fraction of the respondents indicated that maintenance personnel sometimes reused repaired damaged components for maintenance work within the PEI residence. The finding is in line with studies by Ogunbayo et al. (2019), Ajayi et al. (2008), and Ojogwu et al. (2009) that show that challenge of satisfying maintenance requests of the residents of PEI residential buildings is constrained by poor workmanship and management. As shown in the study result, frequent maintenance needs on the residential facilities are primarily because of low-quality material usage, deterioration due to the age of components, pressure on facilities through use, and inexperience workmanship for maintenance work and vandalism. The finding is similar to the study of Owolabi et al. (2018), Nduka et al. (2018), and Ogunbayo et al. (2021) that building components deteriorate with age in respective of construction design and method used in their construction and maintenance.

5. Conclusion and Recommendation

This study appraised the maintenance needs in a residential facility of PEI in Nigeria. The study, however, indicated that to avoid frequent maintenance needs within PEI residential facilities, maintenance officers and personnel should respond to maintenance needs early through early inspection and repairs of damaged components reported by residents. The maintenance department of PEIs should employ enough well-trained maintenance personnel with the required skill needed for maintenance operations to avoid delays in carrying out the maintenance needs within the PEI residential facilities. The study also suggested that maintenance activities within residential facilities of the PEIs should be based on a planned maintenance system. The study further indicated that the maintenance management department should have a quality assurance unit with trained personnel to certify materials required for maintenance activities before usage within the PEI residential facility. The study concluded that provided residential facilities within PEIs should meet the residents' immediate economic, social, and academic needs. The replacement material during the maintenance stage should be of quality standard. The study contributes to the body of knowledge by making maintenance managers of educational institutions understand the facility requirement of users of residential facilities of educational institutions toward improving their academic and administrative performance.

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Unravelling the encumbrances to better information management among Quantity surveyors in the 4IR: A qualitative study

[1]Samuel Adeniyi Adekunle, [2]Clinton Ohis Aigbavboa, [3]Obuks Ejohwomu, [4]Opeyemi Olanrewaju Oyeyipo, and [5]Wellington Didibhuku Thwala

[1,2]cidb Centre of Excellence, University of Johannesburg, Johannesburg, South Africa
[3]Department ofMechanical, Aerospace and Civil Engineering (MACE), University ofManchester, Manchester, UK
[4]Department of Quantity Surveying, Bells University ofTechnology, Ota, Nigeria
[5]College of Engineering, Science and Technology, Department of Civil Engineering, University of South Africa (UNISA)
[1]adekunlesamueladeniyi@gmail.com

Abstract
In the last decade, Building information modelling has become a topical issue of discussion in the construction industry. Its adoption has been researched from different perspectives. This is aimed at achieving a more productive and technologically driven construction industry. However, a dearth exists in the adoption among professionals in the construction industry. This paper investigates BIM adoption as a tool for an enhanced information management process in the fourth industrial revolution(4IR) among quantity surveyors in developing countries. The study adopted a qualitative research approach through interviews to achieve the study objectives. Using Nigeria as a case study, the study identified the peculiar encumbrances to BIM adoption among quantity surveyors in developing countries. Furthermore, the drivers and solutions to the identified challenges were identified. The data collected was analysed and discussed. The result was thematically discussed under two major categories – private stakeholders and the government. The study provides a deeper and robust knowledge of the peculiar dynamics among Quantity surveyors regarding BIM adoption in developing countries. The implementation of the study findings will enhance the quantity surveyor's value management function and be 4IR aligned.

Keywords
BIM adoption dynamics, Building Information modelling, developing countries, global south, information management, qualitative research, 4IR

1. Introduction
Building information modelling (BIM) is the new yardstick for collaboration and value delivery on construction projects in the construction industry. Many studies have established its benefits to the industry theoretically and via case studies (Bensalah et al., 2019; Bryde et al., 2013; Stanley & Thurnell, 2014). It has been established that it promotes cost efficiency, reduces conflict, aid accelerated project completion, enables more efficient designs, promotes collaboration among stakeholders, and other benefits. The adoption of this revolutionary technology in the construction industry has witnessed an upsurge as the UK, the US, and some other countries have witnessed a good level of adoption and implementation.

Despite this development witnessed in other parts of the world, studies have shown that many developing countries are still struggling and are faced with diverse challenges(Ofori, 2007). These challenges have made BIM adoption a challenge in developing countries. Consequently, if these challenges are not eliminated, the developing countries will not be well-positioned for the fourth industrial revolution and to compete globally. Ofori identified, among others, culture and 105nstandardize; the culture of working in isolation by the construction industry in the developing countries will not help them compete globally or achieve technological adoption. This is because technology has broken down international borders, and 105nstandardize has made it possible for foreign firms with superior resources to compete with indigenous firms.

The case of the Nigerian construction industry is not peculiar as regards slow adoption of innovation as the construction industry has generally been observed to be slow in technological adoption. This tradition has been established to affect the construction industry in general (Gerbert et al., 2016). Defending this tradition, Georgiadou, (2019) claimed that the uptake of new tools, techniques, and methods require significant time, skills and capital investment. The study also provided the solution out of this web, thus: readiness to build strategic leadership, capacity building, and development of the adequate capacity to operate in a digital environment.

However, it appears that the construction industry in other countries has been able to find its way out of this slow adoption stigma. A study by Jung and Lee, (2015) established a disparate level of BIM adoption. The study shows that among the six continents – North America, Oceania, Europe, Asia, the Middle East/ Africa, and South America; Middle East/Africa and South America are still considered at the beginner's phase of adoption. Similarly, a more recent classification was done by Adekunle et al., (2021) when they classified the digital transformation in the construction industry globally. The study opined that the Nigerian construction industry is a "DT contemplator" regarding digital transformation.

This study was embarked upon to understand better BIM adoption focusing on the quantity surveying profession. This study provides an insight into the state of the quantity surveying profession in the 4IR. It provides a framework of achieving better information management through BIM adoption by the quantity surveyors via the following objectives:

- To investigate the perceived encumbrances to BIM adoption among quantity surveyors
- To proffer a solution to promote better information management among the Quantity surveying profession in the 4IR

Although there have been different studies on BIM adoption in the construction industry, a dearth exists in the professional perspective. This study is different and required in its methodological perspective and focus. Previous studies on BIM adoption in the Nigerian construction industry were achieved through a quantitative research approach. This study adopted the qualitative research approach (phenomenology) to investigate the root cause and profer solutions. Furthermore, previous studies focused on diverse professionals as the respondents. However, considering the importance of the Quantity surveying profession to the construction industry, this study is quantity surveying profession focused.

8. BIM Adoption in Nigeria

According to Olawumi and Chan, (2019), the first BIM education conference for construction professionals in Nigeria was in 2016. Unfortunately, the Nigerian construction industry is still struggling with BIM awareness years after. At this same period, other construction industries are developing frameworks, roadmaps and maturity models for BIM (Olawumi & Chan, 2019). These BIM leading countries are already reaping the benefits of adopting BIM. Searching literature for BIM studies in Nigeria, the focus has been mainly on factors affecting BIM awareness in Nigeria. Table 1 gives a record of BIM adoption-related studies carried out in the Nigeria Construction industry (NCI); these studies identified many barriers to BIM adoption in the Nigerian construction industry. The factors identified include lack of government support, cost issues, infrastructure, lack of awareness, lack of technical know-how, among others. It is interesting to note that many of these factors were derived through quantitative studies. The quantitative approach adopted is not wrong; however, it limits respondents to the options presented to them, thus providing a limited knowledge of the studied phenomena. Also, quantitative study is disadvantaged because it cannot go into depth about issues and subjects(Kumar, 2011). The previous quantitative studies identified the barriers to BIM adoption, including cost, 106nstandardized106, infrastructure deficiency, education, and training.

Consequently, this study was embarked upon to unearth the peculiar barriers to BIM adoption in developing countries from Quantity surveyors perspective using Nigeria as a case study. The study decided to adopt Quantity surveyors because the profession is needed on every construction project; it plays a central role in the construction process as its roles cannot be relegated. Consequently, Quantity surveyors interface with all professionals in the construction industry, thus possessing a well-rounded knowledge of the industry through association.

Table I: Barriers to BIM adoption in the Nigerian Construction Industry (NCI) from literature

Author	Findings
Ozorhon and Karahan, (2016)	standard platforms for integration and communication, cost of development, education and training, 106nstandardized106 (product and process), clear definition and understanding of users' requirement
Ibem *et al.*, (2018)	high level of awareness of BIM among architects in Lagos (common BIM software packages used are Autodesk Revit Architecture, AUTOCAD, and Google Sketchup.)
Olapade and Ekemode, (2018)	low level of awareness, low-level adoption of BIM for FM
Hamma-Adama, Kouider and Salman, (2018)	key players are generally not familiar with the term "Building Information Modelling" or "BIM" although mostly aware of some of its tools (i.e. AutoCAD, Revit, etc.), low level of using BIM tools, no legislative provision on BIM adopting or regulation, lack of experts on BIM
Ugochukwu, Akabogu and Okolie, (2015)	Poor knowledge of BIM application among professionals, Use of BIM in projects is non-existent, lack of BIM awareness

Ryal-Net and Kaduma, (2015)	low level of BIM knowledge, low level of awareness, low level of 107 nstandardi amongst stakeholders
Ezeokoli, Okoye and Nkeleme, (2016)	Structure/culture of the industry, Level of Knowledge and Awareness index, Availability of the appropriate Technology and Infrastructure, Individual/Personal Disposition
Akerele and Moses, (2016)	low level of awareness.
Onungwa and Uduma-Olugu, (2017)	lack of infrastructure, lack of skilled workers, lack of awareness, lack of support from leadership in the offices and lack of belief in the usefulness of the software.
Amuda-Yusuf *et al.*, (2017)	Clients' low level of awareness, lack of funding, poor power supply, legal uncertainty, lack of transparency.
Fadason, Danladi and Akut, (2018)	Lack of BIM education, Lack of Information on BIM, Lack of Investment in BIM Technology, Lack of Government Support through legislation, Lack of Standards to Guide Implementation, Lack of sufficient ICT Infrastructure
Abubakar *et al.*, (2014)	social and habitual resistance to change, legal and contractual constraints, High cost of integrated software, Lack of enabling environment (policies and legislations of government towards the adoption), lack of trained professionals
Mansur Hamma-Adama and Tahar Kouider, (2018)	Low level of BIM adoption, Reasonable level of awareness, lack of policy and guideline, serious lack of experts
Usman and Said, (2014)	Culture, policy, cost
Adekunle, Aigbavboa and Ejohwomu, (2020)	Transparency, infrastructure

2. Research Methodology

A phenomenological approach was adopted to understand better the BIM implementation among the quantity surveying professionals in the Nigerian construction industry. The phenomenological inquiry approach is adopted when uncovering meaning through respondents' experience is adopted. The results of the phenomenology approach in qualitative research is considered rich and detailed (Creswell, 2014). It is also believed to unearth the root cause of a challenge (Ebekozien et al., 2021). This study believes this approach will achieve the purpose of the study, which is to unearth the peculiar encumbrances and understand the BIM adoption dynamics among quantity surveyors. Firstly, an extensive study of literature on previous works about BIM barriers in the Nigerian construction industry highlighted the erstwhile established barriers. Afterwards, the study adopted a qualitative approach to investigate the peculiar barriers to BIM adoption in developing countries. This approach was adopted to provide a deeper knowledge through the experiences of those who have directly experienced the phenomenon under study (Castleberry & Nolen, 2018), in this case, the barriers to BIM in developing countries. Qualitative studies do not thrive on large sample size, unlike quantitative studies. According to Kumar, (2011), "the numbers of people you are going to contact depend upon the attainment of the data saturation point during the data collection process…which can provide you, as far as possible, with the detailed, accurate and complete information that you are looking for". To this end, there has been various discussion on the accepted number of respondents. Researchers have adopted different numbers of respondents in a qualitative study (Boddy, 2016; Dworkin, 2012; Hennink & Kaiser, 2022). These literature suggests that 5 to 50 respondents are adequate for a qualitative study. The most significant factor for selecting respondents is their depth of experience of the problem being studied and the concept of saturation. Adopting this method overcomes the drawbacks of willingness and the busy schedules of respondents to be available for interviews.

Therefore, six quantity surveyors were interviewed through purposive and snowball sampling. These two sampling methods were employed to choose qualified participants. Their suitability for this study was based upon their exposure in the Nigerian construction industry (size and nature of construction projects handled, among others). These respondents have experience on international projects and work with firms that support ICT with between 20 – 30 employees. Their firms are also among the highest paying in the land; thus, it can be inferred that the firms' turnover is impressive. Respondents and their firms are always available and visible at the Quantity surveyors professional parent body (Nigerian Institute of Quantity Surveyors) events. This also indicates the firm's support for research and development. Lastly, all respondents were professionally 107nstandard members of the Quantity surveyors governing body in Nigeria: Nigerian Institute of Quantity Surveyors (NIQS).

This study employed virtual interviews due to the COVID-19 pandemic ravaging the world. This was adopted to overcome the associated challenges of getting an appointment and avoiding physical contact with correspondents. Also, to afford respondents flexibility: to respond at their convenience. This method also ensured the ease and accuracy of record-keeping on dialogues. Respondents were first contacted to request their audience and willingness. Those that signified their willingness were interviewed for the study.

Interview questions focused basically on assessing BIM awareness level in the construction industry, the encumbrances to BIM penetration among quantity surveyors, and the drivers to BIM adoption. The responses were collated and transcribed appropriately. The process of achieving a good analysis of qualitative data using thematic analysis was adopted according to (Castleberry & Nolen, 2018). They established five steps; they are: compiling (transcribing the data), disassembling (making meaning out of the data), reassembling (putting data into context for the study), interpreting (establishing themes) and concluding. The study discussed the results under two main themes categories. Questions were asked from respondents individually, and the validity was through logic. The analysis was carried out manually based on the main themes (Castleberry & Nolen, 2018; Kumar, 2011).

3. Results and Discussion

3.1 BIM awareness level of Quantity surveyors

Firstly, the study established the BIM awareness level in the construction industry. The respondents unanimously agreed that the BIM awareness level in the Nigerian construction industry is very low. Although a respondent mentioned an upsurge in inquiries; however the inquiries lack depth. Respondents opined that the awareness level must be improved to achieve a good implementation level in the Nigerian construction industry. Also, respondents were unanimous in stating that the industry has been working in isolation. Thus the efforts have been in silos, and the impact is not evident in the industry.

3.2 Encumbrances and drivers to BIM adoption by Quantity surveyors

The study's findings were 108 nstandardi and discussed under two focused themes: private stakeholders and government. This classification is from the perspective of the government and the governed. Under these themes, there exist many sub-themes and their interwoven relationships. A brief discussion of this classification is provided below:

Theme 1: *Private stakeholders*

It was established that people are currently clueless and working in isolation. The cluelessness, according to respondents, is implementation related in an environment void of infrastructures supporting BIM adoption. Furthermore, respondents' responses classified people as all construction professionals, clients, contractors, academia and professional bodies. Identified barriers among the people are ego, unhealthy rivalry and 108 nstandardized information-sharing protocols. Other challenges identified include rigidity (a respondent said: "all stakeholders fully decide to move away from the traditional ways of construction and embrace technology in its entirety". Another respondent said, "Learning is difficult for most people. Even with the availability of the software if the willingness to learn is not there then it becomes useless"), high cost of operations required, 108 nstandardized turnover and 108nstandardiz size, and cluelessness. It was reported that the cost management professionals are behind in the BIM implementation. A respondent stated that "Amongst the professionals, we have large disparity on knowledge about BIM. Architects / Engineers are far ahead of others because they are currently using some of the BIM tools"

Theme 2: *Government*

The respondents considered the government to be clueless at the moment regarding BIM implementation. This cluelessness is unrelated to the lack of awareness of the government. Good knowledge of the benefits of BIM to the economy and the effective delivery of infrastructural projects will be a good incentive for the government. However, most of the respondents opined that adequate knowledge of BIM would encourage the government to provide an enabling environment that makes BIM implementation cheaper and affordable for stakeholders. Most of the Respondents stated that government policy and legislation are required to implement BIM fully. Others advocated for a collaborative front between the government and other stakeholders for the BIM implementation drive. The government has been advocated for as the major stakeholder based on the success recorded in the UK driven by government policies.

Table II: Summary of peculiar barriers

Stakeholders	Peculiar barriers	Common barriers
Consulting professionals	Ego, unhealthy rivalry, 108nstandardiz turnover/size, high cost of operation, unreliable information sharing, 108nstandardized operation procedure, the rigidity of professionals	
Client	Organisation turnover	Rigidity, 108 nstandardiz turnover/size, high cost of operation
Academic	Overhaul of the existing syllabus to incorporate BIM education	
Contracting 108nstandardiz	Organisation turnover/size, the rigidity of contracting 108nstandardiz, high cost of operation	
Professional bodies/ other stakeholders	Rigidity	

Table III: Peculiar broad challenge to adoption

Identified drivers	Identified common challenge
Government Private stakeholders	Cluelessness, lack of awareness, isolated efforts

The identified drivers by respondents are government and other private stakeholders (professional bodies, academia, contracting 109nstandardiz, consulting professionals, among others) in the industry. However, the identified common challenges include cluelessness, lack of awareness and isolated efforts. Thus, collaboration is the solution to overcoming the challenges of BIM adoption in the industry. Stakeholders and the government must present a concerted effort to overcome the difficulties identified in the industry. However, professional bodies across all construction professions need to intensify awareness campaigns and educate the government. Academia should provide roadmaps through research to fully adopt BIM in the Nigerian construction industry. This will solve the challenge of cluelessness and lack of awareness in the industry. Table IV provides the solution to other challenges confronting the Nigerian construction industry.

Table IV: Solution to peculiar challenges

Themes	Solution
Ego/ Unhealthy rivalry	The traditional fragmented approach in projects and the drive to gain competitive advantage among professionals and firms must have given birth to this. Ego and unhealthy rivalry breed mistrust, a barrier to collaboration. The readiness of stakeholders to jettison with perceived differences and operate healthy collaboration is essential to adopting BIM.
Organisation turnover/size; High cost of operation	The earning strength determines the purchasing power of businesses. Adoption hasn't been possible due to the inability of stakeholders to fund the high cost of BIM tools and infrastructures, staff training, and low financial turnover. Stakeholders stand to gain a massive return on investment as BIM offers value, competitive advantage, and efficiency, making them earn more than the investment cost.
Unreliable information sharing	Poor record-keeping was identified as the major cause. Stakeholders are to keep accurate information as BIM thrives on the accuracy of shared information. Meticulous records keeping of project information is essential
Unstandardised operation procedure	There should be a 109nstandardiz operational procedure among consulting organisations. This will aid information accuracy. Also, it will provide 109 nstandardiz, common and formal information keeping procedure.
Rigidity of professionals	Professionals are observed not to be flexible and receptive to change. Many are still holding on to the traditional approach; some are not ready to learn new software. Professionals should change their mindset and attitude towards adopting recent technological trends and developing international standards responsible for achieving a competitive edge.
Overhaul of the existing syllabus	Respondents opined that the current academic syllabus is outdated compared to the technological revolution presently being experienced. Thus, the current syllabus is to be overhauled and restructured to incorporate BIM education

Conclusion

The study investigated the dynamics involved in BIM adoption in developing countries using the Nigerian construction industry as a case study. The study observed a not too encouraging level of awareness and cluelessness among the Nigerian Construction Industry (NCI) stakeholders. This is the main barrier to implementing BIM in the Nigerian Construction Industry (NCI); hence it is not surprising to observe a very low level of readiness to implement BIM in the industry due to the current awareness level. Also, it was established that there exist rigidity and unwillingness to learn among professionals. They are unwilling to move with technological advancement. The study also observed some peculiar challenges among professionals in the Nigerian Construction Industry (NCI), including the isolated nature of efforts among professionals, ego/unhealthy rivalry, and 109 nstandardized work protocol/unreliable information transmission.

Consequently, for full BIM implementation in the Nigerian Construction Industry (NCI), the study recommends the need for the government and every stakeholder in the industry to collaborate and drive BIM implementation. The existing isolated pockets of efforts should be collapsed to achieve a concerted drive for better results. Willingness to learn among professionals and the discontinuation of the traditional ways of doing things is also encouraged. Also, it revealed that professionals in the industry have more to do to help the industry overcome its awareness and cluelessness challenges. The study has built on previous studies and thus provided a comprehensive knowledge of the Nigerian Construction Industry (NCI) adoption dynamics, thus providing a better perspective to Building Information Modeling adoption.

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ID 16

Preliminary Assessments of Washrooms Conditions in Malaysia Hospital Buildings

Christtestimony Jesumoroti [1] and Soo Khor [2]

[1] Department of Construction Management, Universiti Tunku Abdul Rahman, 31900 Kampar, Perak, Malaysia
[2] Department of Construction Management, Universiti Tunku Abdul Rahman, 31900 Kampar, Perak, Malaysia
christtestimony@yahoo.com

Abstract
Healthcare building conditions require efficient services delivery to afford the users and others stakeholders in the hospital buildings for a serene and safe environment that accelerates wellbeing. The objective of this study is to evaluate the washrooms conditions of hospital buildings, to achieve this goal, hospital buildings must adopt good approaches and services that will enhanced washrooms conditions in the hospital buildings. Apart from ensuring the safety of the environment, users of the buildings must be satisfied with the quality of available services, particularly, those offered to patients. Survey questionnaires were administered to users of hospital buildings in Malaysia. The most significant washrooms conditions reported concerned are hand driers, water closet, water taps, doors lock, plumbing (pipes) signage, wash basins, floors condition, floors (floor tiles / floor finishes), walls (finishes / painting), columns (finishes / painting), ventilators, doors, lighting bulbs, workable alarm bells and lamps ceilings. The washrooms conditions were slightly affected by defects that depreciate the appearance, functionality and utility of hospital buildings thereby lessening their performance and efficiency. Malaysia washrooms conditions are slightly good but require improvement. Therefore, this study asserts the pertinence evaluating of the washrooms conditions approaches employed towards the rectification of the washrooms conditions in hospital buildings across Malaysia. The study posits the adoption of systemic proactive maintenance procedures to preempt decay, causalities (falls of the users as a results of wetness and slippery floors), and reduce cost implications of washrooms conditions. According to the washroom condition assessment, defects, tidiness and cleanliness of washroom areas as well as the quality of the service delivery are the main factors predicting maintenance service delivery efficiency. User attitudes, misuse, abuse, bad maintenance tactics, and weather are all important factors in determining the maintenance management practices of hospital buildings for washrooms conditions. Maintaining good washroom conditions is essential to ensuring service quality, meeting the expectation of users, and reducing the number of avoidable faulty washroom components.

Keywords
Construction Strategies, Poor Materials, Proactive Maintenance, Structural defects, Performance.

9. Introduction

Hospital buildings conditions necessitates the findings of this study, such that washrooms conditions are the major concern, and as these was mar by many factors in which defects is one of them. For instance, physical defects indisputably deface washrooms conditions and degenerate their productivity. This is especially true for hospital buildings as reputes washrooms conditions. Hence, generally hospital building conditions constitutes an urgent issue of global concern. Historically, the subject of building conditions has been a deserted area of technological discourse. However, the recent increase of global attention to the relevance of building conditions has not only brought it to the fore, but has also stimulated intensifying investigations into emerging maintenance management practices. In Malaysia, the state of building conditions has not too much fared any better to be in the trend of global competitiveness (Tan, 2018; FMT Reporter, 2019; Boo Su-Lyn, 2020; Boo Su-Lyn, 2020 & Olanrewaju *et al*. 2018).

Recently however, there has been concerted efforts by the Malaysian government to invest in building conditions, but this is yet to yield valuable results (Au-Yong *et al*. 2019). Hospital buildings are places where the sick receive treatment and recuperative therapy, thus they ought to always be in an optimal state of aesthetical appeal and functionality. The prevalence of defects in the washroom precipitates the unhealthy conditions or state or ageing process of such a building and drastically decreases its productivity and lifespan. This study reported the preliminary findings of this research on the washrooms conditions of hospital buildings. Hospital buildings differ significantly from other buildings because of their function, size, and density. Healthcare buildings are vital components of any meaningful society, therefore their design, construction, and functionality have a remarkable influence on the users' health and wellbeing (Guenther & Vittori 2008).

Researchers argue that if hospital buildings are to function to the required standards, the maintenance service delivery approach must not be cost and budget-driven, instead, it should be value-driven (Olanrewaju *et al*. 2019; Au-Yong 2018). By doing so, the overall essence of maintenance management scheme will be boosted if the conditions of the building are given proactive maintenance procedures in order to be in a good state at all times. This also implies that users will experience low disturbances, distractions and disruptions thereby increasing the user satisfaction and productivity of the buildings.

2. Literature Review

The term maintenance has multiple meanings depending on the context of usage. Often, it is used in reference to the notion of upkeeping, restoration to a specific purpose, or some kind of improvement of an object. In simple terms, maintenance can be defined as a set of actions performed upon a given object to enhance its efficacy (Lind & Muyindo 2011). For Ahzahar *et al*. (2011), building maintenance can be considered effective when a building is in a good state or building's defects are averted through a precise program of recurrent maintenance systems. The conditions of a building depend on defects activities which was addressed or guide against. There are numerous kinds of defects that can exist in a building. For instance, in recent studies conducted in New Zealand, the most significant defects identified include poor flooring, dysfunctional door fixatures, wrongly fixed door and window handles, uneven painted surfaces, nail pops, poor finishes, building cracks, inefficient toilet plumbing, and faulty concreting (Rotimi *et al*. 2015 & Paton-Cole & Aibinu 2021).

From a management viewpoint, maintenance issues such as incompatible maintenance management, poor building detailing and deficient budgetary designs were the culprits pinpointed in Malaysia that mar building conditions (Rahman & Salim 2013). The proliferation of defects in buildings is linkable to a multitude of causes, these issues have devastating consequences for maintenance management albeit their sources. For example, the cause of building defects has been attributed to foundational issues such as unsuitable design requirement and inappropriate construction for the building conditions. Another research categorizes the three broad root causes of defects as inferior materials, design defects and inefficient workmanship which negate the state of the building (Anderson 1999). This resonates with the findings of other researchers who suggest that the main causes of defects relate to workmanship, materials, and maintenance (Chong & Low 2006).

Similarly, Georgiou (2010) found negligent construction and poor maintenance processes as the two primary origins of defects in his study. More broadly however, building defects are attributable to the lack of proper drainage systems, poor architectural designs, ineffective construction strategies, incompetent workmanship, poor materials, analysis, and faulty installations (Auchterlounie 2009) to mention a few, the washrooms conditions had inappropriate and inefficient toilet plumbing problems (Paton-Cole & Aibinu 2021). However, the findings of (Salleh, et al. 2020) on systematics review of hospital buildings conditions stated that public toilet conditions not too good, and also, (Lauren McShane, 2016) highlighted that public toilet conditions in Malaysia especially washrooms conditions are in a state of dilemma.

In same vain, the findings of (Jesumoroti & Khor, 2021b) on maintenance management determinants appraisals for hospital buildings in Malaysia specified that washrooms conditions required better approach. In addition, some key issues were highlighted by (Lauren McShane, 2016) for the toilet conditions in Malaysia; and stated; (i). You will always leave the toilet with wet feet, (ii) Shoe marks on the toilet bowl, (iii) The smell, (iv) You may have to pay, and (v) You have to have the equilibrium of a kung fu master.

10. Method

This study adopted structured questionnaires to gather primary data for aim of this study. A structured questionnaire is also known as a standardized question. Since it encourages standardization, the structured questionnaire minimizes errors due to diversity of the questions (Sekaran & Bougie 2016, Cohen *et al*. 2017). The data was analyzed using the Statistical Package of Social Science 25 (SPSS), several tests were conducted: standard deviation, validity, mode, T-test and reliability, and a Bartlett test was conducted to make the equipment more accurate. It appears partially that problems exist in the washrooms condition for hospital buildings, as indicated by the one-way t-test. The standard error of the sample mean is an indication of how close the sample mean is to the population mean.

The respondents were hospital buildings users who were demanded to rank parameters according to the washrooms conditions in their hospital buildings. The respondents consisted of health care professionals such as physicians, psychologists, dentists, veterinarians, medical doctors, medical officers, nurses and users of the hospital buildings. The respondents willing agreed to participate in the research and 214 respondents responded. The survey was administered from February, 2021 to December, 2021, and consists of demographic; respondent's information, professional affiliations, academic background, numbers of years working in the hospital, position in the hospital, average age of building and conditions of washrooms.

The structured survey questionnaire composed of five-point scale with the use of a "level of importance" on a five-point scale whereby 1= Very Uncomfortable, 2=Uncomfortable, 3= Slightly Comfortable, 4=Comfortable, and 5=Very Comfortable, and comprises of 19 variables for conditions of washrooms which are; cleanliness of the washrooms, plumbing (pipes) signage, lamps ceilings, floors (floor tiles / floor finishes), walls (finishes / painting), columns (finishes / painting), beams, ventilators, doors, doors locks, windows handles, windows frames, water taps, wash basins, water closet, Floors condition, hand driers, lighting bulbs, workable alarm bells and others. 85% of the questionnaires circulated for the survey were retrieved and valid, 5% were invalid, while 10 % had no response. They were accordingly analyzed by ranking.

11. Results

Due to space constraint, I only presented three tables. Table 1 and 2 showed the academic background and educational level of the users. In (Table 1), Administration 5.6%, Biomedical Science 6.0%, Finance 5.1%, Nurse 32.2%, Science Laboratory 3.7%, Accounting 1.9% and majority which are others has 31.8%, as most of the users did not stated their academic background. In (Table 2), Diploma/STPM 52.3%, Bachelor 29.0%, Master 0.5%, PhD 1.0%, MBBS, MRCP 5.1%, and Others 12.1%. Most of the building users are medical staff, while the remaining non-medical staff and executives have experienced the buildings over the years (working experience). More than 57% of the building users have been the hospitals over a period of years (position in the hospital).

Table 1: Academic Background for User

Academic Background	Frequency
Administration	12
Biomedical Science	13
Economics & accounting	1
Engineering	2
Finance	11
Medicine	26
Nursing	69
Science Laboratory	8
Accounting	4
Others	68
Total	214

Table 2: Education Level for Users

Education Level	Frequency
Diploma/STPM	112
Bachelor	62
Master	1
PhD	2
MBBS, MRCP	11
Others	26
Total	214

The condition of washrooms as shown in the (Table 3) below, the overall sum of the mean is 67.6, and standard deviation is 15.8 Based on the results from the survey, 214 respondents rated the washrooms condition rudiments in the (Table 3). The mean values of each element were shown and the rankings were based on their mean values. To put it another way, the higher the rank, the higher the mean value. The mean (Table 3) ranges from 3.7857 to 3.2143, with the circumstances of the Windows Frames in the roof accounting for the greatest mean value (3.7857) and the conditions of Hand Driers accounting for the lowest mean value (3.2143). The mean and standard deviation for the entire group were 67.6and 15.8, respectively. The standard deviation value gives you an indication of how scores are distributed around the average mean. The lower the standard deviation, the closer the score is to the average. As a result, the average standard deviation of washroom conditions ranging from (0.8601) to (0.7726) is fairly close to the average.

Table 3: The Condition of Washrooms in Hospital Buildings for the Users

Condition	Mean	Std. Deviation	Rank
Hand driers	3.2143	0.7726	1
Water Closet	3.3571	0.8113	2
Water Taps	3.3571	0.8112	3
Doors Locks	3.4286	1.0498	4
Plumbing (Pipes) Signage	3.5000	0.6268	5
Floors condition	3.5000	0.9063	6
Wash Basins	3.5000	0.8238	7
Floors (Floor Tiles / Floor Finishes)	3.5714	0.8207	8
Columns (Finishes / Painting)	3.5714	0.7284	9
Walls (Finishes / Painting)	3.5714	0.7284	10
Doors	3.5714	0.8206	11
Ventilators	3.5714	1.0498	12
Lighting bulbs	3.5714	0.8207	13
Lamps Ceilings	3.6429	0.7178	14
Workable alarm bells	3.6429	1.0425	15
Cleanliness of the washrooms	3.7142	0.6999	16
Windows Handles	3.7143	0.9583	17
Beams	3.7857	0.7726	18
Windows Frames	3.7857	0.8601	19

12. Discussion

(Table 3) depicts above showed the washrooms conditions as recorded for hospital building. The illustrations explain for that; mean±1 standard deviation (SD) is 70%, mean±2 standard deviations are 95% or mean±3 standard deviation is 99%. If the percentage falls within the range of 70%, it shows that the washrooms conditions is slightly comfortable, If the percentage falls within the range of 95%, it shows that washroom conditions is comfortable and If the percentage falls within the range of 99%, it shows that washroom conditions is very comfortable. The cumulative mean score of 67.6 and cumulative standard deviation 15.8. As the results illustrate, the washrooms conditions were slightly affected by defects for the ongoing findings assessments, based on the results of this findings it reveal that the washrooms conditions are slightly comfortable.

Other washrooms conditions detected in the building include cleanliness of the washrooms, windows handle and beams. From the data represented in the (Table 3), it is evident that the washrooms conditions indicated that, is was slightly comfortable, but this does not mean that it can be improved to avoid being deteriorated to bad state which can constitutes a core factor in the propagation of buildings conditions and subsequent depreciation of the building's components. Building users are often irritated by the absence of relevant maintenance services on the washrooms condition which was occupy. The collective types of building conditions for washroom include: defective floor of washroom, column of washroom, lamb ceilings, roof, floor tiles, floor finishes, beams external areas, windows handle external areas, window frames external areas, staircases, lamps, walls finishes, walls paintings as stated by (Ahzahar et al., 2011) and this obvious in the hospital buildings.

Moreover, mold, fungus, or termite, dry rot, wood rot, or vermin infestation can be as an effect of a building condition which could also deter the building and affect the performance. Ideally, maintenance services should be conducted periodically to ensure the continuous efficacy and productivity of the buildings conditions for all the users. Based on the results, good washroom conditions, proper wards, external areas and both roof and floor needs to be in good states, and are required in the hospital buildings.

Interestingly, the users of the hospital buildings indicated that the workers thought the knowledge that some maintenance staff had acquired on the job was insufficient to handle conditions of washrooms and maintenance works. Also, building management can be hampered by unreliable maintenance cost estimates which may include replaceable components, thus resulting in underfunding, opting for inferior materials, which ultimately leads to maintenance difficulties for this ongoing study. Apparently, defects in hospital buildings have an adverse effect on the conditions of the buildings especially washrooms, as it could lead to accident or disasters and procure higher cost of maintenance in the long run. This study recommends that the prevalence of defects such as defective floors (floor tiles / floor finishes), walls (finishes / painting), columns (finishes / painting), ventilators, doors, lighting bulbs, workable alarm bells and Lamps Ceilings amongst others must be guarded against in washrooms and buildings conditions (Salleh, et al. 2020).

The deferment of maintenance activities must be eschewed as this only exacerbates the conditions components of the buildings (washrooms conditions), which will continue to degenerate in functionality until the building endangers its users and residents or becomes uninhabitable (Tan, 2018). Thus, this finding reemphasizes the urgent need for the allocation of adequate funding to enable maintenance management groups to deliver quality services using competent professionals to address the problems for washrooms conditions. Nonetheless, the building conditions has some defects and safety hazards as its components were not too comfortable to the requisite standards. The conditions of buildings in particular can be judged in contradiction of the result the condition has, with adverse effect it will have on the building then the related facilities.

Therefore, the influence that defects have on the conditions of building if this is not well attended to, this will depend on how maintained it is and this will generate the factors with the nature of the defects, the user, the building integrity, needs and wants as well as the consecutive maintenance programme from the findings of (Olanrewaju et al., 2015), as shown in the hospital washrooms conditions above, this juxtapose accretion. The washrooms condition can be improved to ensure smoother movement and usability of the building, as well as efficient ventilation. Moreover, the maintenance workers demonstrated a desperate need for formal training to acquire the required skills as they were mostly unskilled. As previously mentioned, adequate funding should be made available to the maintenance management department to enable them deliver efficient maintenance services for the building conditions.

Conclusively, the causes of washrooms conditions decay in its state in which defects in the buildings also contributed notwithstanding Salleh, et al. 2020, Olanrewaju & Abdul Aziz 2014, Olanrewaju *et al*. 2018, the fact remains that they significantly deteriorate their quality and performances, diminish user satisfaction and prove extremely exorbitant to refurbish in the long run. Therefore, the proactiveness of the maintenance management department of the hospital buildings is crucial to ensure the efficiency of the buildings and preempt their irreparable decay.

6. Conclusions

This study evaluated the preliminary assessment of washrooms conditions of the hospital buildings in Malaysia and proffer practical solutions to alleviate the issue. The findings herein affirm the need to prioritize maintenance management and urges for the collaborative efforts of all the industry's stakeholders to adopt a proactive and holistic approach towards maintenance management in order to ensure that the hospital buildings conditions are in a good state, and be ready to face the challenges, so as to have morale and good motivation (Jesumoroti, C.& Draai, W., 2021a). In doing so, it is pertinent to tackle the unfavourable conditions challenges that arise due to the slight comfortable conditions of the washrooms using a systematic and planned approach rather than a corrective one. In this regard, it is vital to encourage and imbibe a preservative maintenance management culture by inspiring people to love and care for buildings, amenities and the environment.

Furthermore, if a buildings components conditions is only fixed when it reaches such a critical stage of squalor, the amount of work exceeds what would have been initially required and becomes even more cost intensive. Thus, relevant information and knowledge regarding washroom conditions can be utilized as a precaution to preempt failures before the occurrences and thereby curtail unnecessary expenditure due to unfavourable washrooms conditions. The washrooms conditions can be improved to achieve the desire services, which will be value added. Considering the fact, the onset of defective washroom condition in some buildings occur few years after they have been built, it is advisable to recognize that building components are vulnerable to change in state and initiate maintenance management from the onset. More importantly, instead of undervaluing maintenance management for washrooms conditions as an operational function, it must be prioritized as the paramount responsibility of top management who must include it in all its decision-making processes.

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ID 18

Production Planners' Scope of Action in the Context of Digital Twin Construction

Jhonattan G. Martinez [1], Timson Yeung [1], Rafael Sacks [1]

[1] Virtual Construction Laboratory (VClab), National Building Research Institute, Technion–Israel Institute of Technology, Haifa 3200003, Israel
jonattanm@campus.technion.ac.il

Abstract

Production planning in construction requires numerous agents, or production planners, to make operational decisions that affect the project outcomes. Decisions are based on information collected on the job site and in the project supply chain. However, difficulties accessing real-time information, the numerous production planners involved, and limitations on the planners' degree of freedom of action can hinder decision-making. Digital Twin Construction (DTC) has emerged as a paradigm for systems that increase the situational awareness of the construction project among production planners and reduce uncertainty in the decision-making process. Under the DTC frame, this research seeks to determine the scope of action of production planners. To accomplish the research goal, semi-structured interviews and a literature review were carried out to identify production planners' degree of freedom in decision-making when faced with the need for product or process changes. First, the research identifies the operational decisions that production planners make during a construction project in response to developments (as-built, as-performed information). Second, it presents a detailed analysis of production planners' main limitations during decision-making. Finally, the freedom of action of production planners was defined according to their roles. The findings are summarized in a matrix that associates operational decisions, degree of freedom, and professional roles in the context of DTC. The study results showed that production planners' scope of action is limited by the lack of real-time information concerning the construction project status and technical and legal limitations that affect their decision-making process.

Keywords

Digital Twin Construction (DTC), Production Planning, Production Planners, Scope of action, Building construction.

1. Introduction

Project planning performs a vital role in assisting stakeholders, sponsors, teams, and project managers in coordinating work through project phases. More specifically, planning pursues to identify desired goals, reduce risk and deliver a good quality product or service to the final customer. In construction, master planning is intended to determine the project activities and their logical relationships. Together with the project scheduling techniques, these processes establish the number of work packages and when each should be done.

Overall, production planning defines construction methods to be used, workers and material assignments, and elements' assembly sequence. This process is mainly conducted by production planners (individuals or groups) who decide what physical, specific work will be done in the next short-term planning window. Despite its importance, production planning faces several obstacles, including lack of information regarding construction project status, large numbers of actors or stakeholders involved in the short-term decision-making process, and production planners' limited freedom or scope of action. Scope of action in this sense refers to the range of changes that planners might make to the production system.

With the advent of new construction monitoring technologies, the construction industry has experimented with digitalization and integration of its process at all stages of the value chain (Forcael et al., 2020). Digital Twin Construction (DTC) is a new model for managing production in construction that leverages data streaming from various site monitoring technologies and artificially intelligent functions. Specifically, DTC provides accurate project status information and proactively analyzes and optimizes ongoing design, planning, and production (Sacks et al., 2020). DTC enables production planners to know the real-time status of everything happening on-site and throughout the supply chain. For instance, the current progress and quality of the work, recent locations of workers, equipment and materials, and safety conditions can be determined and evaluated. It is envisioned that DTC-derived real-time information will allow production planners to have better situational awareness and thus make better decisions. However, the quantity and nature of the information to be contained and shared through the DTC for operational level planning should be appropriate to support the types of operational decisions that production planners are able to make. Therefore, we require in-depth understanding of how production planners' scope of action affects the operational decisions in construction projects and thus the information they need.

Thus, this study sets out to understand production planners' operational decisions and limitations during a construction project and their scope of action under the DTC framework. To accomplish the study goals, semi-structured interviews and an in-depth literature review were performed to identify production planners' degree of freedom in decision-making when faced with the need for product or process changes. The findings were validated by an expert panel composed of planners from four European and American construction companies. The study results were summarized in a matrix that associates operational decisions, degree of freedom, and professional roles in the context of DTC.

2. Literature Review

2.1 Production planning in construction

Several decisions and actions are made in the construction domain based on the construction companies' expectations and goals. These decisions and actions can be categorized into two levels. From one side, administrative decisions are intended to determine the products and market the construction company will offer or act (Simu & Lidelöw, 2019). On the other hand, operational decisions frame how operations should be conducted to support the business strategy (Lidelöw & Simu, 2015). Lean construction is a typical example of an operational strategy. Lean construction is defined as a relationship-focused production management system that aims to eliminate waste from the entire construction process and deliver greater value to clients. Lean construction encourages accomplishing six principles to achieve the project goals successfully: (1) Identify the value from the customer point of view, (2) Define the value stream, (3) Eliminate waste, (4) Work to achieve smooth flow of work processes, (5) Implement Pull Planning and Scheduling, and (6) Strive for continuous improvement (Koskela et al., 2002). This approach uses various tools such as 5S, Concurrent engineering, Six Sigma, Poka-yoke, Kaizen, Kanban, and Last Planner System (LPS) to guarantee its proper implementation. At the production planning level, the LPS plays a vital role in the short-term decision-making process. The LPS process enables those who execute the work to make detailed work plans. It requires the team to review the plan near its execution specifically for collaborative planning to remove constraints and to verify that the promises made are tied to milestones and that these commitments are firm, timely, and unambiguous (Ballard, 2000). The LPS is characterized by the involvement of production planners in the decision-making process, specifically those who are required to implement short-term strategies to correct any project deviations (Salazar et al., 2020).

Various researchers have identified production planners' main actions and decisions during the course of a construction project according to lean construction and LPS principles. Pikas et al. (2012) studied different decisions that production planners make based on their perceptions of the state of readiness or maturity of the work. These decisions can result in abandoning (or stopping) the planned work or improvisation and making-do. Later, Lidelöw & Simu (2015) explored construction companies' emergent operations strategies and contrasted these with existing research on decision categories. The authors categorized the operational decisions according to lean construction principles: standardization, capacity/organization in projects, work environment, supply chain, human resources, continuous improvements, production planning, long-term perspective, process vs. project, and performance measurement.

More recently, Simu & Lidelöw (2019) investigated how the perception of operations strategy in construction practice aligns with existing theories of operations strategy. The research result showed that there are two alternative sets of operations strategies: (1) resource efficiency and (2) flow efficiency. Furthermore, the study found that standardization, supply chain, and organization are perceived as structural decision categories, and human resources, continuous improvements, long-term perspective, process vs. project, and performance management are perceived as infrastructural decision categories in construction. The aforementioned studies focused on defining possible decisions and actions that can be made according to construction companies' strategies and the production planners' perceptions. However, none of these studies established the production planners' scope of action and the limitations associated with their implementation.

2.2 Digital twins in construction

In construction projects, many actors, including production planners, are involved in making design and planning decisions that affect project outcomes. Decisions are made whenever planners determine that the current product designs or process plans can be improved upon. This may be in response to measured deviations from the designs or plans, or they may be proactive steps that result from a review of progress and performance to date. However, difficulties accessing real-time information, the numerous production planers involved, and limitations on the planners' degree of freedom of action can hinder decision-making. Thanks to the adaptation of Industry 4.0-derived technologies, several virtual and physical technologies are applied together to overcome these limitations (Forcael et al., 2020).

The Digital Twin (DT) concept has emerged over the past decade in domains such as manufacturing, production, and operations. A DT concept is defined as generating a visual and digital version of a physical object. The system could be a physical object, a social construct, or a biological system (Rosen et al., 2015). According to authors such as Tao et al. (2019), a DT has three main aspects or elements: the physical artifact, the virtual element, and the connections to bring both together. In the construction domain, a DT is a realistic digital representation of assets, processes or systems in the built or natural environment. The definition above blueprinted the creation of the Digital Twin Construction (DTC) paradigm. DTC is a novel mode for managing production in construction that uses data from various site monitoring technologies and artificially intelligent functions to provide accurate status information, enhance production planners' situational awareness, and support them using predictive analytics (Sacks et al., 2020).

Numerous researchers have explored the application of DTs in the AEC domain. Barazzetti et al. (2015) built a procedure for developing a detailed historical building information model (HBIM) using augmented reality (AR) and virtual reality (VR) to improve user community interest in cultural tourism. Gabor et al. (2016) applicated DT for online planning and presented an architectural framework focused on the information flow inside a cyber-physical system that includes the DT in a general and expandable way. The research implemented the analysis of the information flow between components of a smart cyber-physical system to the engineering process by defining a classification of different methods of controlling system behaviour with respect to the placement of said mechanisms inside the information flow. Alonso et al. (2019) created a platform with the ultimate goal of improving and optimizing buildings' energy design, construction, performance, and management, reducing construction costs and their environmental impact while increasing overall energy performance. Later, Boje et al. (2020) studied BIM applications during the construction stage and highlighted limits and requirements, paving the way to a DTC concept. Lu et al. (2020) implemented DT applications within the context of railway station buildings using a BIM-based simulation of construction work for King's Cross station in London. The research underlined the application and transformation of a 3D model of the King's Cross station building into a 6D building information model. The 6D model included a time and cost schedule with carbon emissions calculation and renovation assumptions.

More recently, Angjeliu et al. (2020) developed a method for creating an accurate digital model that combines the experimental physical reality and using it to study the structural response of the system, its preventive maintenance, and strengthening operations. More specifically, the research addressed the methodological development of structural simulation, analysis, and control models for historical buildings through the DT concept. Lu et al. (2020) performed a semi-automatic approach that establishes a systematic, accurate, and convenient DT system, integrating images and CAD drawings. Finally, Pan and Zhang (2021) developed a data-driven digital twin framework that integrates BIM, IoT, and data mining for advanced project management. The proposed solution was intended to facilitate data communication and exploration to better understand, predict, and optimize physical construction operations.

3. Research Methodology

This study aimed to determine production planners' scope of action in the context of DTC. A four-step process was implemented:

(1) Identification of the research problem and knowledge gap
(2) Develop and validate the data collection instrument
(3) Conduct the field study
(4) Systematize, analyze and validate the field study and literature review results

The following sections further discuss the four steps of the study.

3.1 Identification of the research problem and knowledge gap

During this step, an in-depth literature review related to production planning in construction, its challenges, methods and techniques, and production planning in the context of DTC was realized. Scientific articles and conference proceedings based on Web of Science and Scopus search engines were collected from the last 20 years, along with technical reports, books, and manuals on the indicated topics using the following keywords: production planning, production planning in construction, DTC, production planners' scope of action and production planners' degree of freedom. The results were summarized in the introduction and background sections.

3.2 Develop and validate the data collection instrument

A semi-structured interview was selected as the instrument for the data collection process. The interview template contained ten questions that aim to identify production planners' scope of action in decision-making when faced with the need for product or process changes. Aspects such as production planners' main decisions or actions performed to accomplish the project goals, their roles, limitations faced during the decision-making process, and the information required to take these decisions were covered in the interviews. The instrument was validated and adjusted through an expert panel, which verified its consistency and content. Table 1 presents the content and context of the instrument.

Table 3. Semi-structured interview questions.

N	Semi-structured interview questions	Context
Q1	Describe the main decisions or actions you perform to accomplish the construction project goals	Decision-making
Q2	Describe a situation or case in a construction project that required important decisions to be made to successfully achieve the project objectives.	Case study description
Q3	What decisions were made, and what changed in the production system? For example, did they add, reduce or remove resources (workers, subcontractors, equipment, materials); did they change the design in some way? Did they change something in the schedule or in the construction methods?	Decision-making
Q4	At which stage of the construction project were these decisions and changes implemented? What was the timeframe for their execution?	Case study background
Q5	Who were the main people responsible for making these decisions (owner, contractor, subcontractor, construction manager, project manager, other)?	Decision makers

Q6	Did you require authorization from other project stakeholders to take these decisions? Please explain what type of authorization you required	Authorization
Q7	Describe what types of information you needed to take the proposed decisions (plans, schedule, resources productivity rates, 3D model, budget, others).	Information requirement
Q8	Describe what project documents were modified or updated after the decision-making process.	Documents modified
Q9	Describe any limitations or constraints you faced during the decision-making process and how you dealt with them.	Decision-making limitations
Q10	Tell us about the KPIs you used to measure the feasibility of the decisions that were made and how often they were measured.	Decisions follow-up

3.2 Conduct the field study

In total,18 interviews (one-hour duration) were performed to gather information directly from production planners working in the AEC domain. Semi-structured interviews were implemented with various production planners, including site managers, project managers, foremen, and supervisors from Finland, Spain, Colombia, and Panama. It is important to mention that most of the interviewees had no prior knowledge of Lean Construction. This aspect mainly influenced the type of decisions or actions to achieve the project objectives that they proposed during the interviews. Table 2 presents the interviewees' countries of origin, their professional roles and the number of interviewees in each role.

Table 4. Number of interviewees by role and country of origin.

Interviewees' role / Country of origin	Foreman	Superintendent	Supervisor	Site manager	Project manager
Colombia	1	1		2	
Finland	1			3	
Panama	1		3	1	
Spain			1	3	1
Total	3	1	4	9	1

3.3 Systematize, analyze and validate the field study and literature review results

A qualitative approach was selected to analyze the field study results. First, the semi-structured interview results were consolidated in an Excel sheet for further analysis. Aspects such as type of project, interviewee role, location of the work (interior or exterior), nature of the problems they faced and their categories were helpful for structuring and examining the data. Second, the operational decisions made by the production planners during their construction projects were meticulously analyzed. Third, limitations that production planners faced during the decision-making process were stated. Finally, production planners' scope of action was derived and classified according to their roles and the operational decision types. The field study results were complemented with the literature review.

Production planners' degree of freedom in the process of making decisions or changes to the construction plan were categorized into three types, according to the number of actors involved and the time required to implement these decisions:

- High level decisions: require only the authorization from the site manager.
- Medium level decisions: require authorization from the site manager, project manager, and other field professionals (e.g., geotechnical engineer, structural engineer)
- Low level decisions: require authorization from several parties involved, such as the owner, project manager, site manager, and other field professionals.

An expert panel composed of planners from different European and American construction companies was formed to validate the field study and literature review results. The panel examined the tables of productions planners' operational decisions, limitations, and scope of actions according to their own previous experience on construction projects. Later, the expert panel confirmed most of the types of operational decisions stated in the tables. Finally, based on their previous experience in different construction projects, they helped refine the limitations and better define the production planners' scope of action.

4. Findings and Discussion

According to the field study results and the literature review, the main changes in the production system that production planners make during a construction project in response to developments can be categorized into two groups (see Table 3). The first group embodies decisions or actions that are made based on the conventional production model. In this model, the construction is viewed and modelled only as a series of conversion (value-adding) activities (Koskela1992). The second group embodies decisions that are made according to Lean construction principles to reduce waste and maximize customer value.

Table 5. Changes in the production system

Conventional production model	Lean construction principles
• Increase, reduce, or re-allocate resources (labor, material, and machinery)	• Standardize construction activities to reduce waste and enhance the flow of work,
• Change the original design	• Divide the jobsite into locations for measuring its performance (location-based method)
• Hire additional and/or replace subcontractors into the project	• Reduce the batch size in order to decrease the work-in-progress (WIP)
• Reschedule some construction activities	• Balance the capacity of the resources (labor and machinery) to minimize the non-value-added time
• Modify construction methods	

Production planners claimed that the resource management during the project corresponds to an operational decision that needs to be addressed during the construction phase. This decision can be oriented to adding, reducing, or re-allocating labor, material, and machinery. Another decision is derived from the need to change some aspects of the original design. This decision might involve changes in the production system and project supply chain. Comparable to the resource management decision, incorporating new subcontractors into the project could lead to changes in the production planning process, and more particularly, changes associated with the resource allocations and project duration. Rescheduling or standardizing construction activities also induces changes in the production planning process. According to the study results, this decision is mainly implemented to optimize the production flow and reduce the non-value-added time. Reducing the batch size or balancing the resource capacity are changes intended to minimize the work-in-progress and enhance the construction flow. Finally, modifying construction methods is a reiterative decision during the construction phase. It involves a change in the product and process that implies selecting the most suitable construction methods and then adjusting project resources and restructuring the project schedule.

Concerning the production planners' degree of freedom, planners involved in structural and interior work required diverse authorization levels to make decisions that may affect the project cost and duration. More specifically, decisions requiring design changes demanded a higher level of approval when compared to those that required changes in the construction method and resource modifications. For instance, modifications in the original design led to requesting the owner's approval, hindering the production planners' scope of action. On the other hand, changes in construction methods or rescheduling construction activities needed consent from site managers and other field professionals. Decisions of the latter type required less time for their authorization.

The primary limitations that affected production planners' decision-making were:

(1) lack of information concerning the current status of both interior and structural work.
(2) absence of real-time information about subcontractors' states (productivity rates, number of workers by crew and subcontractor, workers' locations, and subcontractor schedules),
(3) excessive number of people participating in the decision-making process (long chains of command),
(4) legal limitations with regards to the scope of the subcontractors' assignments, and
(5) technical limitations that hindered the implementation of the proposed solution (sch as materials specifications and preliminaries studies).

The abovementioned limitations indicate that the insufficiency of real-time information with respect to the construction project status and resources' performance highly affects production planners' decision-making process. Indeed, production planners stated that the lack of information related to resources' productivity rates, construction site's current progress, and resource locations affected their response to any change in the production system. On the other hand, technical and legal limitations also influenced the production planners' scope of action. These limitations primarily influenced the project time and resources required to implement the proposed changes.

Regarding the information requirements for implementing the proposed changes, plans and schedules were the most frequent data sources employed, especially in exterior work. In the case of interior work, resources' productivity rates were repeatedly used together with schedules. For instance, productivity rates were mainly used for assigning work crews to certain activities depending on their skills. Production planners also relied heavily upon key performance indicators (KPIs) which represented the project cost and duration. The majority of the proposed changes were assessed by comparing the actual costs and durations against the planned ones. In most cases, production planners could not determine the root causes of delays and cost overruns for each proposed change in the production system. Nevertheless, some production planners, especially those associated with structural work, implemented KPIs related to resource productivity, allowing their optimization and continuous improvement. For interior work, various production planners computed the number of defects observed during the finishing work. More precisely, they compared the number of defects identified and fixed by each crew to determine non-conformities per trade crew.

In general terms, the production planners' scope of action was mainly influenced by the availability of real-time information, the predicted impact of the decision on the project cost and duration, and the level of authorization required for implementing the changes. In most cases, site managers were responsible for making decisions during the course of the project. They primarily participated in decisions associated with operational changes that did not require design modifications, such as incorporating, reducing, or re-allocating resources (labor, material, and machinery), rescheduling construction activities, and incorporating new subcontractors. For decisions that required changes to the construction methods, the site manager needed the project manager and other field professionals' consent. For design changes, more stakeholders participated during the decision-making process. Depending on the project cost and duration impact, the owner's representative, external stakeholders (community or public institutions), and other field professionals (e.g., geotechnical engineer, structural engineer, and electromechanical engineer) participated in the design approval process.

The research findings might leverage the use of DTC-derived project status information by defining the production planners' scope of action. More specifically, DTC streams real-time information from the construction project that might be useful for production planners to make short and medium-term operational decisions. However, the literature has not yet defined the primary user of this information, what changes are possible in the production system, and what information is required to implement the actions. To depict these requirements, the following matrix (Table 4) associates operational decisions, production planners' roles, and their scope of action with the information requirements to make short and medium-term operational decisions. In the first column, the operational decisions defined through the field studies are stated. For each operational decision, actors involved during the decision-making process are established together with their degree of freedom. Then, KPIs implemented to assess the proposed solution are defined and the information requirements are associated with each operational decision.

5. Conclusions and Further Research

This study aimed to determine production planners' scope of action in the context of DTC. First a literature review and eighteen semi-structured interviews were carried out with the aim of understanding the operational decisions that production planners make during the course of construction projects. Second, an expert validated the tables of productions planners' operational decisions, limitations, and scope of actions according to their own previous experience on construction projects. Finally, the findings were condensed in a matrix that associates operational decisions, degree of freedom, and professional roles in the context of DTC.

The result showed that production planners' decisions and actions to accomplish the project goals could be categorized into two groups: decisions implemented according to the traditional transformation model in construction and decisions made according to lean construction principles. Both types of decisions are limited by the lack of real-time information concerning the construction project status and technical and legal limitations that influence the production planners' scope of action. In most cases, production planners used KPIs to measure the proposed actions by comparing the actual costs and durations against the planned ones. However, this is seen as insufficient, especially for Lean construction-derived decisions. Finally, the information requirements change due to the decision type and the number of stakeholders involved. For example, for design changes, a large amount of information is required to justify the feasibility of the change. Instead, to balance resource capacity and minimize WIP, only the project schedule was required.

This research has some limitations that need to be stated explicitly. First, the number of semi-structured interviews was limited to only eighteen. Further studies need to be conducted with more production planners of different countries and companies to contrast the result obtained. Finally, the production planners' scope of action matrix did not incorporate a time scale that allows decision-makers to understand the time required for implementing the proposed solutions. Future research needs to be carried out for incorporating temporal relevance into the constructed matrix to associate timescale with the identified actions.

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Table 6. Production planners' scope of action matrix

		Decision makers								KPIs used									Information requirements					
		Foreman	**Superintendent**	**Site manager**	**Project manager**	**Other filed professionals**	**Owner representative**	**Owner**	**Others stakeholders**	**Activity total cost**	**Activity total duration**	**Labor productivity rate**	**Machinery productivity rate**	**Labor utilization rate (per crew)**	**Machinery utilization rate**	**Non-value-added time**	**Work-in progress (WIP)**	**Cycle time**	**Plans**	**Budget**	**Schedule**	**Technical specifications**	**Contract**	**Production planners' degree of freedom**
1	Increase, reduce, or re-allocate resources (labor, material, and machinery)	X	X	X						✓	✓	✓	✓	✓	✓					☑	☑			High
2	Change the original design			X	X	X	X		X	✓	✓	✓	✓						☑	☑	☑		☑	Low
3	Hire additional and/or replace subcontractors into the project			X	X					✓	✓	✓	✓							☑	☑			Medium
4	Reschedule some construction activities		X	X						✓	✓	✓	✓	✓	✓						☑			High
5	Modify construction methods			X	X	X				✓	✓	✓	✓							☑	☑	☑		Medium
6	Standardize the construction activities to reduce waste and enhance the flow of activities.			X						✓	✓	✓	✓	✓	✓	✓	✓	✓		☑	☑	☑		High
7	Divide the jobsite into locations for measuring its performance (location-based method)			X	X					✓	✓	✓	✓	✓	✓	✓	✓	✓	☑		☑			High
8	Reduce the batch size in order to decrease the work-in-progress (WIP)	X		X						✓	✓						✓	✓			☑			High
9	Balance the capacity of the resources (labor and machinery) to minimize the non-value added time	X		X								✓	✓	✓	✓	✓		✓			☑			High

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ID 19

An Experimental Investigation on Strength Characteristics of Concrete Using Wastepaper Sludge Ash (WPSA)

Tariq Umar[1], Abdullah Tahir[2], Nnedinma Umeokafor[3], Amalka Nawarathna[4], Asad Zia[5] Mohamed shaik Honnur Vali[6]

[1,4]University of the West of England, Bristol, UK
[2]Habib Rafiq pvt Ltd, Islamabad, Pakistan
[3]Liverpool John Moores University, Liverpool, UK
[5]Zhengzhou university, Zhengzhou, China; Slovak University of Technology Bratislava Slovakia
[6]A'Sharqiyah University, Oman
tariqumar1984@gmail.com

Abstract
This study explores an experimental investigation in finding the strength characteristics of the concrete made with the addition of (WPSA) as a cementious material. The WPSA has some sort of pozzolanic properties and is high in silica, magnesium and low in calcium. Due to silica and magnesium content, it behaves like cement, and they also increase its setting time. The properties of concrete investigated where compressive strength, flexural strength, split tensile strength, slump test and water absorption test while WPSA was added in different percentages from 0 % to 40 %. The maximum coarse aggregate size used is 20mm.The M30 grade of concrete is designed using British Standard of mix design. The cubes of 150x150x150 mm were casted for the compressive strength test, cylinders of 150x300 mm were casted for split tensile strength test and beams of 100x100x500 mm were casted for the flexural strength test. All the specimens were placed in the water and then tested in the 7, 14 and 28 days. The WPSA concrete has some better mechanical and durability properties as compared to normal concrete. The compressive strength of the concrete was increased by adding 30 % of WPSA. The results further indicates that the split tensile strength and flexural strength of the same samples don't increase. Overall, the addition of WPSA to a minimum of 30 % as a replacement of cement is helpful in increasing the strength value which is helpful in reducing the CO2 emission from the construction industry.

Keywords
Cement, Concrete, WPSA, Compressive strength, Construction Industry.

1. Introduction

The most broadly utilized construction products in the world is concrete (Umar et al., 2020). It is the blend of cement, coarse aggregate, fine aggregate, sand, and water. On one side it is the backbone of the construction industry, but on the other side is the biggest polluter of the environment. The production and use of cement are having many harmful environmental impacts (Akan et al., 2017). The manufacturing of one ton of cement results in the emission of roughly one ton of CO_2 and also emits SO_2 (Umar et al., 2021). One ton of cement production consume approximately 90-150 KWT energy (Ahmad et al., 2013). Thus, the cost of the construction materials becomes very much expensive (Umar, 2020). All these factors contribute to the idea of replacement of waste supplementary materials which can be mixed with the concrete either fully or partially and increase the quality and strength of concrete while reducing the cost. This will help to save the resources and to avoid the environmental degradation.

The developed nations are already implementing the precautions and procedures to eliminate or to minimize the sources which are degrading the environment and are taking steps to use the sustainable energy sources. But in some developing countries this problem is having a huge impact and still they are not doing enough to solve the problem (Umar et al., 2020). China and India are already the world's leading producer of cement and are expected to increase their production within few decades and are the leading environmental polluter in the world (Statista, 2021).

As the world's cement demand is increasing it is estimated to be double in the next 30 years (Umar et al., 2021). By using SCM (supplementary cementitious materials) in place of a fractional replacement with the cement in concrete (Bai et al., 2003; Senthamarai and Manoharan, 2005). We can easily meet our required cement demand and there will be the reduction of energy, CO2 emissions, resource consumption having no harmful environmental impacts and no emission of the greenhouse gases. An additional environmental benefit is that the most used SCM e.g., hypo sludge, fly ash, silica fume are waste products which would otherwise dump in landfills (Umar 2021).

The production of paper generates enormous amount of solid waste which is also known as wastepaper sludge. This paper sludge is then dumped in landfills every year and is a major contributor to air pollution and is a health hazard (Simpson and Zimmie, 2005) It also poses a serious economic and environmental threat to the paper manufacturing companies (Solanki and Pitroda, 2012). Basically, it is a byproduct of the re-pulping and de-inking of the paper, and this waste is dumped because it has no use. It is also used as a land-spreading as agricultural fertilizer, burned in the Combined Heat and Power (CHP) plants at the paper mills. But the most common method is disposal to landfill. It consists of calcium carbonate, China clay and cellulose fibers and contains maximum of 40% moisture content- (Sobol et al., 2020). Physically the material is viscous, sticky and its texture ranges from hard to dry, viscosity to lumpiness. Paper sludge is classified as Class 2 liquid alternative fuels (CEMBUREAU, 2021; Ahmad et al., 2013). It is burned at about 800°C and the remaining fly ash which consists of the same properties of the Portland cement e.g., reactive silica and alumina (in the form of Metakoline) as well as lime (CaO). By utilizing these industrial wastes, we can develop a low-cost concrete and also the pollution problems will also be reduced. The inclusion of SCM in the concrete comes with additional benefits such as the energy consumed in the cement production will be saved, low cost, development in the engineering properties of the cement and the preservation of the environment. Every materials resilience is interconnected with the chemical, physical, and mineralogical and penetrability properties of materials thus the enhancement in these properties is expected to increase the strength characteristics of the materials.

The pozzolanic materials are those siliceous and aluminous materials which chemically reacts with the lime (calcium hydroxide) in the presence of water at the usual temperature to form composites which consists of cementitious properties. Consequently, the addition of pozzolanic materials to the concrete results in the additional improvement of the concrete quality and in its durability **(**Dunster, 2007). The WPSA is very high in calcium chloride and also contains minimum amounts of silica and some other pozzolanic materials. The blending of WPSA with the cement in the presence of the water results in the chemical reaction between Calcium Hydroxide (Ca (OH)2) with the hydrated Portland cement which in results produce Calcium Silicate Hydrate (C-S-H) (Garcés et al., 2008).

Paper sludge ash is in this manner possibly appropriate as a fixing ingredient in the cement kiln feed contributing calcium, silica and alumina. The next section explains the research approach adopted in this research project.

2. Methodology

This research aims to use WPSA powder in concrete and to see its performance (compressive strength) at 7,14 and 28 days. The concrete mix used in this research was M 30 which was made with different percentage of paper waste (0%, 10%, 20%, 30% and 40%). The description of materials used in this work is given as under:

2.1. Ordinary Portland cement (OPC)

The Portland cement (PC) which has been manufactured by the Lafarge Cement UK in accordance with BS EN 197-1, 2000, is used in the following investigation. The used cement is 53 grade OPC, the specific gravity is 3.15 and the initial setting time is 30 min (BS EN 197-1:2000, 2000).

2.2. WPSA

The Hypo sludge used in the experiment was obtained from University of South Wales Laboratory. The specific gravity of hypo sludge is found to be 2.17. The chemical composition of cement and hypo sludge is shown in Table.1.

Table: 1 Chemical Composition of hypo sludge and cement

No	Chemical composition	Cement (in %)	Hypo Sludge (in %)
1	Lime (Ca O)	62	46.2
2	Silica (SiO2)	22	9
3	Alumina	5	3.6
4	Magnesium	1	3.33
5	Calcium sulphate	4	4.05

2.3 Coarse Aggregates

In this experiment the coarse aggregate of crushed granite of 20 mm has been used and having specific gravity of 2. 82. All the physical properties e.g., specific gravity, gradation and fineness modulus are tested in accordance with British standard.

2.4. Fine Aggregates

In this experiment we have used manufactured sand having specific gravity of 2.62. All the physical properties e.g., specific gravity, gradation and fineness modulus are tested in accordance with British standard.

2.5. Water

The normal drinking water is used for the experimentation purpose especially for making of the concrete and curing procedure. The water which is clean and free from harmful Impurities e.g., acid, alkali, oil etc. should be used.
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3. Laboratory Experiment

The experimental program consisted of casting and testing of 50 cubes, 10 cylinders and 5 beams. The aim was to determine the mechanical properties like compressive strength, split tensile strength, flexural strength, and water absorption test respectively for M30/ C 25/30 grade of concrete at different replacement level of cement. The details of the specimens casted are shown in table 2.

Table 2. Details of specimens cast

Sr. No.	Grade of Concrete	Type of Concrete	% Of WPSA	No. of cubes cast 150x150x150mm	No. of cylinders cast 150x300mm	No. of beams cast 150x500mm
1	M30	without WPSA	0%	14	2	1
		with WPSA	10%	9	2	1
			20%	9	2	1
			30%	9	2	1

	40%	9	2	1
Total		50	10	5

The cement used in this experimentation is OPC. The water cement ratio is 0.6. All the specimens are prepared accordingly with BS EN 12350-2:2009 (2009) and BS EN 12350-4:2009 (2009). For the compressive strength test we have casted 45 cubes of 150x150x150mm dimensions (BS 1881-116:1983, 1983). For the split tensile strength test 10 cylinders of 150x300mm dimensions were casted. 5 beams of the 150x500mm dimensions were casted for checking the flexural strength. Finally, 5 more cubes were casted for the water absorption test. After casting and molding all specimens are then placed in water tank for curing for 7, 14 and 28 days respectively at a temperature of 27±2°C. After 7 days the 15 cubes specimens were removed from the water and tested for their compressive strength. The next cubes were tested on 14 days and then finally on 28 days all the remaining cubes, cylinders and beams were tested for their compressive, tensile and flexural strength properties. The specimens were also placed in the oven for 24 hours at 110°C to check the water absorption of the cubes.
A mix of M30 grade was prepared in accordance with the British standard (BS EN 206:2013+A2:2021 (2021). The mix proportion design is shown in below table (table 3).

Table 3. Mix Proportions

Paper Sludge Ash %	w/c ratio	Water (Kg/m3)	Cement (Kg/m3)	Fine Aggregate (Kg/m3)	Paper Sludge Ash (Kg/m3)	Coarse Aggregate (Kg/m3)	Slump (mm)
0	0.6	4.2	7	14	0.00	28	135
10	0.6	4.2	6.3	14	0.7	28	80
20	0.6	4.2	5.6	14	1.4	28	60
30	0.6	4.2	4.9	14	2.1	28	25
40	0.6	4.2	4.2	14	2.8	28	15

4. Test Results and Discussion

4.1 Compressive strength test

The compressive strength test results for the 7th, 14th and 28th days are presented in table 4. The average compressive strength value for the normal conventional concrete without any replacement of WPSA is 17.52 N/mm2, for the 7th day 21.30 N/mm2 for the 14th day and 27.55 N/mm2 for the final 28 days. For the second mix, with 10 % replacement with WPSA the values for the 7, 14, 28 days are 21.50, 24.44, 32.06 N/mm2 respectively.

Table 4. Compressive strength test results

S.NO.	% ADDITION OF WPSA	Average Compressive Strength (fck) N/mm2		
		7th day	14th day	28th day
1	0	17.52	21.30	27.55
2	10	21.50	24.44	32.06
3	20	23.80	25.32	35.20
4	30	24.90	28.50	36.90
5	40	17.15	22.10	25.80

The 3rd mix having 20 % WPSA replacement, its value comes out to be 23.80, 25.32, and 35.20 showing increase in the value from the previous one. For the 4th mix the average compressive values are very high as compared with all other mixtures and are 24.90, 28.50, 36.90 N/mm2 Finally for the 5th mix having 40 % replacement of WPSA the average compressive strength values starts decreasing and becomes 17.15, 22.10 and 25.80 N/mm2 respectively. The compressive strength increases when the percentage of WPSA is increased up to 30 percent (fig. 1). Further addition of WPSA results in the decreasing compressive strength values.

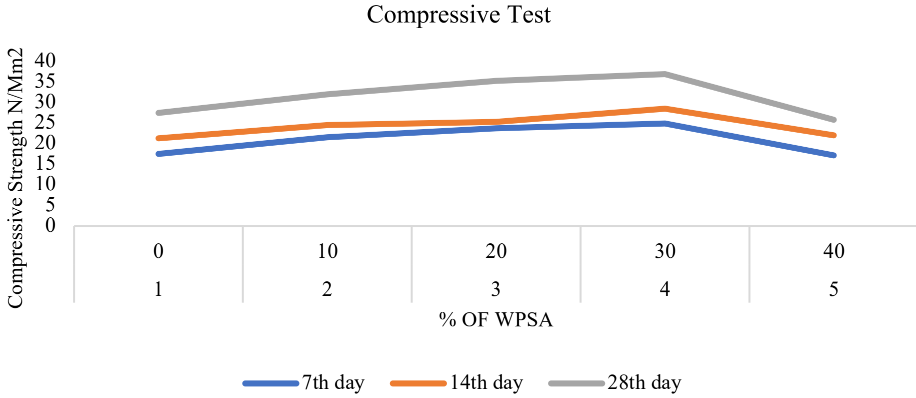

Fig. 1. Compressive Strength Test

4.2. Split Tensile Strength Test

The split tensile strength test results for various replacements of the WPSA are shown in fig. 2. The split tensile strength test was done on the cylinders. For each mix we had made two cylinders. The average value for the 1st cylinder having 0 percent replacement of WPSA is 3.117 (N/mm2), for the 2nd mix which contains 10 percent replacement of WPSA the value decreases and becomes 3.43 (N/mm2). similarly for the 3rd 4th and 5th mixes the values are constantly decreasing. All the tests were carried out for 28 days. From the above table it is noted that there is a continuous decrease in the values of the split tensile test as the WPSA replacement increases and also this decrease is also affected by the number of days in the water. Thus, we can't use WPSA for the tensile strength.

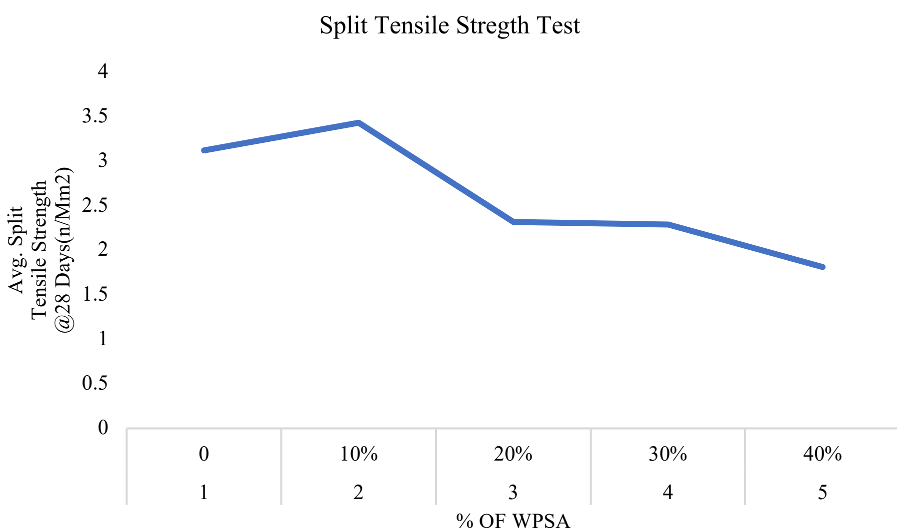

Fig. 2. Split Tensile Strength Test

4.3 Flexural Strength Test

The flexural strength test for different replacement level of WPSA is shown in fig. 3. From the results of flexural test, it is clearly shown that the strength for the 28 days is decreasing as the quantity of WPSA is increased. For the 0 percent WPSA replacement the strength is 3.62 (N/mm2), similarly for all other replacements of 10, 20, 30 and 40 % WPSA the values decrease as 3.27, 2.80, 2.57 and 2.38 (N/mm2) respectively.

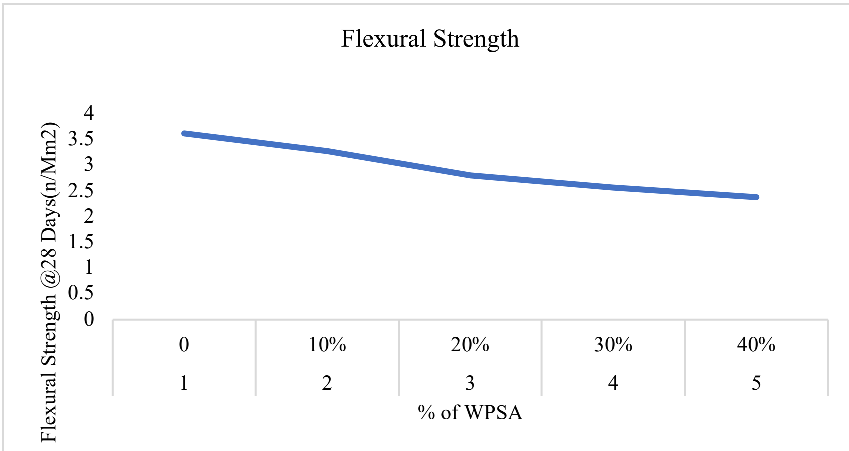

Fig. 3. Flexural Strength

4.4. Water absorption test

The water absorption test is done as per BS 1881-122. The cube specimens, after 28 days curing was evaluated and then are placed in the oven, dried for 24 hours at the temperature of 110°C. Then on the next day they were taken outside the oven and again weighed for the dry weight. Water Absorption Test results for cube specimens of size 150mm x 150mm x 150mm was shown in table 5.

Table 5. Water Absorption Test

Sr. No.	Paper Sludge Ash %	Dry weight of cube (gm)	Wet weight of cube (gm)	Water absorbed (gm)
1	0	2348	2475	127
2	10%	2334	2469	135
3	20%	2319	2457	138
4	30%	2209	2370	161
5	40%	2326	2462	136

The water absorption test shows that the more water is absorbed by increasing the percentage of paper sludge ash. For the 1st mix with 0 percent paper ash the water absorbed is 127 gm. For the 2nd mix having 10 % WPSA replacement the water absorbed is 137 gm. For the 3rd mix which consists of 20 % of WPSA replacement the absorb water is 138 gm. The 4th mix is having water absorption of 161 gm and the last mix have absorption of 136 gm which contains 30 and 40 percent paper ash respectively. From this result we can assume that as the paper ash percentage increases the water absorption also increases this is due to the fact that paper ash is very good in absorbing water at a faster rate and in huge quantities as compared with ordinary Portland cement. But one more thing to notice is that after 30 % paper ash replacement the specimens are unable to absorb more water so we can easily replace up to 30 percent wastepaper ash.

5. Conclusions

The main objective of this study was the utilization of WPSA as a supplementary cementious material (SCM) and to find out the strength characteristics of the materials. The present study is on the effect of the WPSA on the mechanical properties of the normal concrete. For the experimental investigation and analysis, we have conducted series of laboratory tests by adding different replacement levels of WPSA with concrete mixes to study and analysis the strength characteristics of paper pulp concrete. Based on our limited experiments the following conclusions are therefore drawn from this research:

1. The increase in WPSA content results in the decrease of slump values and the workability of the concrete mix decreases. The percentage of water absorption is also increased due to the absorbing capacity of Wastepaper sludge ash at a faster and quicker rate as compared with the normal ordinary Portland cement (OPC). Also, the slump flow diameter decreases due to water absorption.
2. The replacement of WPSA is done from 0% to 40% and it is concluded that with an increase in the percentage of the WPSA there is an increase in the compressive strength value for up to 30 % and after that if we go on increasing to 40%and 50% then the compressive strength suddenly started to decrease. The maximum compressive strength which is achieved at 30 % replacement for the 28 days is 36.90 $N/mm^{2.}$
3. The strength of concrete is unexpectedly decreased in the case with split tensile strength with all percentages of WPSA. Instead of increasing they are decreasing.
4. It is also observed that as the value of split tensile strength doesn't increase for any percentage of the replacement similarly following the trend the strength of the concrete even doesn't increase for the flexural strength but are continuously decreasing.
5. The presence of low silica content in the chemical composition of the WPSA is mainly responsible for decrease in the compressive, tensile and flexural strengths results.
6. The implementation of WPSA in the concrete is very economical because it will help in making low-cost concrete, cost of cement will also be reduced and also the waste sludge is a useless material having no use and is freely available at very enormous quantitites.it will also help the paper industries disposal costs.
7. The utilization of wastepaper sludge ash in the concrete will help a lot to totally eliminate the disposal problem of wastepaper sludge ash which is then dumped into landfills and pollute the environment.it can also protect the environment from the harmful pollutants and emission from the cement manufacturing industry. Thus, it proves to be very eco-friendly. The natural resources will also be saved by the usage of wastepaper sludge ash which would otherwise use into cement manufacturing.
8. As the cost of cement is decreasing the drawback is that at the same time the strength of concrete also decreases.
9. The average weight of the concrete decreases with an increase in wastepaper sludge ash content which results in making concrete very lightweight so it can be used for economic feasibility projects e.g., temporary shelters for people struck by natural disasters.
10. This research concludes that the wastepaper sludge ash can be used as an alternative supplementary cementious material, but engineers have to take very precise judgmental based decisions.

5.1. Recommendations for Future Work

Based on the limiting experimentation the following recommendations are drawn for future and further work:

1. The experimental procedure can be done by mixing WPSA with some silica admixtures, POFA (palm oil fuel ash) or any other pozzolanic materials.
2. The use of gypsum, lime and other materials at the place of cement.
3. The effect of other supplementary cementious materials like Metakaolin, blast furnace slag, ground granulated blast furnace slag, etc., on the strength and durability of paper waste concrete.
4. The specimens should also be placed in the acid (H_2SO_4 & HCL) to study acid durability factors.
5. The specimens to be tested for a greater number of days instead of 7, 14 and 28 days they can tested for 56 and 90 days.

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Effects of Employee Turnover on Employee Performance in the South African Construction Industry-A Review

Sally Chauke[1], Nokulunga Mashwama[2], Clinton Aigbavboa[3], and Wellington Thwala[4]

[3,4]SARChi in Sustainable Construction Management and Leadership in the Built Environment
[1,2]Department of Construction Management and Quantity Surveying
University of Johannesburg, South Africa
chaukesally1@gmail.com

Abstract
This study examines current literature on construction employee performance to identify the effects of employee turnover on employee performance. An employee's quality and characteristics are important attributes for success, for an organisation can't attain its goals and objectives without employees. The study is mainly a narrative review of the effects of employee turnover. The primary findings emanating from the study reveals that an organisation acquires cost when replacing employees who have left the organisation by training new employees. However, training must be carried out when there is a new employee to ensure that the new employee has the knowledge and expertise needed to perform work effectively. The study also identified loss of output, decreased business profitability, increased training cost of recruiting new employees, and deterioration in service quality as the effect of employee turnover on organisation performance and employee performance. The study pinpoints the effects of employee turnover on employee performance for policymakers to use the method for its minimisation.

Keywords
employee, employee performance, performance, effects of employee performance, employee turnover.

1. Introduction

International and local companies are faced with a challenge of employee turnover, which poses a more significant threat to the workforce industry and economic development (Alias et al., 2014). Due to economic, socio-cultural, and technological changes throughout the world, particularly in the employee markets, employee performance is affected, leading to a strain on organization operations. Several academics, authors and or/ researchers have put some effort into defining and conceptualizing turnover concerning employee performance in the construction industry or context. Turnover is arguably a process whereby many employees leave an organization in a certain period (Ali Suba'a Al-sadi, and Khan, 2018). Ngo-Henha (2017) defines employee turnover as a state where an employee stop being a member of an organization.

According to Arokiasamy (2013), it is defined as "entrance of new employees into the organization and the departure of existing employees from the organization" and described as the rate of hiring new recruitments replacing the employees who have resigned. Meaning that turnover is a rate at which a certain number of employees choose or are forced to leave the current organization to pursue better opportunities or unhappy with the current employer or liability as one is no longer adding value to company goals and objectives (Bilau, Ajagbe, Sholanke and Sani, 2015). To clearly understand the turnover concept, the different types of turnover need to be discussed.

In the case where turnover occurs due to restructuring the company, or the employee performance does not meet the company's set expectations. It can also be referred to as the trimming staff and downsizing (Iqbal, 2010; Panigrahi and Rout, 2020). While discharge turnover describes a process of relieving an individual employee of his or her duties based on unacceptable, unethical behavior and job performance problems. Furthermore, a downsizing turnover forms part of reduction based on economic restrains, reducing cost, creating a pool for suitable candidates, and maximizing profits. While voluntary turnover explains the situation where the employee chooses to quit, or turnover instances are initiated by employees' choice to leave the organization (Akinyomi, 2016). Arokiasamy (2013) state that voluntary turnover "An instance of voluntary turnover, or a quit, reflects employee's decision to leave an organization". Voluntary turnover is divided into avoidable and unavoidable turnover. Finally, the circumstances leading to a turnover are avoidable (Aman, 2015). An organization can prevent avoidable turnover by hiring, evaluating, and motivating its employees more efficiently (Arokiasamy 2013) while unavoidable turnover is caused by circumstances beyond an employer's control, such as an employee's death or disability due to tragedy or relocation (Arokiasamy 2013).

2. Research Methodology

The study was conducted as a systematic review with the aim of understanding on effects of employee turnover on employee performance. This study reviewed literatures on causes of employee turnover, effects of employee turnover on employee performance and the strategies for minimize employee turnover. The review of the literature was conducted from a collection of existing resources from the library, online journal articles, hard-copy journal articles, textbooks, theses/dissertations, and published conference papers on employee turnover globally. Retrieved literature include 24 publications in which there are 13 journal articles, 3 dissertation/thesis and 8 conference papers. The retrieved literature was limited to publications relating to the built environment only. Therefore, all studies carried out on other sectors were excluded from this study. The scope and focus of the retrieved literature are summarized in Tables 1 – 3.

Table 1. Courses of employee turnover

Courses	Description	Sources
Poor Remuneration	Poor remuneration is a significant cause of high employee turnover.	Akinyomi (2016), Mabindisa (2014)
Lack of Career Progression	When there are no career prospects in the organisation, employees’ turnover increases.	Akinyomi (2016), Mabindisa (2014), Mrope and Bangi (2014)
Poor Interrelationship between Employees and Management	poor interrelationship between employees and the management tends to lead employees to quit	Akinyomi (2016)
Job Dissatisfaction	employees with pre-eminent job satisfaction have a positive attitude towards the job, but those with negative attitudes are often absent.	Akinyomi (2016), Mabindisa (2014), Mrope and Bangi (2014), Ongori (2007) Mumba (2014)
Work Environment	The work environment should be hazard free and safe for the employee to work.	Mabindisa (2014), Aman (2015)

Table 2. Effects of employee turnover on performance

	Description	Sources
Effects of employee turnover on employee performance	Employee turnover creates greater chances of promotions from lower ranks, motivating employees and increasing organisational performance.	Mrope et al. (2014) Obiero, 2011) Ogony (2017) Akinyomi (2016) Ongori (2007), Bilau, Ajagbe, Sholanke, and Sani, (2015), Mabindisa (2014) Kwame et al. (2017)

Table 3. Strategies to minimize employee turnover

	Description	Sources
Strategies to minimize employee turnover	Employee training. effective leadership to guide and lead employees in all the activities they perform. Imperative to have effective communication with employees	Arokiasamy (2013), Aman (2015) Mabindisa (2014). Wilson (2018).

3. Discussion

An organisation acquires cost when replacing employees who have left the organisation by training new employees. Training must be carried out when a new employee can ensure that the new employee can effectively perform work. Employee turnover affects employee performance because they get interrupted daily work, leading to low employee performance. Employee turnover might increase absenteeism, damage employee morale, and make unnecessary mistakes due to high-stress levels. Loss of output decreased business profitability, increased training cost of recruiting new employees, and decreased service quality due to employee turnover on organisation performance and employee performance.

The literature review indicates that employee turnover is a major problem for organisations with a high cost. The literature review also reveals a positive and significant correlation between job satisfaction and employee turnover, but satisfied employees are also prone to turnover their job. If there is greater job stress, employees tend to leave their jobs, increasing employee turnover. According to Moshood, Adeleke, Nawanir, Sorooshian, and Ajibike (2021) employee turnover in the Malaysian construction industry is at a rate that is greater than 10%. While in the South African construction industry the employee turnover rate as high as 19% (Rijamampianina, 2015).

4. Conclusions

An employee is an important asset in an organization and very essential in performing the organizational process and in achieving the organizational goals and objectives. It is of great importance for organization in the construction industry and other industries to have a clear understanding of the effects of employee performance on has on employee turnover. Employee turnover is significant due to the adverse effects on the operation and the organizational performance. A high employee turnover rate may lead to an adverse effect on organizational profitability. Employee turnover affects employee performance because they get interrupted on their daily work performance, leading to low employee performance. When an employee is unhappy, unsatisfied with their job, they perform poorly and are more likely to leave the organization any chance they get.

Employee turnover has both negative and positive impact on the organisation. The positive effect includes new ideas and skills are introduced into the company, it opens up promotion channel for employees, it helps in reducing redundancy in the organization and it also helps in replacement of poor performers. And the negative effect involves; loss of skilled manpower, additional cost of replacement recruitment, poor quality of work and difficulties in attracting new staff affect the organization most. All the respondents agreed to the positive effects, but options were checked for the negative effects (Ampomah and Cudjor, 2015). This includes Additional costs of replacement recruitment, Poor quality of work, Difficulties in attracting new staff organization, Loss of skilled manpower (Al-Hamed 2015).

Furthermore, research is needed to be conducted on the effects of employee turnover on employee performance in the South African construction industry as there is not enough research done so far. Future research in the area of causes of employee turnover and the strategies to minimize employee turnover in the South African construction industry.

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ID 22

COVID-19 Vaccine Mandates in the Construction Industry

Michele Herrmann[1]

[1] Mississippi State University, Mississippi State MS 39762, USA
mherrmann@caad.msstate.edu

Abstract
In early 2020, Covid-19 became a global pandemic, the effects of which are ongoing. Economic impacts continue to be widespread, with an estimated economic loss of $8.5 trillion (United Nations, 2020). The construction industry has been impacted by Covid-19 in various ways. Using traditional legal research methodologies of searching primary and secondary legal resources, this paper explores the recent and developing policies related to Covid-19 vaccine mandates in the United States and their applicability in the construction industry. The Executive Order on Ensuring Adequate COVID Safety Protocols for Federal Contractors and the Occupational Safety and Health Administration's Emergency Temporary Standard applicable to employers with 100 or more employees will be analyzed and discussed. Relevant caselaw related to vaccine mandates and exemptions will also be analyzed and discussed. Legal challenges to these mandates are ongoing. Nevertheless, in deciding whether to require vaccines companies will need to weigh factors such as the type of projects the company undertakes, how best to protect their employees, and how to maintain their ability to obtain and deliver projects in the face of uncertainty about the future of Covid-19.

Keywords
Covid-19, Mandate, Vaccine

1. Introduction

In early 2020, Covid-19 became a global pandemic, the effects of which are ongoing. As of November 1, 2021 more than 246 million cases of Covid-10 have been confirmed (World Health Organization [WHO], 2021). As of said date, more than 4.9 million deaths have resulted from Covid-19 and more than 6.8 million vaccine doses have been administered worldwide (WHO, 2021). Economic impacts have been widespread and ongoing with an estimated economic loss of $8.5 trillion (United Nations, 2020).

The construction industry has been impacted by Covid-19 in various ways. Initially, the most significant impact came in the form of government-ordered shutdowns and stay at home orders. The United States construction law firm of Foley and Lardner, LLP collected information showing that as of April 17, 2020, 17 states suspended construction activity. Those states only offered limited exceptions for certain categories of projects deemed essential such as healthcare, infrastructure, and emergency repairs (Foley & Lardner, LLP [Foley], 2020). In the remaining states, all types of construction were deemed essential and therefore work was allowed to continue (Foley, 2020).

In locations where construction was allowed to continue, additional precautions were required. Those precautions included things such as daily screenings for symptoms, social distancing, masks, disinfecting and contact tracing (Centers for Disease Control and Prevention [CDC], 2020). In the context of construction, precautions such as social distancing can be difficult to implement because certain tasks require workers to be in closer proximity to each other. Additionally, productivity can be diminished when social distancing requirements result in fewer workers being able to be on site and fewer concurrent activities scheduled. Contact tracing presents challenges on job sites and beyond. For example, if one member of a crew tests positive for Covid-19, the entire crew may then need to isolate or quarantine for a period of time. Outbreaks can hinder progress on the job site and have also hindered productivity in the manufacturing of materials needed for construction. Since early in the pandemic, supply chain interruptions and material shortage have been an issue and continue to be so (Friesen, 2021).

2. Methods

This paper explores the recent and developing policies related to Covid-19 vaccine mandates in the United States and their applicability in the construction industry. Traditional legal research methodologies of searching primary and secondary legal resources were used to derive relevant principles of law. Those principals of law were then used to predict possible outcomes to legal challenges to vaccine mandates.

3. Results

3. 1 Covid-19 Vaccine Timeline

After Covid-19 was declared a public health emergency by the World Health Organization on February 1, 2020, the scientific community responded in record time. By December 2020, the United States Food and Drug Administration (FDA) issued Emergency Use Authorization (EUA) for the Covid-19 vaccine developed by Pfizer-BioNTech (Pfizer) (Immunization Action Coalition [IAC], 2021). One week later, also in December 2020, the FDA issued an EUA for the Covid-19 vaccine developed by Moderna (IAC, 2021). It subsequently issued an EUA for the Johnson and Johnson Covid-19 vaccine in February 27, 2021 (IAC, 2021). The EUAs were initially limited to adults age 16 and older with individual states establishing priority eligibility for the elderly, those with underlying illnesses, and those employed in occupations deemed high risk. The Pfizer vaccine received an EUA for adolescents 12-15 years of age in May, 2021 (IAC, 2021). In August, 2021 the Pfizer vaccine received full FDA approval for individuals 16 and older, while the EUA remains in effect for those aged 12-15 years (IAC, 2021). As of the time of submission of this paper, booster shots of the Pfizer and Moderna vaccinations are authorized for individuals 18 years of age and older under and emergency use authorization from the FDA (U.S. Food & Drug Administration (FDA), 2021).

5.2 Vaccine Mandates

In September 2021, the Biden Administration issued the Executive Order on Ensuring Adequate COVID Safety Protocols for Federal Contractors, Executive Order 14042 (White House, 2021-a). The Executive Order requires, among other things, that all employees of federal contractors and subcontractors either be fully vaccinated against Covid-19 or have a legal exemption from vaccination (White House, 2021-a). Legal exemptions will be discussed below. In the event the Executive Order is in conflict with a state or local law, the Executive Order governs (Franklin, et al., 2021). Ongoing legal challenges have resulted in the mandate being temporarily blocked in Kentucky, Ohio, and Tennessee, while remaining in effect in all other states (Franklin, et al., 2021).

In November 2021, the Biden Administration announced additional vaccine mandates. The first is a requirement that employers with 100 or more employees require that all employees be either fully vaccinated or tested for Covid-19 at least once per week (White House, 2021-b). As proposed, this requirement would apply regardless of whether a company conducts any business with the federal government or not. Exemptions from vaccination would not necessarily be required or at issue since testing is an acceptable alternative to vaccination. This mandate was enacted through the Department of Labor's Occupational Safety and Health Administration (OSHA), which is responsible for ensuring employers comply with requirements intended to prevent employees from being injured or acquiring illnesses while at work (White House, 2021-b). The mandate was enacted under an Emergency Temporary Standard (ETS), which is a temporary measure that can be used when a grave danger exists (Fisher & Phillips, 2021). The temporary implementation is then followed by a 45-day public comment period (OSHA, 2021). In the absence of a grave danger, the public comment period would precede enactment of a regulation (Fisher & Phillips, 2021). In response to legal challenges, the United States Court of Appeals for the Fifth Circuit – which covers Louisiana, Mississippi and Texas – ordered that OSHA temporarily take no action to implement nor enforce the mandate until the legal challenges have been resolved in court (OSHA, 2021). Similar challenges were filed in other districts and the issue will ultimately be decided by the Court of Appeals for the Sixth Circuit, which typically covers cases that arise in Ohio, Michigan, Tennessee, and Kentucky (Fisher & Phillips, 2021). The other mandate enacted in November 2021 related to the health care industry specifically, and is therefore not the focus of this paper.

Aside from Covid-19, vaccine mandates are well established in the United States. The Centers for Disease Control (CDC) recommends 16 vaccines between the age of birth and 18 years old (CDC, 2019). Some of those vaccines require multiple doses administered at specific ages and times. It is then up to each individual state to determine which vaccines are required to attend school (CDC, 2019). All 50 states and the District of Columbia currently require immunization for diptheria, tetanus, pertussis, polio, measles, rubella and chicken pox, at a minimum

(Desilver, 2021). Many states require additional vaccinations for diseases such as hepatitis B (46 out of 51 states) and meningitis (34 out of 51 states), among others (Desilver, 2021).

The Americans with Disabilities Act requires provision for exemptions based on medical reasons. The Civil Rights Act of 1964 (Title VII) requires provisions for exemptions based on religious reasons. Provisions for medical and/or religious exemptions vary from state to state. The Mississippi State Department of Health states that medical exemptions may be requested if certain criteria are met and "there is no local or statewide occurrence of disease such that the exemption would cause undue risk to the community." (Mississippi State Department of Health [MSDH], 2019). Even when a medical exemption is granted, children with medical exemptions may be excluded from attending school "if there is a threat of vaccine preventable diseases occurring in the community." (MSDH, 2019). The exclusion from school will continue until the threat to the child or other children is no longer present. (MSDH, 2019). Although Mississippi considers requests for medical exemptions, exemptions are not allowed under state law for "religious, philosophical, or conscientious reasons." (MSDH, 2019). Religious exemptions will be discussed in further detail in Section 3.3, below.

Beyond school-age children, additional vaccinations and/or booster vaccinations may be required to attend colleges and universities. Among adults, mandatory flu vaccinations have become common for those employed in health care and related fields. In response to a widespread flu season in prior years, in 2008 BJC Healthcare implemented a mandatory flu vaccine policy. Flu vaccinations rates jumped from a pre-mandate rate of 70% to 98.4% after the mandate (Diamond, 2020). Vaccination rates have since remained above 97% in subsequent years (Diamond, 2020). Additionally, BJC Healthcare noted that employees started to get vaccinated earlier in the flu season and the number of religious and medical exemption requests decreased (Diamond, 2020).

3.3 Relevant Case Law

The validity of vaccine mandates has been well established in the United States since the 1905 Supreme Court case of *Jacobson v. Massachusetts*. In that case, Jacobson was challenging the validity of a Massachusetts statute requiring vaccination against smallpox. The Supreme Court found that such a statute was within the broad police power of the state to safeguard public health and safety (*Jacobson v. Massachusetts*, 1905). In so doing, the court stated that the liberty afforded to individuals under the constitution "does not import an absolute right in each person to be, all times and in all circumstances, wholly freed from restraint. There are manifold restraints to which every person is necessarily subject for the common good." (*Jacobson v. Massachusetts* at 26, 1905). The court noted that the vaccine mandate was adopted at a time when smallpox was prevalent in Massachusetts, giving the state the right to "protect itself against an epidemic of disease which threatens the safety of its members." (*Jacobson v. Massachusetts* at 27, 1905). Regarding the safety and effectiveness of the smallpox vaccine, the Supreme Court cited the contemporaneous case of *Viemeister V. White*, in which the New York Court of Appeals stated "the common belief, however, is that is has a decided tendency to prevent the spread of this fearful disease and to render it less dangerous to those who contract it. While not accepted by all, it is accepted by the mass of the people, as well as by most members of the medical profession." (*Jacobson v. Massachusetts* at 34, 1905, citing *Viemeister v. White*, 1904).

Vaccine mandates have not been without challenges in more recent times. In the case of *Fallon v. Mercy Catholic Medical Center of Southeastern Pennsylvania*, Fallon's employment was terminated when he refused to be vaccinated for the flu after having sought and been denied a religious exemption. Fallon alleged that his termination constituted religious discrimination under Title VII of the Civil Rights Act of 1964 (*Fallon v. Mercy Catholic Medical Center*, 2017). While Fallon was able to establish that he had a sincere opposition to the vaccine and was subsequently terminated for failing to comply with the vaccine requirement, the case hinged on whether his opposition to the vaccine was a sincere religious belief (*Fallon v. Mercy Catholic Medical Center*, 2017). The court noted that both traditional and nontraditional faiths can be considered religious and "a belief in God or divine beings is not necessary" (*Fallon v. Mercy Catholic Medical Center* at 491, 2017). The court then referenced the three-part definition of religion established in *Africa v. Commonwealth of Pennsylvania*: "First, a religion addresses fundamental and ultimate questions having to do with deep and imponderable matters. Second, a religion is comprehensive in nature; it consists of a belief-system as opposed to an isolated teaching. Third, a religion can often be recognized by the presence of certain formal and external signs." (*Fallon v. Mercy Catholic Medical Center* at 491, 2017, citing *Africa v. Commonwealth of Pennsylvania* at 1032, 1981). Fallon's arguments failed to satisfy all three parts of the *Africa* test, with the court noting, among other reasons, that Fallon's stated objections to the vaccine related to potential side effects, which are medical beliefs, not religious reliefs (*Fallon v. Mercy Catholic Medical Center*, 2017).

4. Discussion

4.1 Executive Order on Ensuring Adequate COVID Safety Protocols for Federal Contractors

As of the date of submission, the Executive Order requiring federal contractors and subcontractors to require full vaccination or proof of a legal exemption is unambiguous and is likely subject to fewer successful legal challenges than the mandate for employers with 100 or more employees. Because the decision to enter into contracts with the federal government is optional and is considered to be a privilege for qualified contractors, the legal challenges to the Executive Order are less likely to be successful. The vaccine mandate could essentially be thought of as being similar to other prequalification criteria and other requirements for federal contracting, such as E-verification. Therefore, it is highly likely that construction companies that choose to enter into contracts with the federal government will be required to comply with the Executive Order after any legal challenges are resolved. After all, companies are not forced to enter into federal contracts. Contracting with the federal government is deemed a privilege, not a right, and can therefore be subject to conditions meant to protect the interests of the federal government. Therefore, companies that want to profit from federal projects should be prepared to comply with the Executive Order.

Companies may be hesitant to deny employee exemption requests out of concern that employees will file legal challenges. Those companies may therefore be tempted to be lenient in granting exemptions from the vaccine. However, documentation will be required and compliance checks should be expected. Similar to other federal contracting certifications and requirements, noncompliance would likely result in a range of possible consequences ranging from fines to being ineligible to enter into federal contracts in the future. As noted above in Section 3.3, religious exemptions must pass the *Africa* test, discussed above. Large companies are already taking different approaches to reviewing religious exemption requests. For example, employees at Tyson Foods, Inc. are reportedly only asked to complete an exemption request containing two questions (Cutter & Gryta, 2021). In contrast, employees at General Electric Co. and Amtrack are asked to complete much lengthier questionnaires, 13 and 31 questions respectively, that include questions about the nature and extent of their religious beliefs. For example, some questions ask whether the employee's religious beliefs prevent them from taking common medications such as Tylenol or Motrin, whether their religion prevents them from taking other precautions such as wearing a seatbelt, and whether the employee has tattoos or body piercings (Cutter & Gryta, 2021).

Those questions are intended to determine whether an employee's objection to the Covid-19 vaccine passes the *Africa* test. For example, if an employee has complied with all other mandatory vaccines without objection or seeking a religious exemption, what exactly is the nature of the religious exemption to the Covid-19 vaccine that did not apply to other vaccines? Similarly, if an employee has piercings, tattoos, and/or all other required vaccines but objects to the Covid-19 vaccine as an alteration of their body, why did that same religious belief not preclude the piercings, tattoos, and other vaccines?

4.2 Mandate for Employers with 100 or More Employees

The enforceability of the ETS requiring vaccination or testing for employers with 100 or more employees remains to be seen. As noted in *Jacobson v. Massacusetts*, vaccine mandates are typically the purview of health department of each state or local municipality. Similarly, at the federal level the CDC only makes recommendations regarding vaccines; it does not mandate them. It is up to each individual state to determine whether to require certain vaccinations. Nevertheless, Covid-19 has had catastrophic and ongoing health and economic impacts worldwide. Because this mandate is limited in context rather than a blanket nationwide mandate for all individuals, justification may be found for employment-related Covid vaccine mandates. Companies who are not subject to the Executive Order discussed above should still have contingency plans in place in case this OSHA-related mandate is upheld. If it is, compliance will be required. Noncompliance may result in citations and fines of more than thirteen thousand U.S. dollars per violation (Fisher & Phillips, 2021). It also seems possible that similar provisions may follow for employers with fewer than 100 employees.

A few important nuances apply specifically to the construction industry. It is worth noting that in the construction industry, each company on a jobsite is evaluated individually toward the 100-person threshold (Fisher & Phillips, 2021). A company with fewer than 100 employees would not be subject to the mandate simply by working on a jobsite that had more than 100 workers on site. Additionally, employees who work exclusively outdoors are counted in the number of employees to determine if the 100 employee threshold is met. If the company has more than 100 employees the ETS then applies, but employees who work exclusively outdoors do not need to show proof of vaccination or weekly testing (Fisher & Phillips, 2021). It is imperative that those employees at no time work indoors. OSHA specifically noted that holding a brief meeting indoors at the beginning of the day, such as a tool box talk, disqualifies an employee from being considered an outdoor employee (Fisher & Phillips, 2021). While adjustments could potentially be made to day-to-day operations to qualify some employees as outdoor employees that could get complicated under certain weather conditions and may not be possible at all for certain trades. Additionally, it remains to be seen how "outdoor" is defined for these purposes in terms of completion of the building. Is it once an overhead structure is in place, once exterior walls are sheathed, once the building is dried-in, etc.?

5. Conclusions

Vaccine mandates continue to be an ongoing development, as does Covid-19 itself. Each company will need to assess its needs and strategic goals as a company, as well as potential impacts on an already-strained workforce. Companies will need to consider not only their ability to obtain future work, but also their ability to deliver projects. Even companies that do not enter into federal contracts and do not meet the 100 employee threshold may consider strongly encouraging or requiring the Covid-19 vaccine to minimize risks to employee health as well as reduce disruptions and delays to projects. With a free vaccine readily available, it will become more difficult for companies to assert delay claims and request additional time to complete a project. While beyond the scope of this paper, it also remains to be seen whether and for how long health insurance providers will cover the cost of Covid testing and treatment for those who are unvaccinated who become ill.

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BIM Material Passport to Support Building Deconstruction and a Circular Economy

Musab Jamal Maraqa[1], Sabrina Spatari[1]

[1] Technion-Israel Institute of Technology, Haifa, Israel
musab_maraqa@hotmail.com
musab.maraqa@campus.technion.ac.il

Abstract
Advanced computational tools like building information modeling (BIM) have great potential for facilitating environmental life cycle evaluation of buildings, including their construction, to support circular material flows from new and end-of-life (EOL) buildings. Here we introduce a method and case study that combine BIM and material flow analysis (MFA) to define a material passport for a LEED-rated commercial building in Israel. The building was designed using "BIM in the big room", a product development technique in which designers of different sub-systems are brought together to promote communication, collaboration and short-cycle problem solving. Material passports use BIM to classify and quantify building objects by their material constituents to assess their potential for recycling at the building's demolition stage. The material passport can be combined with life cycle inventory data to evaluate the environmental impacts of the embodied material in the building and guide best practices for deconstruction. The BIM analysis shows a high mass of concrete (110, 000 ton) and glass curtain walls (27,000 m^2). The concrete can be recovered from the structural frame if dismantled. The glass curtain walls may also be recovered for reuse in other projects or recycled into new glass products.

Keywords
Building information modeling (BIM), Material passport, Life cycle assessment (LCA), construction and demolition waste (CDW), greenhouse gas (GHG).

1. Introduction

Rising populations in cities around the world are raising demand for continued infrastructure provision to meet housing needs, which incurs demand for natural resources. In addition, the construction industry is one of the most polluting industries in the world (EPA, 2009; UK-GBC, 2018; Li et al., 2019; Choi et al., 2019). Buildings are major consumers of energy and emitters of greenhouse gases, contributing to climate change during all life cycle stages. Worldwide, building construction and operation is responsible for 36% of global energy use and 39% of greenhouse gas emissions (GHGs) (IEA, 2018). While most of these figures relate to building operation, the construction stage also has a role to play in reducing energy use and mitigating climate change. According to the U.K. Green Building Council (UK-GBC, 2018), the construction industry uses more than 400 million tons of material per year, the majority of which has an adverse impact on the environment. For example, 60 million tons goes directly to landfill simply due to over-ordering, mis-ordering or poor handling and breakages. Moreover, the U.S. construction industry accounts for 160 million tons, or 26%, of non-industrial waste generation each year (EPA, 2009). It additionally contributes to 23% of air pollution emissions, 50% of GHGs , 40% of drinking water pollution and 50% of landfilled waste (Willmott Dixon Group, 2010).

In Israel, construction waste forms about 60% of the total solid waste. It consists mainly of concrete, steel reinforcement, steel sections, blocks, tiles, wood, plastic materials, gravel, and soil (Katz and Baum, 2011). The finishing phase in construction generates about three times more waste relative to the construction of the structural frame (Baum and Katz, 2004). The amount of construction waste exceeds 7 million tonnes each year (Gabay et al., 2014). This has raised the importance of possible management alternatives such as reusing and recycling construction and demolition materials along with more effective management of construction and demolition waste (CDW) and construction processes. Also, it raised the importance of implementing innovative management approaches like lean construction and BIM in reducing different types of construction wastes (Cheng et al., 2015; Maraqa et al., 2020; Maraqa et al., 2021; Maraqa et al., 2021).

There is a growing trend among governments, clients, design firms, and construction companies to recapture value from CDW. Several countries in Europe like Denmark, Holland, and Belgium recycle 80-90% of their construction wastes (Symonds et al., 1999). Unlike some European cities, Israel recycles about 20% only, with the remainder disposed in legal and illegal landfilling sites (Katz and Baum, 2011).

The material passport (MP) is a quantitative and qualitative documentation of the materials composition of a building, displaying materials embodied in buildings as well as showing their recycling potential and environmental impact, which in turn gives them value for recycling and reuse (Honic et al., 2019). In a nutshell, the MP can turn buildings into future "databanks" (BAMB, 2020; Heinrich and Lang, 2019; Rose and Stegemann, 2019).

Honic et al. (2019) demonstrated a proof of concept for a material passport on a residential building in Vienna. They evaluated two variants, variant in timber and variant in concrete. The assessment carried out for exterior walls, roof, ceilings and windows. The concrete variant consists of load bearing elements made of concrete, EPS insulation, windows with an aluminium frame and a plaster façade. The timber variant consists of load bearing elements made of cross laminated timber (CLT), the outside façade is wooden, and most of the building components consist of a wood fiber insulation and the windows have a wooden frame. They found that the total recycling potential of the concrete variant is 52% while the timber variant is 34%. However, if the total mass is taken into consideration the timber variant leads to a lower waste generation compared to the concrete variant. The timber variant is associated with 1123 tonnes of waste, while the concrete variant is associated with 1797 tonnes of waste. Also, they compared the life cycle assessment (LCA) results of the two variants and found that the timber variant has lower environmental impact than the concrete variant. The acidification potential (AP) and the primary energy intensity (PEI) metrics are three times higher in the concrete variant compared to the timber variant at year 0 (new building construction) and year 100 (building end-of-life).

The material passport research by Honic et al (2019) was executed on a hypothetical building, not on a real building relevant to buildings in Austria. There are several obstacles and challenges when applying these concepts to real buildings. One is the lack of detailed material composition in early design stages. Also, this work is limited to the design stage, and does not cover the construction and demolition phase, the latter of which is very critically connected to any future effort to recover materials from the building. Finally, while their case study is restricted to Austria, there are some challenges in generalizing the case so that it can be tested in other countries.

This paper aims to develop a BIM material passport for a LEED gold-rated commercial construction project in Tel Aviv. The material passport will help in identifying the different materials used in the construction project. Mass distribution within the building, the share of recyclable and waste materials, and the total amount of global warming potential (GWP), acidification potential (AP), and primary energy intensity (PEI) originating from the incorporated materials.

2. Methods

A case study research method is used to develop a material passport for a commercial building. It combines building information modelling (BIM) and material flow analysis (MFA) to define a material passport for a LEED-rated commercial building in Tel Aviv, Israel. The building was designed using "BIM in the big room", a product development technique in which designers of different sub-systems are brought together to promote communication, collaboration, and short-cycle problem-solving (Sacks et al., 2018). For this finished building, BIM in the big room involved architects and structural, mechanical, and electrical engineers collaborating to optimize the design of the building. Material passports use BIM to classify and quantify building objects by their material constituent to assess their potential for recycling at the building's demolition stage. The material passport can be combined with life cycle inventory data to evaluate the environmental impacts of the embodied material in the building and also guide best practices for deconstruction. Life cycle assessment following (ISO 14040/44, 2006) implemented to quantify GHGs, acidification potential (AP), and primary energy intensity (PEI) for each material. Stadel et al. (2011) outlined the potential for combining BIM and LCA tools. These concepts can be coupled with MFA tools as noted by Honic et al. (2019a) with the material passport. The main outcomes of the material passport are the mass distribution within the building, the share of recyclable and reusable material, and the total amount of GWP, AP, and PEI.

To evaluate the project's environmental effects, each element is modeled to the exact materials and dimensions using BIM. For each element, we allocated the recycling weight, life span, density, separability of materials layers, and accessibility for the materials. Data are required from the construction department in the company. The data includes all the architecture, structural, mechanical and electrical BIM models, material suppliers, the life span for each material, quantities of actual material delivered to the site, and the amount of waste delivered to the landfill during the construction phase (Figure 1). The materials covered in this study are concrete materials, HVAC ducts, firefighting pipes, HDPE pipes, concrete block, gypsum drywall, gypsum blocks, tile, system panel, aluminium mullion and glass. The reason for selecting these materials because they are available within the BIM model, we got from the company that constructed this project.

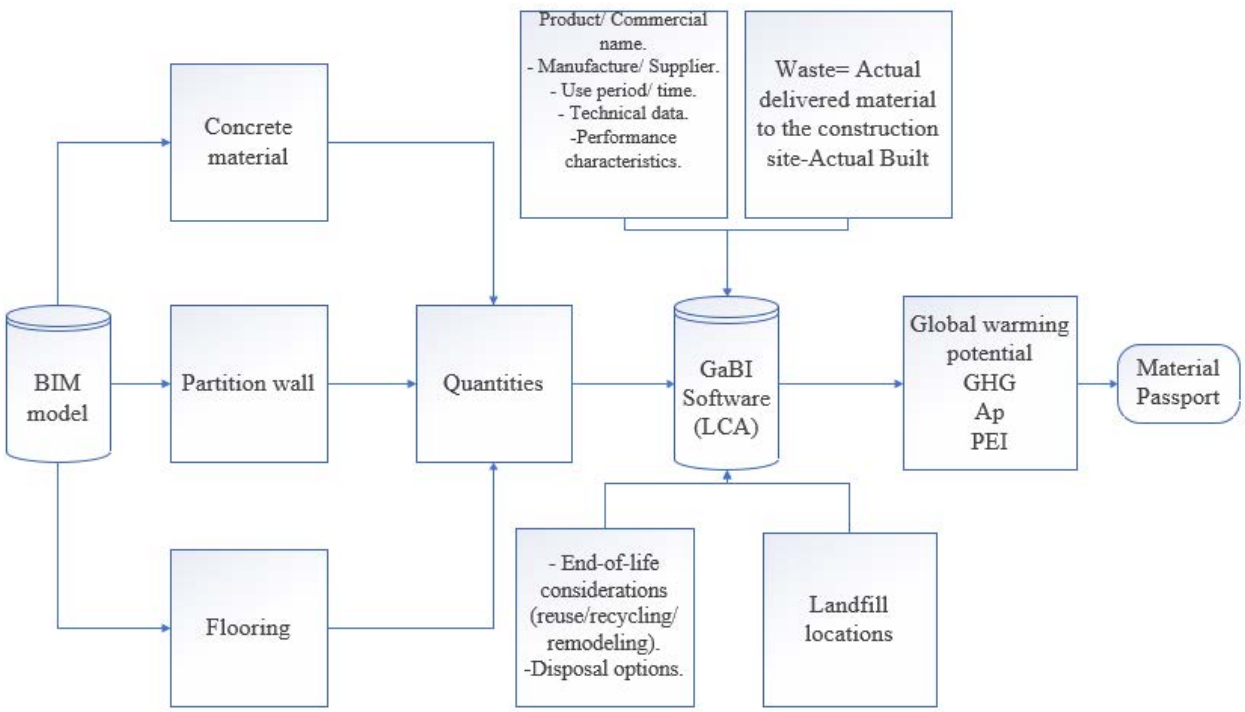

Figure 1. Methodology for the compilation of the Material Passport.

The functional unit in this project is defined as a square meter of built space of a commercial green LEED-Gold rated building with an approximate area of 50,000m2. The building consists of different materials like concrete, aluminum, glass, high-density polyethylene pipe (HDPE), concrete block, cast iron pipes, gypsum plasterboard, gypsum block, ceramic tiles, steel ducts, and steel cable trays.

LCA model was built using GaBi (PE-international 2012) which is a product system modelling developed by a Germany company called PE INTERNATIONAL. GaBi is considered as one of the leading software for building life cycle assessment models (Herrmann and Moltesen, 2014). In this study an LCA model includes all the materials and their quantities with the associated transportation (Figure 2). The transportation distance is assumed to be 30 km from the construction site.

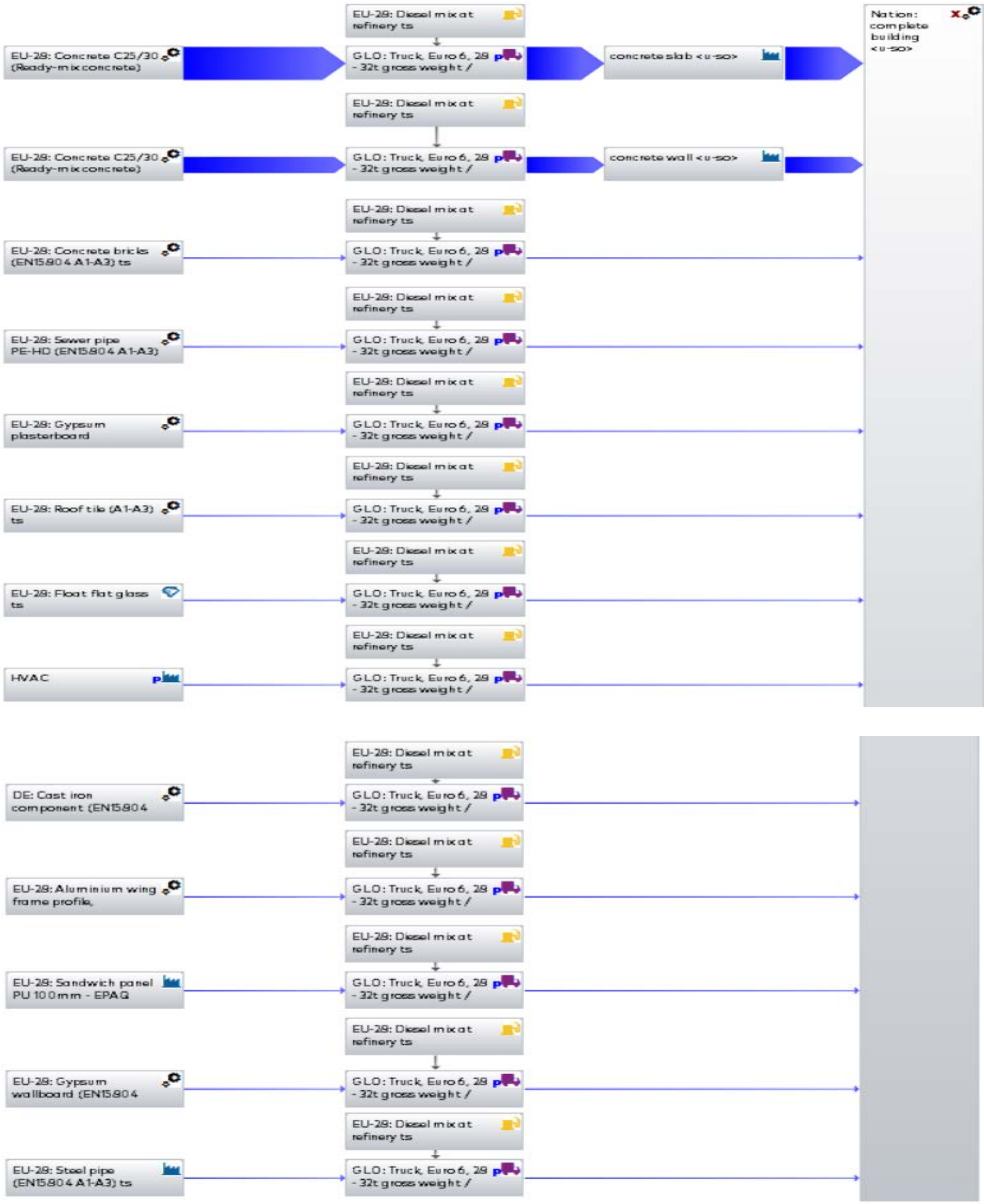

Figure 2. System boundary for life cycle assessment for the construction project

3. Results

The construction building was assessed based on the building components obtained from the BIM model. Each material was classified for each life span and density (Table 1). Some of the materials have constant densities like concrete, concrete block, and gypsum block. Other materials like HVAC ducts, HDPE pipes, cable trays, and firefighting pipes have variant diameters depending on the diameters. For these materials, the densities were calculated by multiplying each different diameter with the corresponding density. The recycling weight for each material was determined from the literature based on a study executed by (Honic et., 2019). Recycling weight 1 means that 75% of the material is recycled while 25% is waste. Recycling weight 2 means that 50% of the material is recycled while 50% is waste.

Table 7. The life span for different materials used in the project with their associated densities

Materials	Life Span (Years)	Density (Kg/m^3)	Density (Kg/m^2)	Density (Kg/m)	Recycling weight
Concrete slabs	100	2400			2
Concrete columns and walls	100	2400			2
Concrete Block	100	2200			2
Gypsum Block	50	850			2
Gypsum drywall	50	530			3
Tile	75	1800			2
HVAC duct	50		6.4		2
HDPE pipe	50			0.113-20.35	2
Firefighting pipe	25				
Aluminum Mullion	60	2710			1
Curtain walls (Glass)	60				1
Steel Panel	20		12.9		1

The BIM model built for this project used to schedule the quantities for the different elements (Table 2). The mass at time 0 represents all the material implemented at the completion of the construction phase. These quantities were input for the GaBi software to calculate the environmental impacts for each material at time 0. From the GaBi software the environmental impacts for the different materials were calculated based on the data stored within its database and represented by GWP, AP, and PEI.

Table 8. Material mass distribution at time 0 and their environmental impacts.

Materials	Mass at time 0 (ton)	GWP time 0 ($Kg\ CO_2\ eq/m^2$)	AP time 0 ($Kg\ SO_2\ eq/m^2$)	PEI time 0 (MJ/m^2)
Concrete slabs	74,816	71.60	0.1030	439.0
Concrete columns and walls	34,684	34.60	0.0497	213.0
Concrete Block	384	0.43	0.0007	3.3
Gypsum Block	1,540	0.51	0.0003	77.9
Gypsum drywall	2	0.01	0.0000	0.11
Tile	2,253	7.87	0.0061	154.0
HVAC duct	116	43.00		-
HDPE pipe	71	1.50	0.0025	63.6
Firefighting pipe	89	2.10	0.0019	39.8
Aluminum Mullion	30	3.43	0.0111	67.2
Curtain walls (Glass)	913	11.30	0.0736	166
Steel Panel	14	0.59	0.0015	10.8
Total	114,915	180.58	0.2530	1235.3

Figure 3 shows the share of the various materials at time 0. The percentage for each material is calculated by dividing its weight by the total material weight. Concrete material includes concrete columns and walls, and the concrete slab is the dominant material. It exceeds 95% of all the materials in the building. Using the global warming metric, the GWP for concrete material is 106.2 Kg $CO_2 eq/m^2$. The AP is 0.153 Kg So_2 eq/m^2. The PEI is 652 MJ/m^2.

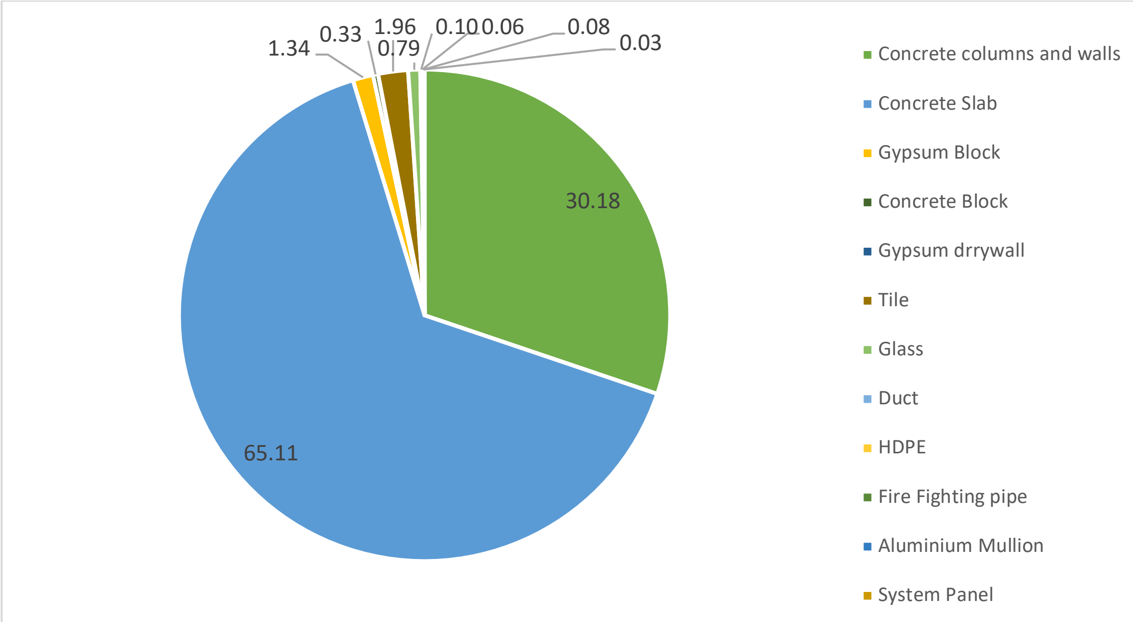

Figure 3. Share of the materials for the construction project at time 0

Table 3 represents the mass at time 100 which includes all the materials implemented during the whole life of the project this includes the material that replaces twice, triple, and until fourth-folds. These quantities were input to the GaBi software to calculate the environmental impacts for each material at time 100. From the GaBi software the environmental impacts were calculated for the different materials and represented by GWP, AP, and PEI.

Table 9. Material mass distribution at time 100 and their environmental impacts

Materials	Mass at time 100 (ton)	GWP time 100 (Kg CO_2 eq/m^2)	AP time 100 (Kg SO_2 eq/m^2)	PEI time10 0 (MJ /m^2)
Concrete slabs	74,816	71.60	0.1030	439.0
Concrete columns and walls	34,684	34.60	0.0497	213.0
Concrete Block	384	0.43	0.0007	3.3
Gypsum Block	3,080	1.02	0.0006	156.0
Gypsum drywall	5	0.010	0.0000	0.2
Tile	4,506	15.70	0.0122	307.0
HVAC duct	232	86.00	-	-
HDPE pipe	143	3.00	0.0050	138.0
Firefighting pipe	356	9.31	0.0077	159.0
Aluminum Mullion	60	6.87	0.0222	134.0
Curtain walls (Glass)	1,826	22.60	0.1470	332.0
Steel Panel	71	2.96	0.0074	54.1
Total	120,174	262.50	0.3720	1938.6

Figure 4 shows the share of the various materials at time 100. Concrete material that includes concrete columns, walls, and concrete slab represents the dominant material. It exceeds 90% of all the materials in the building. The GWP for the concrete material is 106.2 Kg CO_2eq/m^2. The AP is 0.153 Kg So_2 eq/m^2. The PEI is 652 MJ/m^2. Gypsum block represents the second material in the building after concrete, and this is due to a large number of partition walls in the building. The gypsum is high recyclable material, which means that most of the gypsum blocks at their end of life will be grind and reused for manufacturing new gypsum blocks.

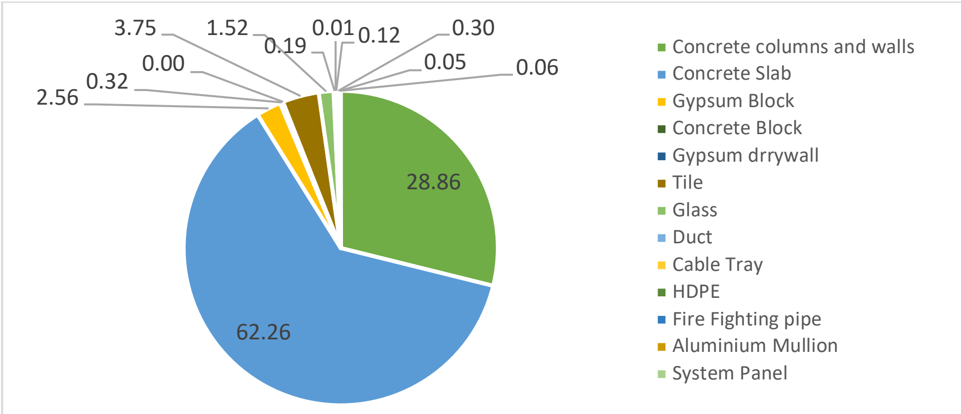

Figure 4. Share of the materials for the construction project at time 100

Figure 5 shows the accruing masses during the life cycle of the building, whereby the first building elements need to be exchanged in the year 20. As each material has its lifespan, it is substituted at a different point in time, and therefore the masses accrue at varying times. Thus, each material is also recycled or disposed of at a specific time. From figure 5, it is clear that during the building life cycle, there will not be significant replacement of the building's elements, because the dominant material is concrete which will be replaced at the building's end of life.

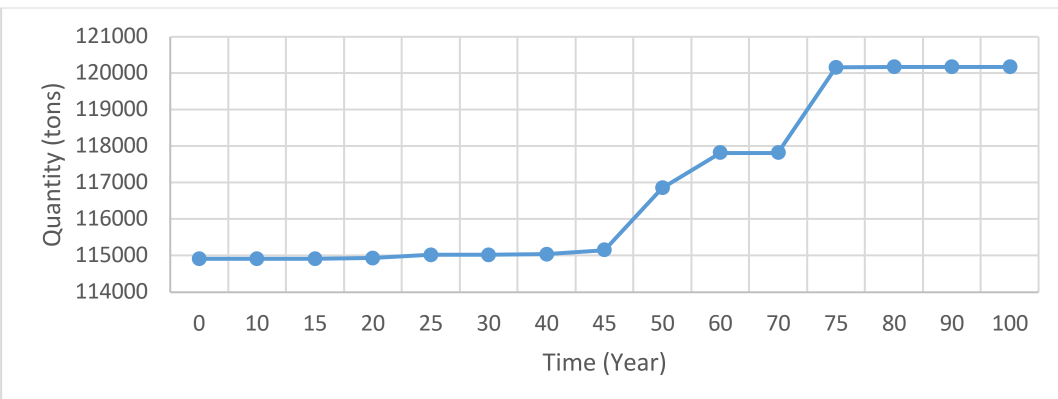

Figure 5. Accruing masses during the life cycle of the building (100 years)

5. Conclusions

The construction project studied herein demonstrate the importance of building material passport in showing the embodied materials in the building during the whole life cycle. The material passport gives a unique opportunity to the engineers to identify the environmental impacts for all the building elements during the construction phase and at the building's end of life. This can help in optimizing the materials that have low recycling potential and have a lot of hazards to the environment. Moreover, it allows completing the material flow analysis and selects the best method to process each material at its end of life and identify to which secondary market it should be delivered.

Based on the results obtained from this case study, the concrete material is the dominant material at the time 0 and time 100. It corresponds with around 95% and 90%, respectively. Concrete has a negative environmental impact. Its major constituent cement is a major emitter of GHGs. Moreover, at end-of-life, concrete is used as a filling material or base course, which is a low value material. Results from this study encourage using lightweight materials like wood and steel, which also have a lower environmental impact, and more recycling potential.

This research presents a material passport for a commercial construction project by displaying the embodied materials and their environmental impacts. There are many limitations and challenges to get data from construction companies to calculate the material waste during building construction. The material waste during construction is calculated by subtracting the actual material built from the actually delivered materials. Lack of data about the characteristics and properties of some materials leads to making certain assumptions and relies on data from the literature. A major challenge in this research is reliance on European LCA data for the analysis; this underscores the necessity to create a country-specific database for the materials available in the local market.

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ID 24

Experimental Analysis of Aggregate Densities and Deflections for Compaction Quality Control with Light Weight Deflectometer

Yi Jiang[1], Shuo Li[2], Guangyuan Zhao[3]

[1] School of Construction Management, Purdue University, West Lafayette, IN 47907, USA
[2] R&D Office, Indiana Department of Transportation, 1205 Montgomery Street, West Lafayette, IN 47906, USA
[3] Department of Civil & Environmental Engineering, University of Waterloo, Waterloo, Canada
jiang2@purdue.edu

Abstract
Nuclear gauge has been widely used to determine the in-place dry densities of pavement layers in compaction quality control. However, there is a trend for transportation agencies to use light weight deflectometer (LWD) to measure compaction sufficiency of pavement construction. LWD measurement can provide the in-situ modulus of geomaterials that is one of the key parameters used to characterize the properties of pavement structural layers. Since the measurements of nuclear gauge (density) and LWD (deflection) are different, it is necessary to analyze their relationships with compaction properties, such as moisture content, layer thickness, and construction condition. This study performed intensive laboratory experiments on the aggregate materials to evaluate the effects. Extensive experiments were also performed in the test pits with LWD to determine the effect of aggregate layers on pavement structure. Proctor tests were conducted on selected pavement base materials to establish the moisture-density relationships. Material deflections were also measured on the compacted materials in the Proctor molds to reveal the moisture-deflection relationships. Through the test pits experiments, the contribution of each aggregate layer to the pavement structure capacity was analyzed and quantitated. It was concluded that moisture content has a significant effect on LWD deflection or modulus. Aggregates compacted near the optimum moisture are capable of providing a stable deflection value. After compaction, LWD measured deflection decreases as the moisture content decreases.

Keywords
LWD, Compaction, Moisture Content, Dry Density, Deflection

1. Introduction

Light weight deflectometer (LWD) is designed to measure the compaction quality of a structural layer (Umashankar et al., 2016; Kavussi et al., 2019). However, the measured deflection and modulus are affected by the underlying structural materials. The measured modulus is the modulus of the entire structural system, rather than the modulus of the compacted top layer. Therefore, the effects of the materials below the compacted top layer should first be analyzed to accurately measure the modulus of the compacted material in the top layer with LWD. In this study, Proctor tests were conducted on selected pavement base materials to establish the moisture-density relationships. Material deflections were also measured on the compacted materials in the Proctor molds to reveal the moisture-deflection relationships. According to the pavement engineers of the Indiana Department of Transportation (INDOT), the No. 53 aggregate has been the major type of granular materials with specified gradations for subgrade treatment, and granular base and subbase for Portland cement concrete pavement and hot mix asphalt (HMA) pavement in Indiana. Therefore, the main effort of the laboratory experiments was focused on the properties of the No. 53 aggregates related to the construction quality, including gradation, optimum moisture content, maximum dry density, deflection, and modulus. In addition, some other materials recently used for road construction, such as No. 43 aggregate, steel slag, and recycled asphalt pavement (RAP), were also tested to provide first-hand data and baseline information. In addition to the indoor Proctor-LWD experiments, outdoor test pits were designed and constructed to simulate the real pavement structures. Through the test pits experiments, the contribution of each aggregate layer to the pavement structure capacity was analyzed and quantitated.

2. Laboratory Experiments of Material Modulus

2.1. Gradations of the Sample Materials

No. 53 aggregates samples, denoted as No. 53A and No. 53B, were obtained from two different suppliers for this study as shown in Figure 1. The information on the materials from the suppliers includes gradations, optimum moisture contents, and maximum dry densities. Table 1 presents the gradations provided by the suppliers of the two samples along with the INDOT gradation specifications (INDOT, 2017). The given gradations of the material samples were within the INDOT specified ranges and, therefore, satisfied the requirements of the gradation specifications. Sieve analyses were conducted with the two material samples. The results of the sieve analyses as well as the gradations given by the suppliers are also presented in Table 1. It is shown that the actual gradations were very close to those provided by the suppliers. Therefore, both No. 53A and No. 53B aggregates meet the standard specifications.

(a) No. 53A (b) No. 53B

Fig. 1. Two Samples of No. 53 Material

Table 1. Gradations and Specifications for No. 53 Aggregates

Sieve Size	% Passing Sieve Size				
	No. 53A		No. 53B		INDOT Specification
	Supplier	Test	Supplier	Test	
1½" (37.5mm)	100.0	100.0	100.0	100.0	100
1" (25 mm)	90.9	90.7	91.3	94.0	80 - 100
¾" (19 mm)	79.2	79.7	80.7	84.3	70 - 90
½" (12.5 mm)	66.0	66.0	64.0	66.5	55 - 80
3/8" (9.5 mm)	58.7	60.6		59.4	
#4 (4.75 mm)	47.1	51.6	39.6	39.4	35 - 60
#8 (2.36 mm)	33.1	35.4	29.5	29.4	25 - 50
#30 (0.6 mm)	14.5	14.0	16.0	17.7	12 - 30
#200 (0.075 mm)	8.9	8.1	10.0	10.0	5 - 10

2.2 Maximum Dry Density and Optimum Moisture Content

The optimum moisture content and the corresponding maximum dry density of a soil mixture are the most important values for achieving the desired compaction. These values provided by the suppliers of No. 53A and No. 53B are shown in Table 2. The given optimum moisture content and maximum dry density for No. 53A are 8.9% and 134.2 pcf, and those for No. 53B are 10.9% and 127.8 pcf. To analyze the relationships between the degree of compaction and LWD measurements, Proctor tests were performed to establish the moisture-density relationships for No. 53A and No. 53B materials. Notice that the AASHTO Designation T 99 Method D (AASHTO, 2017) was chosen for the

Proctor tests. This method is applicable to the materials with a maximum of 30% of the particles retained on the 19.0 mm (3/4 in.) sieve. As illustrated in Table 1, the No. 53A aggregate sample contained 20.3% of the particles greater than the sieve size of 19.0 mm (3/4 in.) according to the lab sieve analysis. The No. 53B aggregate sample had 15.7% of the particles greater than the sieve size of 19.0 mm (3/4 in.).

Table 2. Proctor Test Results for No. 53 Aggregates by Suppliers

Proctor Test Value	**Aggregate Sample**	
	No. 53A	**No. 53B**
Optimum Moisture Content	8.9%	10.9%
Maximal Dry Density	134.2 pcf	127.8 pcf

With Method D of the AASHTO Designation T 99, all aggregate particles larger than the sieve size of 19.0 mm (3/4 in.) is defined as oversized material. Therefore, a correction may be necessary if the oversize material is above a certain percentage specified by the agency. If the agency does not specify such a percentage, it is recommended that a correction be made when more than 5 percent by weight of oversize particles is present (NDDOT, 2015). Since INDOT did not have the specified the percentage of oversize material, according to the recommended 5 percent criteria, corrections were necessary for both No. 53A and No. 53B materials. The correction method for Method D of the AASHTO Designation T 99 is specified as the AASHTO Designation T 224 (AASHTO, 2010). Correction tests were conducted for the two No. 53 aggregate samples to adjust the densities to compensate for oversize coarse particles that were greater than the sieve size of 19.0 mm (3/4 in.). Presented in Figures 2 and 3 are the original and corrected Proctor curves for both the No. 53A and No. 53B aggregate samples, respectively.

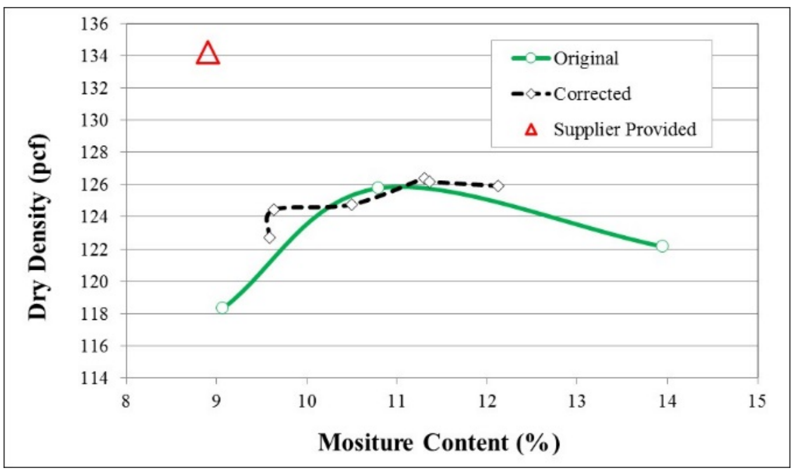


Fig. 2. Original and Corrected Moisture-Density Curves for No. 53A

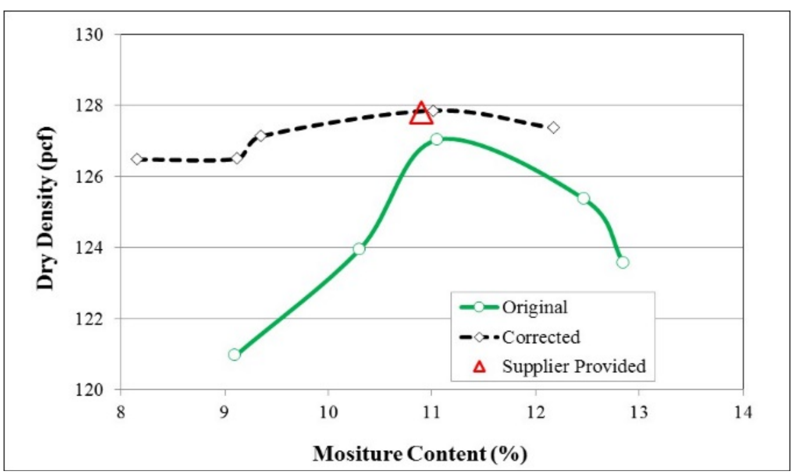


Fig. 3. Original and Corrected Moisture-Density Curves for No. 53B

It is shown that for No. 53A aggregates, the original maximum dry density and optimum moisture content were 125.8 pcf and 11.2%, while the corrected maximum dry density was 126.3 pcf and the corrected optimum moisture content was 11.4%. The corrected values were both slightly higher than their corresponding original values. For No. 53B aggregates, the original maximum dry density and optimum moisture content were 127.0 pcf and 11.1%, while the corrected maximum dry density was 127.9 pcf and the corrected optimum moisture content was 11.0%. The corrected values were very close to the original values. Therefore, the differences between the original and corrected maximum densities and between the original and corrected optimum moisture contents for both materials were not significant for practical applications. For comparison, the moisture contents and dry densities provided by the two suppliers are also presented in Figures 2 and 3. It is apparent that the laboratory results and the supplier provided values are quite different for No. 53A aggregates. For No. 53B aggregates, however, the optimum moisture content and the maximum dry density from the supplier are very close to those from the laboratory tests.

Table 3 summarizes all the moisture and density values from the suppliers and from the laboratory tests for both No. 53A and No. 53B aggregates. Comparing No. 53A and No. 53B aggregates, the laboratory tests, original or corrected, yielded very similar values of optimum moisture contents and maximum dry densities of the two material samples. Also, as presented in the sieve analysis results, the gradations of No. 53A and No. 53B aggregates were also similar. It was therefore justified to use either No. 53A or No. 53B to represent No. 53 material in the experiments and analysis. Therefore, only No. 53A was utilized to perform other experiments and analysis henceforth. The material would then be denoted as No. 53, rather than No. 53A, as presented in the remaining sections of this chapter.

Table 3. Supplier Provided and Laboratory Moisture-Density Values

Sample	**Optimum Moisture Content**			**Maximum Dry Density**		
	Supplier Provided	**Original (T 99-D)**	**Corrected (T 224)**	**Supplier Provided**	**Original (T 99-D)**	**Corrected (T 224)**
No. 53A	8.9%	11.2%	11.4%	134.2 pcf	125.8 pcf	126.3 pcf
No. 53B	10.9%	11.1%	11.0%	127.8 pcf	127.0 pcf	127.9 pcf

2.3 Laboratory Testing of Material Densities and Deflections

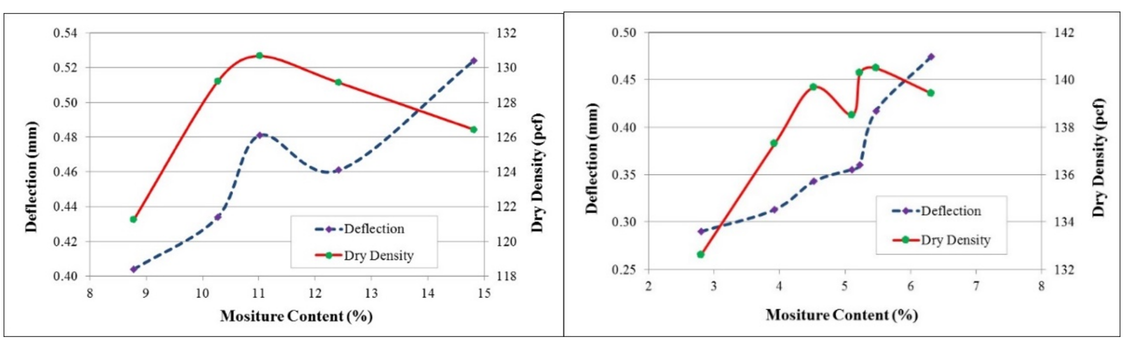
To establish the relationship between optimum moisture content and LWD measurement, a series of laboratory tests were conducted. In addition to No. 53 aggregates, some other types of materials, including No. 43 material, steel slag aggregate, and reclaimed asphalt pavement (RAP), have also been utilized in pavement bases in Indiana. The samples of these materials were obtained and used in the laboratory experiments for modulus analysis. As it is well known, for a given compaction effort, a soil's dry density will increase to a peak point as the moisture content of the soil increases and then the dry density will decrease if the moisture content further increases beyond the peak point of the dry density. A moisture-density curve of a soil from the Proctor test is typically a bell-shaped curve. The bell shape of the moisture-density curve is usually more apparent for clayey soils. Therefore, a clay sample was also included in the laboratory tests because of its typical plastic moisture-density relationship and its widespread existence in pavement subgrade in Indiana.

Like the study by Schwartz, et al. (2017), an aggregate sample was first compacted confirming to the AASHTO standard Proctor method, and then, the LWD measurements were made directly on the compacted sample in the Proctor mold. Figures 4 demonstrates the Proctor compaction and LWD measurement during the laboratory experiment. The deflections were measured six times on the material sample in the mold with the LWD. The first three deflection values were discarded and the average of the last three of the six deflection values were calculated as the measured deflection. The device was a Zorn LWD with a 5 kg drop weight and a 150 mm diameter base plate.

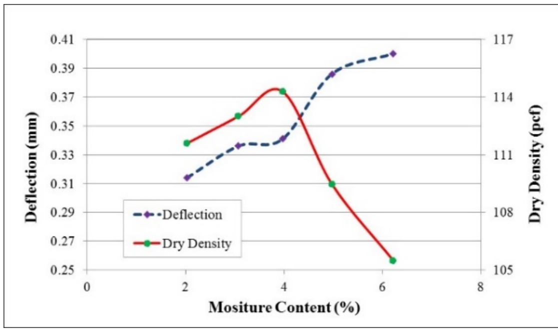
(a) Proctor Compaction (b) LWD Test in Mold

Fig. 4. Photos of laboratory LWD testing

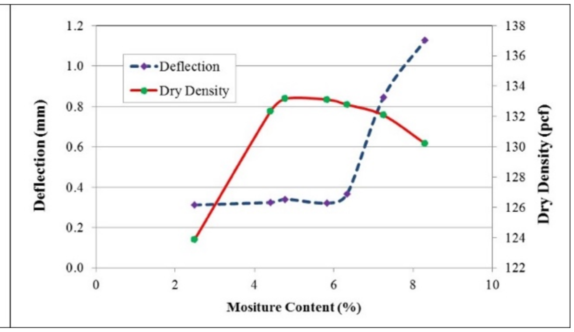
The main purpose of the LWD measurements over Proctor compacted materials was to reveal the change patterns of deflections and moisture contents in comparison with the moisture and density relationships. Plotted in Figure 5 are the moisture-density curve and the moisture-deflection curve for No. 53, No. 43, steel slag, RAP, and clay samples. It was expected that the changes of deflections and densities would have an inverse relationship so that as density increases the deflection decreases and vice versa. As shown in Figure 5, however, the materials do not demonstrate the inverse correlations between density and deflection. Only RAP and clay materials show slight deflection declines and reached a minimum deflection value as density increases within a limited range. In general, the materials exhibited a common pattern that as moisture content increases the deflection increases. It is indicated that the moisture content plays important but different roles in densities and deflections. Different from the well-known bell-shaped moisture-density relationship, the moisture-deflection relationships do not commonly show an optimum moisture content at which the deflection would be at a turning point. Therefore, the results of the laboratory experiments imply that a minimum deflection might not exist in terms of different moisture contents. This is because aggregate modulus increases as density increases, moisture content decreases, and aggregate interlocking increases. Compaction increases soil density and interlocking by reducing the voids in a soil with permanent deformation, while deflection is induced by an instant LWD impact with recoverable deformation.



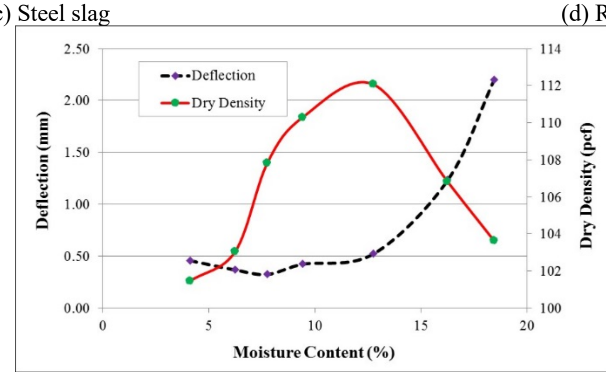
(a) No. 53 aggregate (b) No. 43 aggregate



(c) Steel slag



(d) RAP



(e) Clay soil

Fig. 5. Moisture, dry density, and deflection relationships for different materials

An important implication of the moisture-density and moisture-deflection relationships is that a range of moisture contents must be specified when establishing the maximum allowed LWD deflection value to effectively control compaction quality. Therefore, during construction, compaction should be performed when the moisture content is at or close to the optimum moisture content and the LWD deflections should be made as soon as the compaction is completed or before the moisture content decreases beyond the specified range. That is, it should not be allowed to measure LWD deflections on compacted layer after the moisture content has dropped below the specified range of moisture contents.

2.4 Effect of Moisture Content on Modulus

Moisture content is one of the important factors affecting the degree of compaction of geomaterials. In the traditional moisture-density controlled compaction process, a layer of pavement material is compacted at the optimum moisture content until the dry density of the material has reached the specified value. To examine the effect of moisture content on the modulus of geomaterial, laboratory tests were conducted to measure LWD deflections on the compacted materials at different moisture contents.

Two sets of the laboratory experiments were performed to reveal the change patterns of modulus at different moisture contents under compaction. The first set of the laboratory experiments was to compact the material specimen in Proctor mold at the optimum moisture content and to measure the deflection of the compacted specimen immediately after the compaction. After the first measurement with LWD, the specimen was placed in an oven at 230°F for 30 minutes and then deflection was measured, and the moisture content was determined. This process was repeated until the specimen was completely dried. The second set of the laboratory was to compact material at a moisture content in Proctor mold and to measure the deflection on the compacted specimen. This laboratory was conducted on six material specimens of different moisture contents to obtain the corresponding deflections. The measured deflections were all converted to moduli with the following equation.

$$E = \frac{Hq}{d}\left(1 - \frac{2\mu^2}{1-\mu}\right) \quad (1)$$

Where, E = material modulus; H = specimen height; q = LWD measured pressure; d = LWD measured vertical deflections; μ = Poisson’s ratio.

Because a range of Poisson's ratio μ=0.1 to 0.4 is recommended in the Mechanistic-Empirical Pavement Design Guide (MEPDG) (AASHTO, 2015), μ=0.3 was selected to calcuate the modului from the LWD measured deflections. Plotted in Figures 6 and 7 are the results of the laboratory experiments for No. 53 and No. 43 aggregates, respectively. The first observation from the two charts is that, for both No. 53 and No. 43 materials, after the material was compacted at the optimum moisture content the modulus increased considerably as the moisture content was reduced each time. This phenomenon may have some significant practical implications in compaction quality control with LWD devices. The practical meanings of compaction quality control with LWD would include: 1) Compaction must be performed at the optimum moisture content to achieve sufficient dry density; and 2) LWD deflection or modulus must be measured within a limited time window after compaction to obtain meaningful deflection values pertinent to the degree of compaction. The second observation from the laboratory results is that No. 53 and No. 43 reflected differently to the changes of moisture contents in terms of moduli when the materials were compacted at different moisture contents. The modulus of No. 53 remained relatively stable at different moisture contents. On the other hand, the modulus of No. 43 material increased noticeably as the moisture content decreased. The different patterns of the two materials indicate that the coarser material (No. 43) was more sensitive to the moisture content than the finer material (No. 53) with respect to LWD measured deflections or moduli.

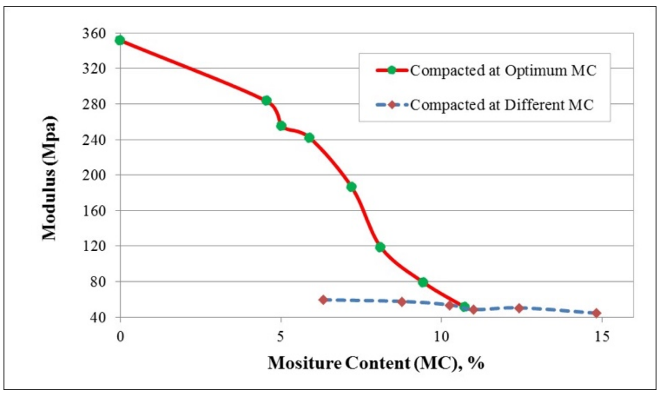


Fig. 6. Variation of Modulus with Moisture Content for No. 53 Aggregates

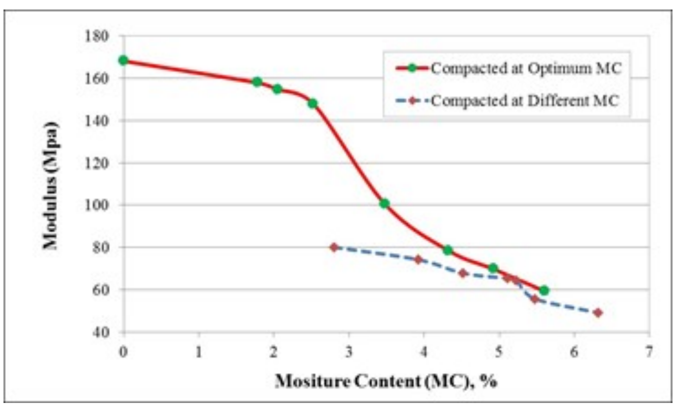


Fig. 7. Variation of Modulus with Moisture Content for No. 43 Aggregates

3. Test Pits Experiments of material deflections

Two 1m×1m×1m test pits were constructed to test the No. 53 and No. 43 aggregate materials. The soil in the bottom of the pit was first compacted before placing aggregates. The process of the experiment included the following steps (Figure 8): mixing water with the material, placing a layer of the material and compacting the layer with a jumping jack, leveling the layer, and measuring deflection at the center of the pit with LWD. To assure sufficient compaction at each layer, the moisture content of the material must be at or close to the optimum value and the material must be compacted at least two times and deflection must be measured after each compaction. If the difference between the two deflections is less than 0.01 mm, the compaction is considered satisfactory. Otherwise, additional compaction will be performed until the difference between deflections of two adjacent compactions is below 0.01 mm.

(a) Adding Water (b) Compaction

(c) Leveling (d) LWD Measurement

Fig. 8. Test Pit Experiment Process

The thickness of each layer was 6 inches for the No. 53 material and was 4 inches for the No. 43 material. The compaction and measurement process at each test pit was repeated until the test pit was full. The test results are illustrated in Figure 9. The two curves in the figure demonstrates different effects of the materials on the deflections or moduli as more materials were added to the structures. For No. 53, the deflection decreases as the structure thickness increases. It is apparent that the No. 53 material improves the overall stiffness of the structure. However, for No. 43, the deflection remains stable when as much as 8 inches of the material are added to the structure. That is, the No. 43 material would not contribute to the structural capacity during construction when the thickness of the material is less than 8 inches.

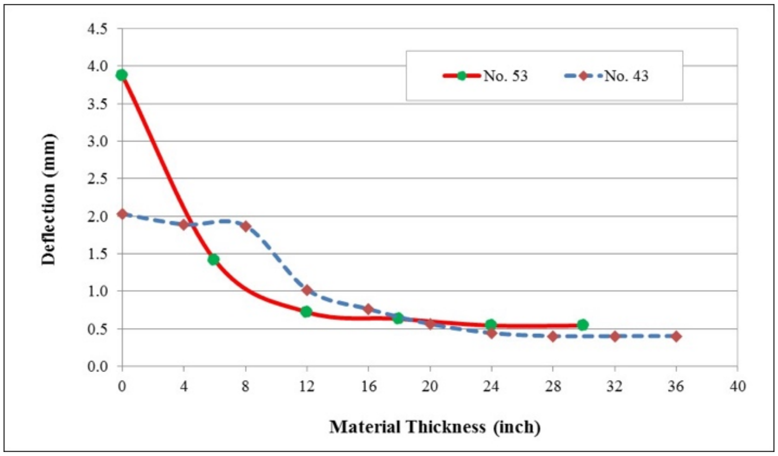


Fig. 9. Variation of Deflection with Layer Thickness in Test Pits

4. Conclusions

The Proctor test for aggregates was performed in accordance with the AASHTO Designation: T 99 by INDOT. Corrections may be necessary if the oversize material is above a certain percentage. However, the laboratory test results indicate that the differences between the original and corrected maximum densities and between the original and corrected optimum moisture contents for both materials were not significant for practical applications. Different from the well-known bell-shaped moisture-density relationship, the moisture-deflection relationships for aggregates did not show an optimum moisture content at which the deflection would be at a turning point. The results of the laboratory experiments imply that a minimum deflection may not exist in terms of different moisture contents. When compacted at the optimum moisture content, the modulus of aggregates increased considerably as the moisture content decreased. When compacted at a random moisture content, the modulus of No. 53 aggregates remained relatively unchanged, but the modulus of No. 43 aggregates increased noticeably as the moisture content decreased. Coarser aggregates are more sensitive to the moisture content than finer aggregates with respect to deflection or modulus. The results of LWD tests in the test pits indicate that No. 53 aggregates can contribute to the structural capacity, but No. 43 aggregates can only contribute to the structural capacity when its thickness is eight inches or more. The deflection decreased as the thickness of aggregate layer increased. As the layer thickness increased to a certain level, the deflection became stable.

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Bibliometric Analysis of Factors Influencing Poor Performance of Water Infrastructure

Gift Laolang[1], Innocent Musonda[2], Motheo Meta Tjebane[3]

[1,2,3] University of Johannesburg, Department of Construction Management and Quantity Surveying, University of Johannesburg, P.O. Box 17011, Doornfontein, 2028, South Africa
gift.laolang@gmail.com

Abstract
Purpose - Access to safe drinking water is still a challenge in developing countries. Water is a basic human needs and water quality already present a threat to serious health risks to humans, personal hygiene and livestock. Current droughts and poor performance of water infrastructure have a negative impact on the domestic demand for quality of water. Though, not much is published concerning factors influencing poor performance of water infrastructure in water sector.
Design/methodology – Scopus was used to gather existing literature for bibliometric analysis for this paper. Publications from the year 2017 and the year 2021 was gathered using bibliometric analysis. Keywords used for this search includes, *Water, Infrastructure, Poor and Performance.* From the analysis a total of 50 documents from Scopus database met these criteria. Further, Vosviewer (Visualization of Similarities) was used as a tool to analyse the data.
Findings – From the analysis, it was established that the number of studies on factors influencing poor performance of water infrastructure in water sector in the reviewed journals has not been increasing and not many articles are available.
Research limitations/implications – The dataset was mainly extracted from the Scopus database for the analysis.
Originality/value - This study will help policymakers in water sectors. Moreover, the study provides useful information on the key performance of water infrastructure and thus help in formulating better strategies and regulatory tools to enhance efficiency and effectiveness in the performance of water infrastructure.

Keywords
Performance, Water, Infrastructure,

1. Introduction

Water systems are a special kind of infrastructure systems since they perform a dual role: they provide water services while also reducing risks to other services from natural hazards such as floods and droughts (Stip *et al*., 2019). According to Dinka (2018) safe drinking (potable) water is the water that can be delivered to the user and is safe for drinking, food preparation, personal hygiene and washing. Futhermore, water is connected to every aspect of human day-to-day activities directly or indirectly. Nevertheless, at a basic level, everyone needs access to safe water in adequate quantities for drinking, cooking, personal hygiene and sanitation facilities that do not compromise health or dignity. Subsequently, access to safe and dependable (clean and fresh) water is the fundamental/basic right of humans. Cosgrove and Loucks (2015) alluded that the lack of adequate clean water to meet human drinking water and sanitation needs is indeed a constraint on human health and productivity and hence on economic development as well as on the maintenance of a clean environment and healthy ecosystems. However, water sector has numerous challenges, such as increased water deficits, waer pollution, droughts, floods, depleting ground water aquifers and degeneration of the quality of water, while the demand is increasing in form and quantity; water aging and waste water infrastructure; the impact on water resources due to climate change (Saravanamuttu, 2022; Edokpayi *et al*., 2017). Feathermore, water-scarce with demand in certain cities that already exceeds supply. Roodbol (2021) alluded that water is not consistently distributed through the worlds geographic space and the condition of water). Feathermore infrastructure continues to deteriorate and therefore, the need for water infrastructure to be improved to address issue of water scarcity and water quality. According to Herbig (2019) the deteriorating state of municipal wastewater and sewage treatment management is one of the largest contributing factors to the numerous pollution problems experienced in most parts of the developing countries and a major contributor to environmental and human health problems. Moreover, Lukhele (2017) articulates that the deterioration of water infrastructure reduces economic growth and poor health for citizens. This study provides an in-depth literature review of factors influencing poor performance of water infrastructure. Despite a number of prior studies that have similarly investigated water infrastructure, studies specific to the factors influencing poor performance of water infrastructure in the developing countries within water sector remain scarce. Hence, the study aims to fill this knowledge gap within develpoing countries under water sector. As a result, through the scope presented in this article, aiming to close gaps in the literature, the study has adopted a comprehensive review approach, which incorporates bibliometric analysis by targeting the following objectives:

1) To determine factors influencing poor performance of water infrastructure;
2) To find out the most influential journals in this domain and
3) To propose research directions for future researches, gaps and opportunities do drive further studies.

2. Research Methodology

Bibliometric analysis has developed rapidly and applied to many research fields, because it is an effective way to evaluate the merits of a given subject area or a certain journal (Wang *et al*., 2020). Bibliometric analysis is an indispensable statistic tool to map the state of the art in a given area of scientific knowledge and identify essential information for various purposes, such as prospecting research opportunities and substantiating scientific researches (José de Oliveira *et al.*, 2019). Furthermore, methods compasses instruments to identify and analyse the scientific performance of articles, authors, institutions, countries, and journals based on the number of citations, to reveal the trends of the field studied through the analysis of keywords, and to identify and cluster scientific gaps from most recent publications (Zare *et al.*, 2017). Over the past years, a large number of publications related to factors influencing water infrastructure were published. Ansorge *et al*. (2021) study focused on bibliometric analysis of water footprint research in countries of former Yugoslavia. Li *et al.* (2020) study focused on bibliometric analysis of water resource management. Olusanmi *et al*. (2021) applied bibliometric study on water management accounting research from 2000 to 2018 in Scopus database. Lastly, Goh and See (2021) looked at the twenty years of water utility benchmarking: a bibliometric analysis of emerging interest in water research and collaboration. This study looked at the bibliometric analysis of factors influencing poor performance of water infrastructure

This study piloted a documentary analysis of factors influencing poor performance of water infrastructure related papers published between 2011 and 2021, acquiring a diverse and in-depth of factors influencing poor performance of water infrastructure research within the water sectors using science mapping method. Bibliometric overview to analyse the evolution of the academic journals publications, identifying the main countries, authors citations and institutions working in water infrastructure and scientific relationships over time.

2.1. Preliminary Search

To enrich the quality of the preliminary search, only peer-reviewed articles were identified for further analysis. However, books and conference papers were excluded during preliminary search. This is due to reasons that journal publications provide more valuable and accurate information due to the rigorous review process, and most of the similar studies in the field of construction are journal publications (Zheng *et al*., 2016; Zhao, 2017). The preliminary controlled searching criteria were defined with a focus on the factors influencing poor performance of water infrastructure. To ensure that the research covered a wide range of review, other forms of search criteria were used. Therefore, each article selected in a search engine consisted of the "title or keywords or abstract" to regulate the level of relevance and eligibility. The search period was fixed between the years 2017–2021.

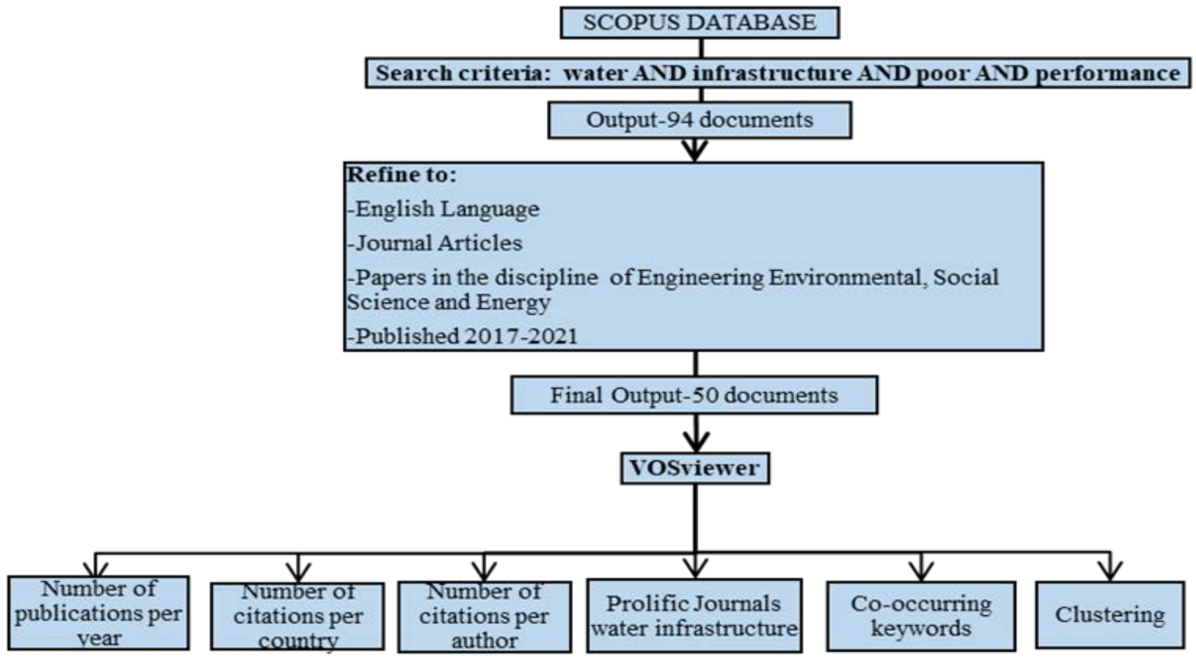

Fig.1. Research design

2.2. Identifying Research Articles

Focusing on the factors influencing poor performance of water infrastructure in the water sector. A more critical comprehensive and visual search of the targeted water infrastructure journals was concluded via the search engine. Under the search engine, the following were excluded from the analysis: “articles in papers”, “letter to editors”, “discussions and closures”, “book review” and “editorial”. This step excludes papers with an unclear application purpose or with little potential to apply for organisations, such as a purely technical system development or mathematical algorithms. After this screening process, 94 articles were identified as the review range for this study.

A total of 94 articles are aligned with the foundation and research scope of this research. The bibliometric data were downloaded in Comma Separated Values (CSV) file. However, the CSV file was imported into Vosviewer to scientifically map the factors influencing poor performance of water infrastructure research literature. The search string used was (water AND infrastructure AND poor AND performance). The research was further limited in the subject areas such as “environmental science”, “engineering” and “social science” with the document type of “article”. The full search code is as follows:

TITLE-ABS-KEY (water AND infrastructure AND poor AND performance) AND PUBYEAR > 2016 AND PUBYEAR < 2022 AND (LIMIT-TO (DOCTYPE, “ar”)) AND (LIMIT-TO (SUBJAREA, “ENVI”) OR LIMIT-TO (SUBJAREA, “ENGI”) OR LIMIT-TO (SUBJAREA, “SOCI”)) AND (LIMIT-TO (LANGUAGE, “English”)) AND (LIMIT-TO (SRCTYPE, “j”)).

2.3. Selection of Database

Scopus was used to get the existing literature for bibliometric analysis for this paper. Bass *et al.* (2020) articulated that Scopus is one of the largest curated abstract and citation databases and ensures that only the highest quality data is indexed by a diverse Content Selection and Advisory Board (CSAB) by stringent content selection and re-evaluation. For this research, the study used journal articles published between 2017 to the 21st of November 2021.

2.4. Selection of Tool and Data Acquisition

The Vosviewer (Visualization of Similarities) was used as a tool to analyse the data. According to van Eck and Waltman (2017) Vosviewer is a software tool for creating maps based on network data and for visualizing and exploring maps. Moreover, the functionality of Vosviewer can be summarized as creating maps based on network data and visualizing and exploring maps. Dagiene and Xie (2021) articulated that Vosviewer was developed to construct various networks based on scientific literature. Furthermore, provide an overview of the topics in the publications. Networks are bibliometric; they are based on co-authorship or citations. Additionally, such maps represent connections between researchers, their institutions, countries, or journals and individual papers. Therefore, researchers worldwide use Vosviewer to create, visualize, and explore networks based on textual and bibliographical data. A quantitative-based science mapping technique was arrayed for this paper. It was prudent to adopt a technique that could quantitatively map out particular networks and patterns in a larger set of bibliometric data (Cobo *et al*., 2011). The primary method used in the present study was "science mapping". This method was selected due to its proven capabilities in picturing systematic patterns in comprehensive bodies of literature and large bibliographical units. Science mapping acts both as a descriptive and a diagnostic tool for research policy purposes, processing immense reservoirs of bibliometric data (Tijssen and Raan, 1994). It allows researchers to conduct systematic literature-related discoveries by linking literature concepts that have been overlooked in manual review studies (Su and Lee, 2010).

3. Results

3.1. Research Articles Timeline Series

Annual timeline series of the 50 publications between the year 2017 and the year 2021 respectively. The number of publications on this field of science per year is described (see Fig.2).

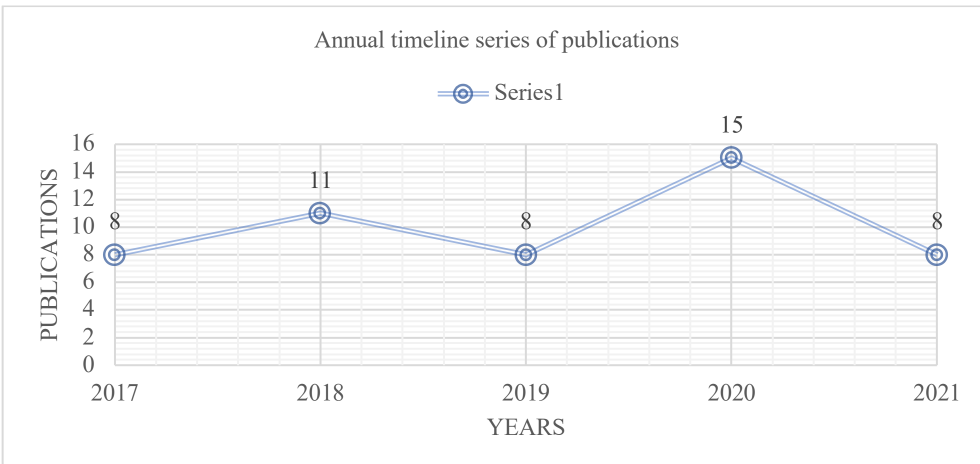

Fig. 2. A timeline series range of publications in water infrastructure from the year 2017 and the year 2021.

3.2. Countries research origins of Factors Influencing Poor Performance of Water Infrastructure

Table 1**.** below, is the analysis of top 10 countries that met these criteria with regards to the factors influencing poor performance of water infrastructure computed by VOs tool.

Table 1. Publications by 10 different countries

Countries	Documents	Citations
China	6	312
Malaysia	2	209
United Kingdom	4	120
United States	14	95
Australia	5	48
Canada	5	48
Spain	3	43
Brazil	3	36
Netherlands	6	34
Sri Lanka	2	16

Fig 3 and **4** below, is the analysis of top 10 countries that met these criteria with regards to the factors influencing poor performance of water infrastructure by citations and publications.

Fig. 3. Citations by top 10 countries

Fig. 4. Documents by top 10 countries

3.3. Publishing Journals

Table 2. Top 10 Profolic Journals Publications

Source	Documents	Citations
Journal Of Cleaner Production	4	136
Water (Switzerland)	3	18
Science of The Total Environment	2	29
Water Resources Management	2	15
Applied Energy	1	109
Sustainable Development	1	100
Construction and Building Materials	1	18
Environmental Impact Assessment Review	1	17
Water Research	1	17
Journal of Urban Affairs	1	16

3.4. Author Co-Citation Network

Table 3. Presents a summary of the top 10 most cited papers relating to factors influencing poor performance of water infrastructure 2017 to 2021.

Table 3. Top 10 Authors citations

Author(Years)	citations	Country
Tan *et al*.(2017)	109	China
Khan *et al*.(2019)	100	United Kingdom
Wu *et al*.(2018)	59	China
Perales-Momparler *et al.* (2017)	39	Spain
Lopes *et al.* (2017)	32	United States
Stroski *et al.*(2020)	21	China
Pickel *et al.* (2017)	18	Canada
Wang *et al*. (2019)	17	China
Van Genuchten *et al.* (2020)	17	Netherlands
Lewis (2017)	16	Australia

3.5. Co-Occurring Keywords Analysis

Table 4. Presents a summary of the most trending authors keywords relating to factors influencing poor performance of water infrastructure.

Table 4. Trending authors keywords

Keyword	Occurrences	Total Link Strength
Water Supply	13	30
Water Management	10	29
Water Treatment	5	19
Developing Countries	6	18
Water Quality	5	18
Performance Assessment	6	17
Potable Water	4	17
Canada	4	15
Runoff	4	15
Storms	4	15
Developing World	5	14
Environmental Management	4	14
Green Infrastructure	4	13
Infrastructure	6	13
Water Pollution	4	13
Article	4	12
Water Supply Systems	4	11
Infrastructure Planning	5	10
Sustainable Development	5	9
Irrigation	4	8
Utility Sector	4	7
Climate Change	4	5

Table 5. Outlines the cluster of keywords co-occurrences. However, the keywords occurrences have been categorised by clusters, colours and terms respectively.

Table 5. Cluster of authors keywords

Cluster No	Color	Terms
Cluster 1	Red	Climate Change, infrastructure, irrigation, performance assessment, portable water, utility sector, water management, water supply, water supply systems
Cluster 2	Green	Canada, green infrastructure, runoff, storms, sustainable development,
Cluster 3	Blue	Article, developing countries, developing world, environmental management, water pollution, water treatment

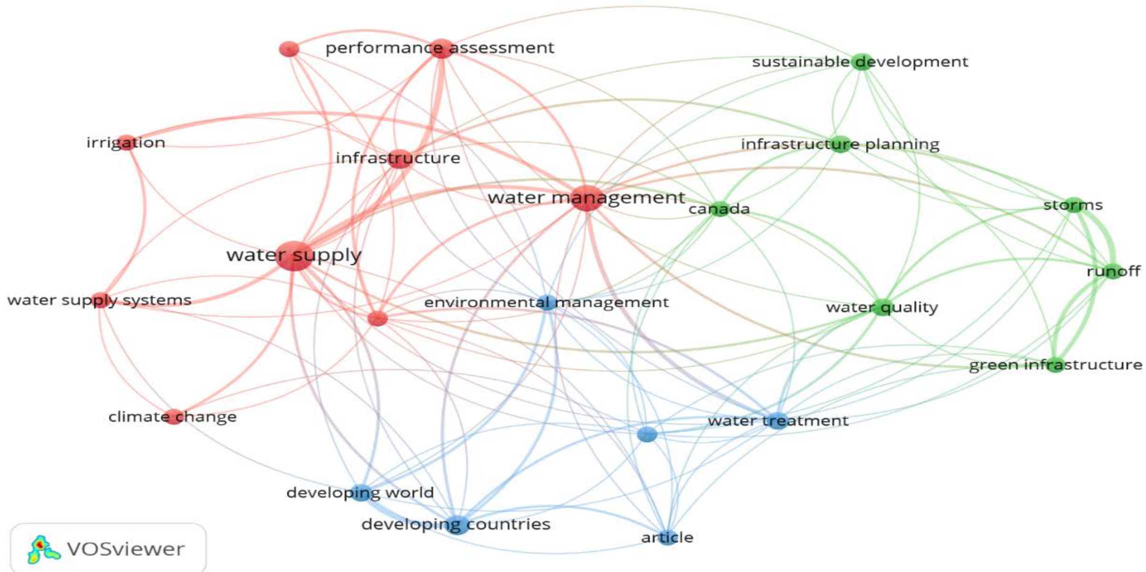

Fig. 5. Authors keywords

3.6. Cluster of Co-Occurrence Keywords

The following Table 6. Outlines the cluster of keywords co-occurrences. However, the keywords occurrences have been categorised by cluster 1, 2 and 3 respectively.

Table 6. Cluster of co-occurrence keywords

Cluster No	Number of Items	Terms
Cluster 1	9	Climate Change, infrastructure, irrigation, performance assessment, portable water, utility sector, water management, water supply, water supply systems
Cluster 2	7	Canada, green infrastructure, runoff, storms, sustainable development,
Cluster 3	6	Article, developing countries, developing world, environmental management, water pollution, water treatment

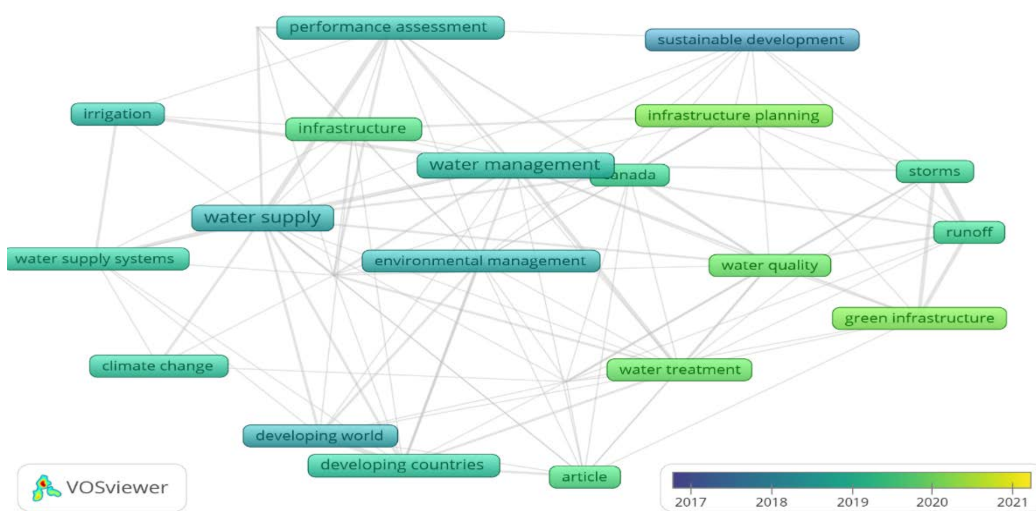

Fig. 6. Cluster of co-occurrence keywords

4. Discussion

The results contained extensive data in relation to the *Factors Influencing Poor Performance of Water Infrastructure* progression timeline series from the year 2017 to 2021 respectively. From the Scopus database only 8 publications were done in the year 2017, 2019 and 2021.In addition to the publications found in the Scopus database, there was also significant increase of publications that is worth noting, 11 publications in 2018 and 15 publication in 2020. Therefore, the timeline series revealed the evolution of researches relating to factors influencing poor performance water infrastructure has been conducted. The analysis revealed that studies relating to factors influencing poor performance water infrastructure are declining during the year 2021 with 8 documents. The results revealed that out of G20 countries (China, United Kingdom, United States, Australia, Canada, Spain and Brazil) met the search criteria and contributed 80% of documents and 73% of citations. Nonetheless, Malaysia, Spain and Netherlands account to 20% documents and 27 % citations contribution. China reported as the highest country with citations accounting to 312 and 6 documents. However, out of the top ten counties, non-African country met this criterion. The results revealed there's a decline in the number of water infrastructure publications in the year 2021. Moreover, from the analysis, the results also highlighted that Journal of Cleaner Production is the leading journal publication with 4 journals that account for 136 citations. The study also analysed the citations in order to involve the counting number of times and article cited by works to measure the impact of publications or authors. However, the study by Tan *et al*. (2017) was the highly cited with 109 citations, focusing on applied energy. Lastly, the results showed that co-occurrence keywords such as *Water Supply, Water Management, Water Treatment, Developing Countries, Water Quality, Performance Assessment, and Potable Water*, were the most frequently used and occurred the most from the researchers.

5. Conclusions

The study has been able to determine the perceived factors influencing water infrastructure in developing countries. Moreover, presented scientometrics analysis of factors influencing poor performance of water infrastructure in water sector. The results contained extensive data in relation to the *Factors Influencing Poor Performance of Water Infrastructure* progression timeline series from the year 2017 to 2021 respectively. The bibliometric analysis of *Factors Influencing Poor Performance of Water Infrastructure* indicated publications by countries, authors citations, institutions and academics journals publications working in water infrastructure and scientific relationships over time. The study has brought a light to the perceived challenges influencing poor performance of water infrastructure affecting the success. Devastation of poor performance of water infrastructure generally results in decrease access to suitable quantity and quality of water users. Poor performance of water infrastructure poses a great challenge on high water demand and supply in both urban and rural settlement. Furthermore, the lack of extensive support from the government on financing water infrastructure remain to be an issue in developing countries. This will result to a poor performance of water infrastructure. However, studies relative to the factors influencing poor performance of water infrastructure the numbers are extremely low. The data was primarily gathered from the Scopus database for the analysis. Moreover, the bibliometric results highlight the interest in this study and opens new doors for future publications this research field of study. In conclusion, access to safe drinking water is still a challenge in developing countries. Lastly, there is no studies specific to the factors influencing poor performance of water infrastructure in developing countries within water sector and remain scarce when compared to large organisations.

From a theoretical aspect of things, water sectors to implement adequate water by-laws and proper maintenance plan on existing and future water infrastructure for future sustainability. Financing water infrastructure projects will result in improvements such as enhancing profitability and enhancing good performance timeously. Moreover, this will result in efficiently, productivity and outstanding good performance on water infrastructure. National and provincial government may find these results helpful in policy formulation and research prioritisation of water infrastructure development in developing countries. Water policymakers could utilise this study as a starting point to identifying key issues amongst the factors influencing poor performance of water infrastructure in water sector for further research in policymaking. Lastly, this study will help water industry practitioners in developing a consistent view on the actions, movements and needs to advocate for the transformation on the water sector towards outstanding performance of water infrastructure by using emerging technologies such as automation, data gathering and analysis, and machine learning tools, commonly known as smart water technologies. This is important as these technologies are widely employed in the water industry to improve access and supply of quality drinking water with the right level of service.

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ID 27

3D Simulation Game for Teaching Concrete Formwork

Pavan Meadati, Ph.D.[1], and Parminder Juneja, Ph.D.[2]

[1,2] Kennesaw State University, Marietta, Georgia 30060, USA
pmeadati@kennesaw.edu

Abstract
Engaging technology savvy students in the concrete formwork learning process with their preferred learning style is a challenging task. The differences in teaching and learning styles result in problems such as disengagement of students and loss of learning aptitude. This active student engagement challenge can be addressed through three dimensional (3D) concrete formwork simulation game learning environment. This learning environment engages students in active learning processes and helps them to focus on their learning. It also encourages students to take more responsibility for their own learning process. This ubiquitous learning environment provides anytime time access, facilitates the students to learn at their own pace and promotes learning beyond the regular classroom boundaries. This paper discusses about the 3D simulation game for teaching concrete slab formwork to enhance the learning ability of the students. This paper also discusses about a usability study results of this game.

Keywords
3D, Simulation Game, Concrete, Formwork, Visualization

1. Introduction

The ability to visualize the built environment and learn construction processes is critical for students in the architecture, engineering, and construction disciplines (Irizarry et al., 2012; Nikolic et al., 2011). Due to lack of experience, it will be challenging for students to visualize the design assumptions, different components and construction processes of the concrete formwork (Wasim et al., 2011). Incorporating site visits in the curriculum helps the students to corroborate the learning components to the real world. Due to current COVID situation inclusion of site visits in the course became challenging. This pandemic has forced to change the teaching modality from in person face to face to online mode. This online teaching modality has added one more dimension of difficulty to engage and involve the students in the active learning environment. Some of these challenges faced by construction programs across the nation and the world can be addressed by using three-dimensional (3D) simulation games in construction education. Studies have demonstrated that the game-based approach can enhance students' learning process through their active participation (De Gloria et al., 2014). Virtual Constructor Simulator (VCS) was developed and implemented to engage students in active learning environment about planning and management of a construction project (Castronovo et al., 2015). 3D game environment was used to impart trench safety education to the construction trade students (Dickinson et al., 2011). The success of these 3D game learning environment in construction education motivated the authors to use 3D simulation game for teaching material quantity take off and construction process of concrete formwork. This 3D simulation game will create visual and kinesthetic learning environments and will actively engage students in the learning process in both in person face to face and online mode. This visual rich learning environment will improve the student visualizations skills and enhances their performance. The 3D simulation game will promote ubiquitous learning environments. For example, anytime time access facilitates the students to learn at their own pace and promotes learning environment beyond the regular classroom boundaries. This simulation game focuses on the material quantity estimation and construction aspects of concrete slab formwork. The authors want the game to be deployed on various platforms such as Mac, Windows and mobile phones. This can be accomplished by developing a game on an engine which has capability of publishing on multiple platforms. Considering all these requirements, Unity software was chosen to develop the 3D simulation game. Unity has powerful game development engine which can work on Mac and Windows. It has capability of deploying games on desktop, mobile, web and consoles. It can create standalone desktop game on PC, Mac and Linux operating system [Unity, 2021]. It can deploy games on major mobile ecosystems such as iOS, Android, Windows Phone 8 and BlackBerry 10 [Unity, 2021]. It can deploy on consoles such as Xbox one, Xbox 360, PlayStation, PlayStation Mobile and Wii-U [Unity, 2021]. It can provide stable and efficient web deployment on all major browsers such as Explorer, Chrome, Safari, and Firefox [Unity, 2021]. The following sections discusses about the 3D concrete slab formwork simulation game and it's usability study results.

2. 3D Concrete Slab Formwork Simulation Game

Formwork for concrete must be designed to support all applied vertical and lateral loads until these loads can be carried by the concrete structure itself. In general, formwork system consists of sheathing to retain concrete and supporting members necessary to hold the sheathing firmly in place. The typical components of slab formwork are shown in Figure 1. Members which provide support to the sheathing are referred as joists. The cross members which support joists are usually refereed as stringers. The vertical members which support stringers are referred as shores. Based on these concepts a 3D concrete slab formwork simulation game was developed. This game helps to understand design assumptions, to learn about the slab formwork components, to learn about the slab formwork construction steps, and to learn about the slab formwork material takeoff. In this project, plywood is used for sheathing and lumber is used for joists, stringer and shores. The 3D concrete slab formwork simulation game has five modules. These include (a) Main Menu, (b) Shop, (c) Cut, (d) Assembly and (e) Finish. The details of these modules are discussed below.

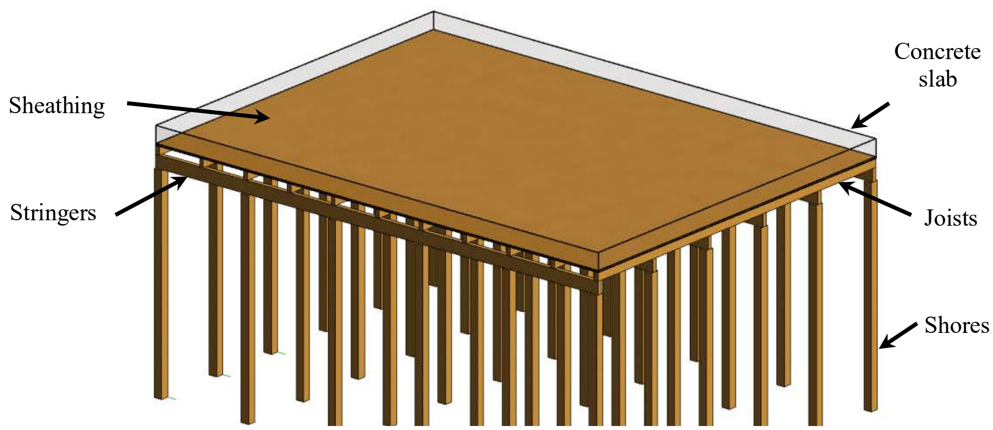

Fig. 6. Typical components of slab formwork

2.1 Main Menu

This component provides the details of the slab to be formed. These include design assumptions, cross section dimensions of members, plan and elevation views. Using this information, the player will estimate the required quantities of materials. A sample screen shot of the main menu interface is shown in Figure 2.

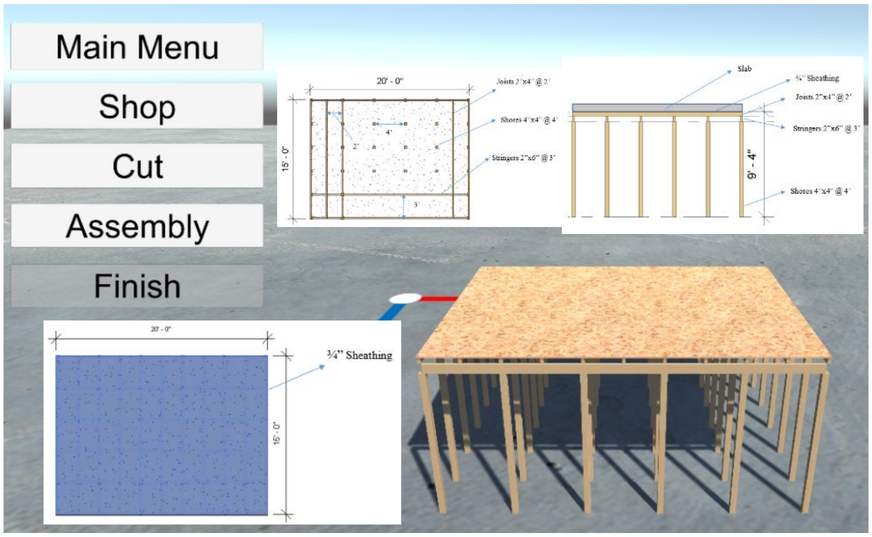

Fig. 2. A sample screenshot for Main Menu window of slab formwork

2.2 Shop Module

This portion of the game will test the players' understanding of the concept of material loss due to resizing and cutting, and the necessary additions to material dimensions for proper construction of the formwork, such as overlapped edges and how to maximize component pieces usage to reduce wastage. For example: The player will be asked to input the amount for each type of material which the player believes to be necessary for completing the formwork with as little waste as possible and without having to return to purchase additional materials. A sample screen shot of the shop interface is shown in Figure 3. Penalty will be imposed once the player buys the material and returns to the shop module to purchase more materials.

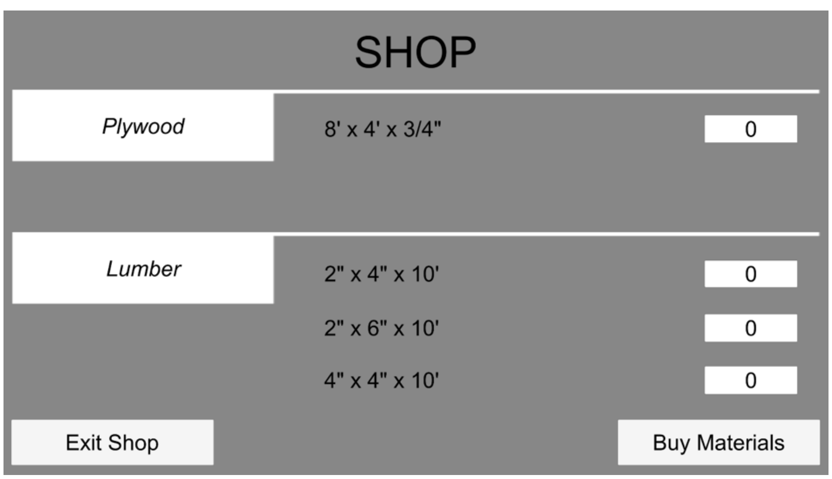

Fig. 3. A sample screenshot for shop window

2.3 Cutting Module

This component of the game deals with the cutting of the materials. Based on the size calculations, the player will be given option to cut the materials to the required dimensions size as necessary to built the formwork. Player must account for excess material needed for proper construction. A sample screen shot of the cutting interface is shown in Figure 4. Based on the purchased materials from shop module, the player is presented with the amount of available materials on left side. On right side, player will have drop down boxes to enter the required cut dimensions and quantity.

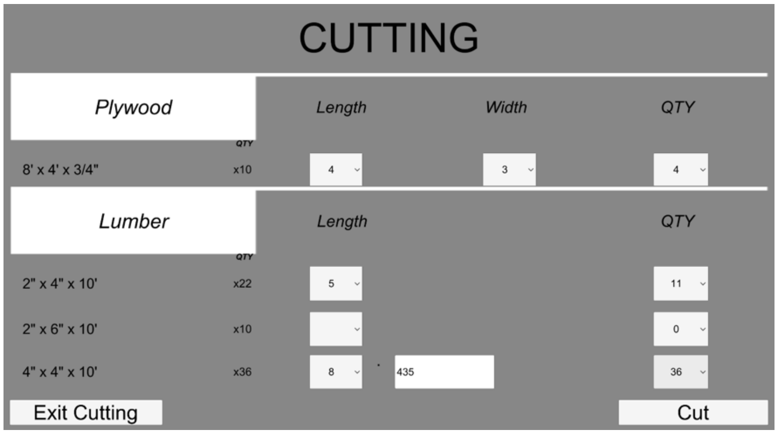

Fig. 4. A sample screenshot for Cut interface window

2.4 Assembly Module

In this module, using the stockpiles of cut formwork component pieces, the player will construct the formwork needed for the concrete slab. A sample screen shot of the assembly interface is shown in Figure 5. Based on the shop and cut module inputs, available materials inventory will be presented at bottom. In this view, a ghost image of the components to be placed is displayed. This will guide the player to snap the formwork components. The stock pile of the materials get dynamically updated as the player utilizes the material. Once the player snaps the component color changes to assigned material color. The player will have option to go to shop or cut module for making additional purchase or cut. However, these additional visits will come with penalty.

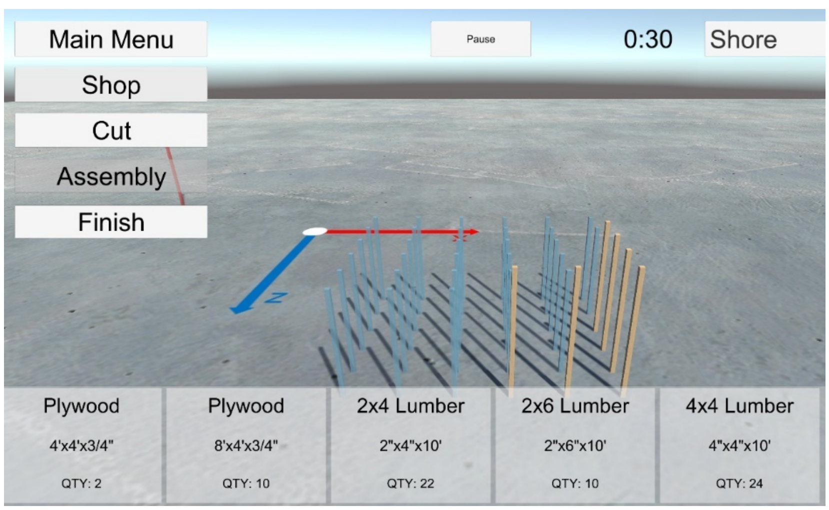

Fig. 5. A sample screenshot for Assembly of Slab formwork

2.5 Results Module

This module focuses on the assessment of the player's ability to learn concepts of concrete formwork. This is accomplished by grading shop, cut and assembly modules. In shop module, players are graded on how efficiently they select the quantities. Once the player purchases estimated quantities, then these quantities are compared with actual quantities for scoring. A penalty will be imposed for inaccurate quantity estimation and purchase. Inaccurate estimate includes a positive error (when the player estimates more than the actual) or negative error (when the player estimates less than the actual). In cut module, players are graded on how efficiently they choose what dimensions to cut. This is done by calculating how much waste material remains when cutting is completed and comparing it to a known lowest waste amount. In assembly module, players are graded based on the construction sequence of the formwork. The player construction sequence is compared with correct sequence and appropriate score will be awarded. A sample screen shot of the results interface is shown in Figure 6. In this screen, points gained in each step and overall points are displayed.

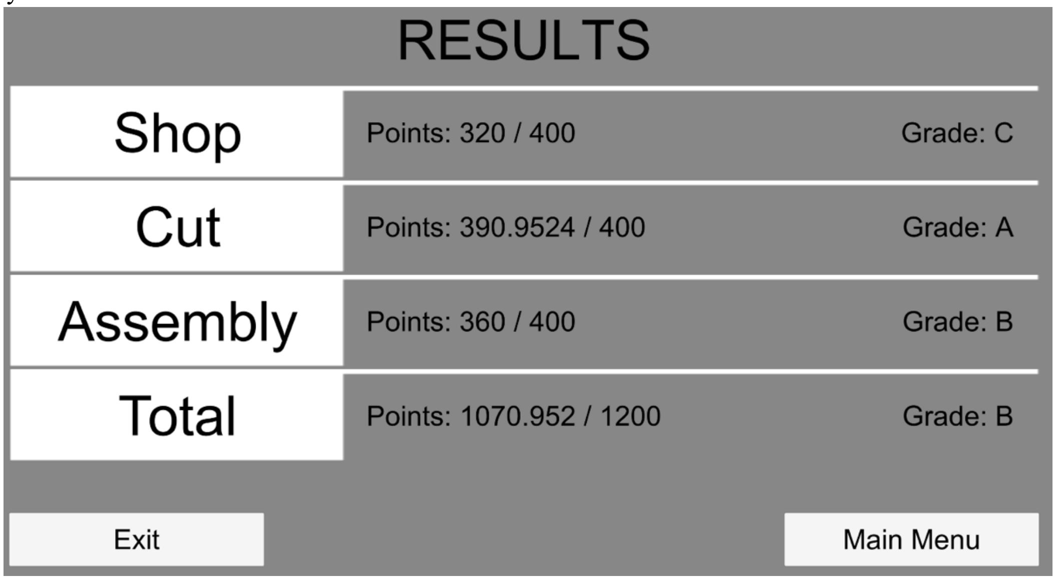

Fig. 6. A sample screenshot for Results of Slab formwork

3. Usability study

The game was developed by using Unity software. The game was evaluated by conducting twelve play test sessions by twelve different students. Four steps were included in each play test. They include i) instructions were provided to play the game; ii) students were given some time to practice and familiarize the navigation commands; iii) students were let to play the game and necessary help was provided when needed; iv) after finishing the game the students were asked to provide feedback about the usefulness of the game through a survey. The survey was designed to assess the usefulness of simulation game to help the students to understand design assumptions, to learn about the slab formwork components, to learn about the reducing the material wastage, to learn about the slab form construction steps, and to learn about the slab form material takeoff. Students were asked to express their satisfaction on these with 5-point Likert-type scale (1= Strongly Agree, 2 = Agree, 3=neutral, 4= Disagree, and 5=Strongly Disagree). The analyses of the results are shown in Figure 7. Most of the students were satisfied with the usefulness of simulation game.

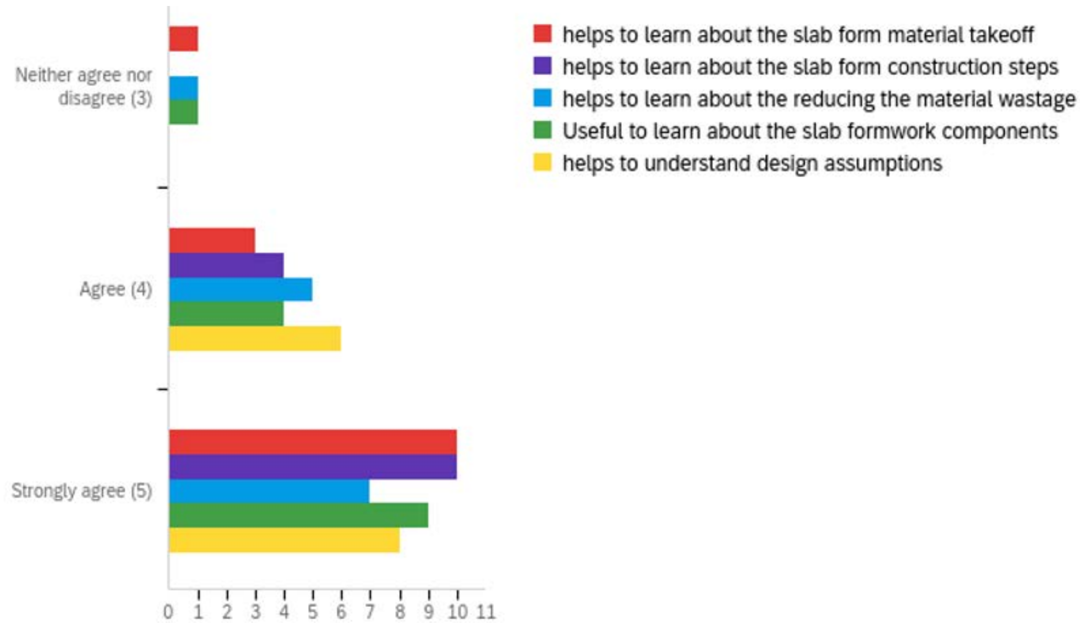

Fig. 7. Usefulness of simulation game survey results

The students were asked to express their satisfaction on ease of learning to play the simulation game with 5-point Likert-type scale (1= Strongly Agree, 2 = Agree, 3=neutral, 4= Disagree, and 5=Strongly Disagree). The analyses of the results are shown in Figure 8. Most of the students expressed their agreement with the statement "Overall, I am satisfied with ease of learning" (65% strongly agreed and 22% agreed).

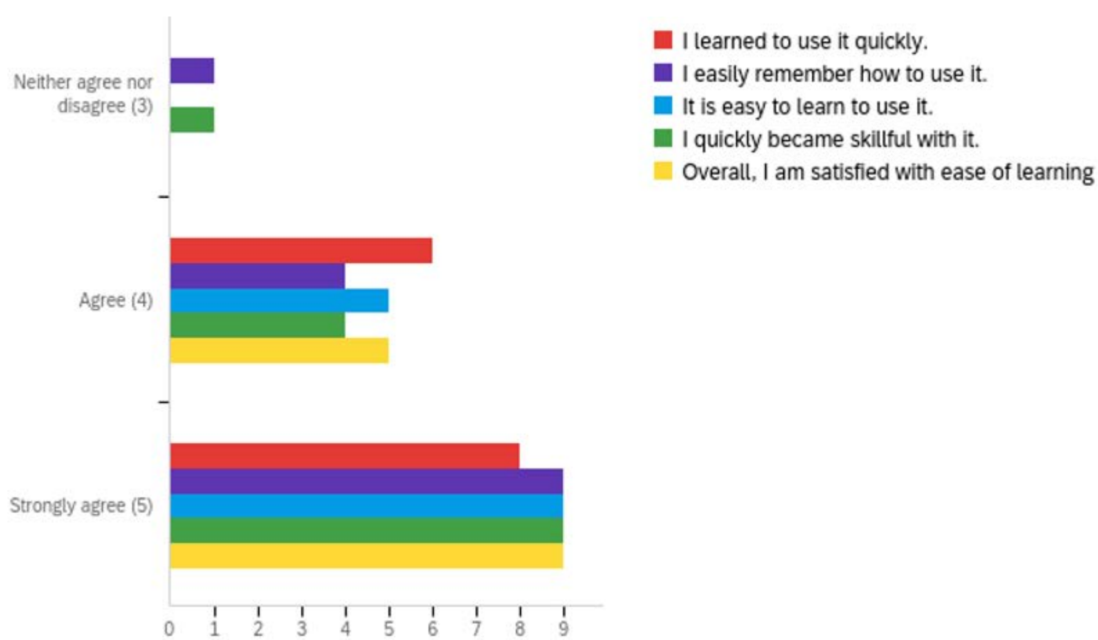

Fig. 8. Ease of learning to play the simulation game survey results

4. Conclusion

Concrete slab formwork 3D simulation game serves as a new teaching tool and helps to be more effective in communicating the information to the students. This learning environment provide 3D visualization and helps students to be actively engaged in the learning process. The 3D simulation game environment has the potential to make a paradigm shift in teaching and learning process. Although the game is proven to be effective for learning concrete slab formwork, there are some limitations to this study. They include 1) the number of paly test sessions were limited. The large number of play tests may reveal bugs which are not found at this stage; 2) the game simulates only slab formwork project further research may modify the game to make it capable of simulating different projects such as column and wall formwork projects. The framework of the slab formwork discussed in this paper serves as an initial step to further develop column and wall formwork 3D simulation games.

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ID 28

Willingness of Users to Adopt Blockchain Technology on Construction Projects

Benedict Amade[1], Achimba Chibueze Ogbonna[2], Leonard Chijioke Raphael[3], Dominic Anosike Obodoh[4] and Ogaga Linus Okore[5]

[1]Department of Project Management Technology, Federal University of Technology, P.M.B. 1526, Owerri, Nigeria
[2]School of Computing and Engineering Sciences, Babcock University Ilishan-Remo, Nigeria
[3]Department of Project Management Technology, Federal University of Technology, P.M.B. 1526, Owerri, Nigeria
[4]Department of Building, Nnamdi Azikiwe University, P.M.B. 5025, Awka, Nigeria
[5]Postgraduate Scholar, Department of Building, Ahmadu Bello University, Zaria, Nigeria
corresponding-author-benedictamade@futo.edu.ng

Abstract

This paper examined the main factors that influence the willingness and intention of construction project practitioners to adopt and use Blockchain technology in Nigeria. The examination has been done with reference to the UTAUT2 model and against the challenges identified in the general literature as being inherent in a developing country like Nigeria. [This seems redundant]. A quantitative approach and data surveyed from information and communication technology-savvy practitioners with regards to construction projects in Imo state, Nigeria, was utilized. Data analysis was achieved via Structural Equation Modeling (SEM) with the aid of IBM SPSS Statistics 25.0. The study's findings provide a framework which depicts the "intention to use and adopt" behaviours of practitioners in the Nigerian construction industry. Consequently, this study highlights trust, habit, perceived security, price value, and effort expectancy as the main constructs influencing users' willingness to adopt Blockchain technology in construction projects. This study provides an empirically based model of the factors influencing the intention to use and adopt Blockchain technology. The findings of this study provide impetus for decision-making in both the public and private construction project service sectors in terms of policy development and practical implementation as a catalyst to achieving better project outcomes in developing country scenarios where project performance remains most critical to economic development and growth.

Keywords

Blockchain, Construction projects, Technology, UTAUT2, Willingness of users to Adopt/Use.

1. Introduction

Blockchain technology, which emerged as a popular decentralised transaction and data management technology, enables the distribution of digital information without tampering (Trivedi, Mehta & Sharma, 2021; Wang, Wu, Wang & Shou, 2017). In a typical construction environment, data is accessed from a myriad of points via a central database. Hence, the main issue in this context is the issue of security, as the transaction data can be compromised by an intruder. According to Tezel, Papadonikolaki, Yitmen, and Hilletofth (2020), distributed ledger technologies (DLTs), of which Blockchain is a component, are continuously being explored by researchers and practitioners alike as a credible solution to the myriad of challenges hampering the performance of the construction industry. Business transactions should be less prone to disputes. There should be more transparency in collaboration, safeguards for private information, secure data storage and retrieval systems, and more secure and traceable data storage and retrieval systems.

As a compendium of existing technologies with new ways of looking at an existing phenomenon, the ideas behind digital signatures, hashing, cryptography, open-source and distributed systems, as critical components of blockchain (as applied to bitcoin cryptocurrency), are not new (Eze, Eziokwu & Okpara, 2017). However, what is of interest is how they could be deployed in the decentralisation and control of proof of ownership for both tangible and intangible assets. As opined by Grover, Kar and Janssen (2019), blockchain has the potential to entrench a lot of transformations in the socio-economic and political environment. A lot of people are talking about it now, but its main use and spread has been in the finance industry. Other industries are starting to think about its potential and how it could change their businesses for the better.

Information on technology adoption is important for making an informed decision when investing in a competitive venture. In light of the preceding assertion, studies on technology adoption exist, resulting in theories to provide information on the strength (s) and relationships among interacting factors (Awa, Ukoha, & Igwe, 2017). A synthesis of existing models on technology adoption (acceptance) has been carried out by researchers like Venkatesh, which gave birth to the unified theory of acceptance and use of technology (UTAUT) model (Venkatesh, Thong & Xu, 2012). The model synthesised existing components from the following models: theory of reasoned action, motivational models, TAM and TPB models, PC utilisation model, theory of planned behaviour, innovation diffusion theory, and the social cognition theory (Ajzen & Fishbein, 1980; Ajzen, 1991; Davis, 1989; Rogers, 2003). Not satisfied with the outcome of the UTAUT, an extended investigation was carried out with the view of ameliorating previously articulated constructs which later metamorphosed into the UTAUT2 model. The UTAUT2 was developed from the initial UTAUT model and was adjudged to be convenient for the user's intention or willingness to adopt. The ability to predict an individual's reactions and temperament towards various types of technology was found as a component embedded in UTAUT2 (Tamilmani, Rana, Prakasam & Dwivedi, 2019; Venkatesh et al., 2012).

As shown in the literature, Blockchain technology has begun to gain more ground in other industries compared to the construction industry (Belle, 2017). The willingness of users (practitioners) in the construction industry to deploy this technology specifically to the Nigerian environment has not been established. Accordingly, this study intends to empirically study and validate, amongst other important aspects, the user's perceived satisfaction and security towards Blockchain technology adoption on construction projects, hence filling the gap and doing so using construction projects within Imo State of Nigeria. As a result of these and other factors, Imo State was chosen. Imo State is located at the crossroads and represents the construction industry in Nigeria's "Niger Delta," which is a group of states. It is also known as the "Eastern Heartland."

Next, we explain the theoretical framework and conceptual model. Then, we show how we used structural equation modelling (SEM) to look at the data. Finally, we talk about some of the limitations of the study and suggest ways to improve it in the next section, which is called "Theoretical Framework and Model."

2. Literature Review

A blockchain is defined as a distributed public ledger that records all transaction data exchanged between parties within the system. As a result, it offers a consistent and coordinated record of transactions for all parties involved in a business network. To complete a data transaction, the confirmation of all system participants is required. The blockchain ledger records every sequence of transactions from beginning to end, resulting in certain, verifiable, and immutable records of all transactions ever made (Ahmadisheykhsarmast & Sonmez, 2018). While Shojaei, Flood, Moud, Hatami, and Zhang (2020) identified Blockchain as a Distributed Ledger Technology (DLT) that is simply a transaction database, Blockchain transactions are stored on multiple network nodes, making the system completely decentralised.

Transactions are synchronised on a regular basis, ensuring that the scheme is always up-to-date. Satoshi Nakamoto, the creator of the cryptocurrency Bitcoin, invented blockchain technology (Grover et al., 2019). But what is being watched today in all parts of the world is not only the power of crypto curriculars that are changing global business and finance, but also the potential behind the fundamental technology behind Bitcoin, known as blockchain technology (San, Choy, & Fung, 2019), which many other industry experts are interested in attempting to discover and develop.

As Li, Greenwood and Kassem (2019) say, the unchanging, transparent nature and redefining of trust relationship by offering fast, stable and publicly or privately sourced solutions are key advantages. Blockchain has been described as an “internet of value”, and its effect over the next 10 to 20 years may be close to that of the internet due to its decentralization and irrevocable existence (Li, et al., 2019).
It can alter the way applications are created, productivity is generated, and digital transformation is done in many industries, maybe all of them, including the construction industry. Distributed ledger technologies (DLTs), such as blockchain, are being looked at more and more as a way to improve the efficiency of the construction industry. These technologies could help with open communication, safe and traceable data storage and retrieval, smoother business transactions, and protected privacy and intelligence (Tezel et al., 2019).

2. 1 Blockchain in Construction

According to a study conducted by Research and Markets (2018), more than 80% of new construction activities will incorporate at least one form of emerging technology or related smart building technologies. At this point, the commercial smart building market is projected to expand almost tenfold to more than $51 billion globally by 2023 over the next five years. Owing to its inefficiency, low productivity, and automation, the construction industry is frequently criticised (Hamma-adama et al., 2020; Shojaei, 2019; Teisserenc & Sepasgozar, 2021).

The construction industry's disaggregated structure, its sequential existence where work needs to be performed in a sequential and chain-like framework, and the number of stakeholders involved in each project with different interests are defined as the root causes of its problems. They address the disintegrated structure of the construction industry, the order in which the work must be carried out in a sequential and chain-like manner, and the number of stakeholders involved in each project with different interests. As a result, manual reporting has become difficult and costly to coordinate all the operations, contract management, claims, and supply chain management needed. In the case of project design and management in a Block Chain Building Information Model (BIM) integrated with a self-imposing intelligent contract supplied in a larger circular economy by selected suppliers controlled through a blockchain network, blockchain may provide a direct solution to each of these problems or a holistic framework (Shojaei, 2019). As Faraji (2019) says, blockchain technology can revolutionise all of the construction industry's numerous stakeholders.

In any relationship, it can potentially bring several benefits, such as building trust, transparency, decentralization, transparency, immediacy, intermediary elimination, transaction automation, unchangeable records, democratising and distributing transactions, network sharing principles, and reading only reports (leaders). Moreover, blockchain technology makes transactions much more transparent than centralised networks do. However, disseminated network-based trust (i.e., other Blockchain users) is not used to execute transactions (Hamma-adama et al., 2020). As noted by Hewavitharana, Nanayakkara, and Perera (2019), one of the notable advantages of blockchain technology is its use to make payments without evidence and enforce trust.

Intelligent contracts use technology to eliminate delays and interruptions, as well as reduce paperwork in construction contract decision-making processes. Belle (2017) also reiterated that today, DLT and smart contracts are driving the growth of business models in sectors that depend heavily on financial transactions and information sharing, and if successful, not only services and products will change profoundly, but also the way work is organized. Compliance with trust in the construction industry is always difficult, and the use of blockchain in contractual construction management is one sure way of maintaining trust between all parties (Shojaei et al., 2020).

2. 2 Theories for Technology Adoption- A UTAUT2 Approach.

To solve problems, Awa et al. (2017) claim that the use of technology is dependent on information. Recent decades have seen a surge in interest in the adoption, purpose, and use of ICT (Merhi, Hone, & Tarhini, 2019; Venkatesh et al., 2012). Users' tolerance, acceptance, and satisfaction with technology have been extensively studied in the academic literature. Ajzen (1985), Davis (1989) and Venkatesh et al. (2003) have all proposed TPB (Ajzen, 1985) and TAM (Venkatesh et al., 2012) theories. This paper's final section discusses UTAUT 2. People use ICT for planning, as well as adoption and implementation. TAM was also mentioned by Venkatesh et al. (2003) as a common way to study how people like new technology.

Due to TAM's shortcomings, a lot of research has gone into developing new constructs and models (Benbasat & Barki, 2007). UTAUT was developed to address the shortcomings of later theories and models (Hujran, Abu-Shanab, and Aljaafreh, 2020). People's behavioural intentions (BI) are influenced by four key predictor variables. Effort expectancy, social influence, perceived expectancy, and facilitating conditions are the main designs. Existing theories have benefited from UTAUT's essence. When compared to previous theories, UTAUT can detect roughly 70% of variances in adoption intention (Tamilmani, Rana, & Dwivedi, 2019; Venkatesh et al., 2003; Hujran et al., 2020).

On the other hand, UTAUT's methodology lacks parsimony and power to justify its use (Casey & WilsonEvered, 2012; Van, Raaiji, & Scheppers, 2008). This led to the creation of UTAUT 2 by Venkatesh et al. Recent updates focus on variables that influence individual customer or user behaviour. Hedonic motivation and price appreciation are involved. For organisations and customers/users, this inclusion has increased the approach's generalisability. UTAUT 2 described more differences in people's attitudes toward technology than UTAUT did.

Perceived protection and privacy as key components of technology adoption issues were recognised in the current study model by Gutierrez et al. (2018) and Chopra, Korfiatis, Sivakumar, and Lytras (2018). These factors are shown and explained in great detail in the next parts of this work, which is based on the UTAUT 2 model.

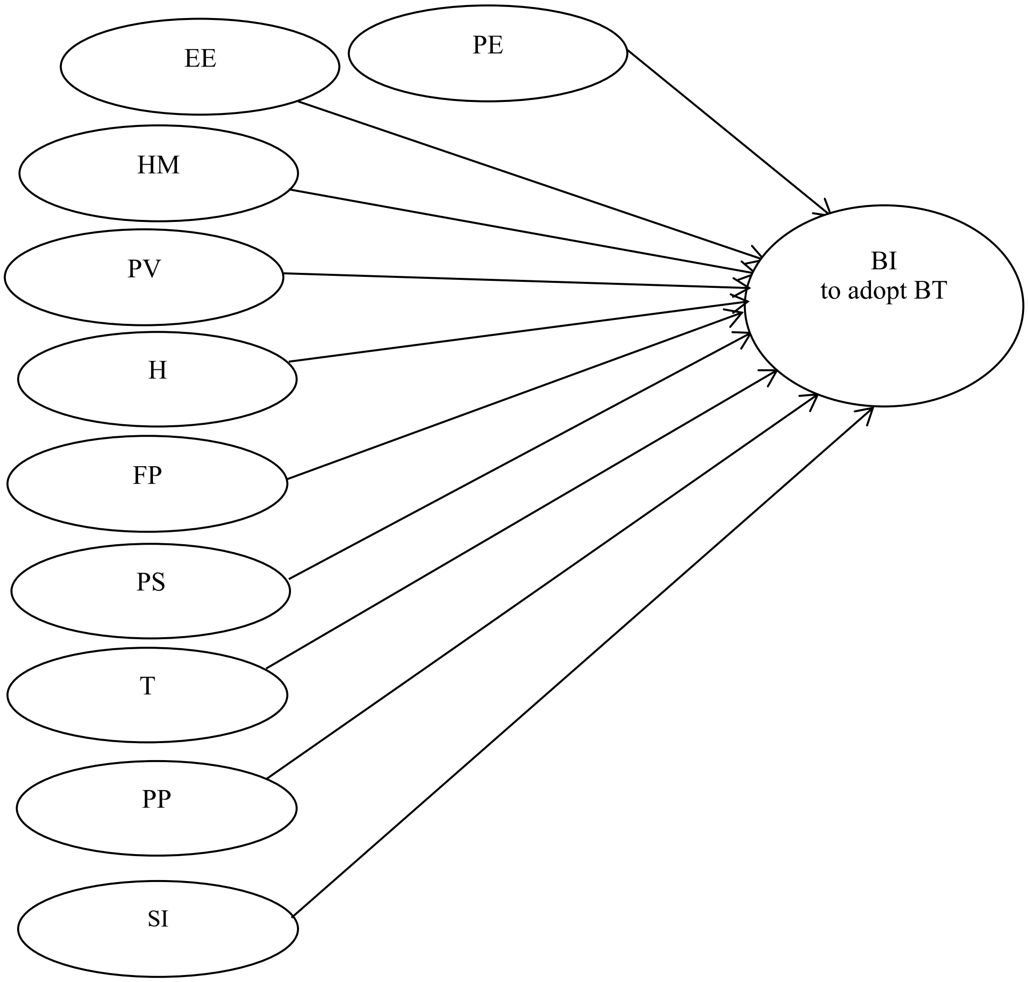

Fig. 7. Conceptual framework model.

Performance expectancy (PE)

Performance expectancy is the degree to which a client accepts that a thing will give them an advantage in performing specific tasks using a new innovation (Alazab, Dick, and Maleki Far, 2020; Venkatesh & Davis, 2000). Earlier literature on technology adoption and appropriation found this construct to greatly influence users' goal of embracing technology. Thus, clients may be happier with Blockchain technology if they perceive it as more beneficial and profitable in their job functions. Also, the following hypothesis is proposed:

H1: Performance expectancy will affect user's readiness to adopt BT on construction projects.

Effort expectancy (EE)

Effort expectancy is associated with ease of use of IT. If clients believe they can use IT without major issues and can do so purposefully, they are more likely to achieve normal performance (Zhou, Lu, & Wang, 2010). The following hypothesis is proposed:

H2: Effort anticipation will affect client's eagerness to receive BT on development ventures.

Hedonic motivation (HM)

It is particularly important in decisions involving new technologies and interpersonal interaction tools (Brown & Venkatesh, 2005). Venkatesh et al. (2012) define hedonic motivation as pleasure and enjoyment gained from using specific technologies. So, here's the hypothesis:

H3: Hedonic motivation will affect user's eagerness to embrace BT on construction projects.

Price Value (PV)

Prices of goods and services have varying effects on users' choices. Venkatesh et al. (2012) link user satisfaction to the cost of implementing new technologies like blockchain. Similarly, users will not be fully satisfied with their BT experience if the apparent benefits do not match the financial costs. As required, the following hypothesis is proposed:
H4: Price value will affect user's readiness to adopt BT on construction projects.

Habit (H)

Habit is a factor that influences users' ability to select and use IT services. Repeated movement or action can lead to a daily routine or habit (Ajzen & Fishbein, 2000). Adults, according to Venkatesh et al. (2012), rely on their habits, abilities, and schedules. As a result, the following hypothesise:
H5: Habit will affect user's ability to adopt BT on construction projects.

Facilitating conditions (FC)

The assets and backing available to perform a certain behaviour are described by Brown and Venkatesh (2005; Venkatesh et al. (2003) as "facilitating conditions." Using technologies, such as mobile shopping apps, requires certain assets and skills, such as using a phone or tablet, connecting to the internet, installing apps, and knowing a lot about mobile service transporters and security, according to Chopdar et al. (2018). A good set of enabling conditions will therefore encourage more people to use shopping apps. The following hypothesis is advanced:
H6: Facilitating conditions will affect user's readiness to adopt BT on construction projects.

Perceived security (PS)

The user's perception of danger is based on their vulnerability or fear of the consequences of their actions. Slade, Williams, and Dwivedi (2013) discovered that perceived security/danger is the second most important indicator of behavioural intentions. Merhi, Hone, and Tarhini (2019) agree that security flaws were frequently considered to prevent customers from accessing sensitive data online. Furthermore, mobile security breaches impacted mobile technology adoption rates. The hypothesis is as follows:
H7: Perceived security will affect user's ability to adopt BT on construction projects.

Trust (T)

Trust is an emotional belief that someone will keep their promises, and it plays a big role in questionable financial transactions where the system's clients are vulnerable to financial loss. According to Slade et al. (2013), trust is higher in electronic exchanges due to anonymity and lack of meaningful gestures. Thus, trust is assured when a domain has sufficient capacity, consideration, and respectability (Merhi et al., 2019). Trust, due to its opposite relationship to risk, was discovered to be an important influencer of embracing technology. Thus, greater trust in an innovation reduces perceived risk and influences the social goal. The hypothesised theory is:
H8: Trust will affect user's readiness to adopt BT on construction projects.

Perceived privacy (PP)

In this context, perceived privacy refers to a person's right to control the collection and use of personal data. In addition, it prevents unauthorised data exposure (Merhi et al., 2019). The following theory is proposed:
H9: Perceived privacy will affect user's readiness to adopt BT on construction projects.

Social Influence (SI)

Venkatesh et al. (2003) claim that social influence reflects how much an individual believes the importance of others will empower others to accept the use of new technology. They define social influence as the impact of a person's circle of friends or climate, including reference groups, family, companions, and partners, on their desire to receive an IT facility. Also proposed is the following hypothesis:
H10: Social influence will affect user's ability to embrace BT on construction projects.

Behavioural Intentions (BI)

Behavioural intentions depict an individual's willingness to engage in a specific action (Ajzen, 1991). Due to the fact that intentions are frequently viewed as preceding conduct, it is generally agreed that intentions have a huge impact on usage conduct (Gupta & Dogra, 2017). They also stated that people will generally participate in specific activities if their intentions are positive.

3. Materials and Methods

This study's population included users of Blockchain technology on construction projects in Imo State, Nigeria. The population is made up of professionals from various fields. Practitioners are concerned about rising IT demand and internet use in the construction industry, both formal and informal.

The study used non-probability sampling to find Blockchain users in Imo state. Purposive sampling was chosen for this study because it increases the likelihood of receiving accurate and reliable information. This study was conducted in Imo state from June to October 2020. It included data collection from built environment professionals. A self-administered questionnaire was given to the targeted participants.

The objects were rated on a five-point Likert scale. View, action, and attribute are the three types of data variables used in this study's questionnaires. The principal model constructs were calculated using previously validated scale items. For example, the UTAUT2 system has been adopted (Venkatesh et al., 2003; Venkatesh et al., 2012). Items for perceived privacy and protection were created to match the function that best describes users' understanding of Blockchain technology. So far, 232 of the 250 questionnaires have been returned, and 211 are useful for further statistical analysis. This is a 92.8% response rate. Prior to the main survey, a small sample of 30 practitioners was used to test the survey's reliability. All Cronbach alpha values were above the recommended level of 0.70 (Su & Yang, 2010). The aim of the empirical study was to apply structural equation modelling to the adapted UTAUT2 model (SEM). SEM has become the dominant method for testing social science theories in research related to information systems and technologies. To use constructs in indicator variables while accounting for measurement errors (Amade et al., 2019; Memon et al., 2013). SEM was developed to help clarify the cause-and-effect relationship between dependent and independent constructs in exploratory science. The method also aids in predicting a set of relationships hypothesised to better understand dependent variables' contradictions (Memon et al., 2013).

3. Results

3. 1 Results and analysis

A CFA was used to estimate the measurement model's fit. The findings were based on common model-fit measures (Su & Yang, 2010). The CFA model fit results are shown in the tables below. The measurement model's adequacy was assessed based on the results of reliability, convergent validity, and discriminant validity. First, composite reliability (CR) values were examined. Table 1 shows that all values are above 0.7, indicating the composite's sufficiency and reliability (Memon et al., 2013). The average variance extracted (AVE) for all variables was higher than the threshold value of 0.5, indicating the scale's convergent validity (Memon et al., 2013). The AVE of each latent factor is compared to the squared correlation coefficients between potential variables to determine discriminant validity (Amade et al., 2019). Table 2 shows that the squared correlation coefficients between possible variables are less than 1, indicating discriminant validity. SEM was used to test hypotheses using IBM SPSS Statistics 25.0. Thus, determining the model's goodness-of-fit for each variable is critical before evaluating the hypotheses via path coefficients using SEM. Thus, the goodness-of-fit metrics (X2 = 477.612, df = 210, p = 0.000, CMIN/df = 2.274, RMR = 0.052, GFI = 0.875, NFI = 0.855, IFI = 0.924, CFI = 0.918, RMSEA = 0.053) were identified. Table 3 shows the results of the hypothesis testing for each variable. PE (t = -10.278, β=-0.831, p = 0.082) had no significant positive impact on practitioners' behavioural intentions to adopt BT, thus not promoting H1. H2 was found to be enhanced by the use of the EE (t=2.254, β= 0.138, p=0.025). The HM (t = -4.06, β=-0.234, p = 0.069) had no significant impact on BT intentions, thus denying H3. PV (t = 8.790, = 0.641, p = 0.000) has a positive effect on the purpose of use, supporting H4. The H (habit) (t = 10.482, β= 0.907, p = 0.000) agreed with H5. FC (t = -7.570, β=-0.707, p = 0.078) harmed the purpose of continuous use, thus rejecting H6. As shown in t = 8.443, p = 0.000, perceived security (PS) influences the purpose of use, H7 is proposed. The purpose for continuous use was not influenced by trust (T) (t = 9.457, β= 0.999, p = 0.000). The effect of perceived privacy (PP) (t = -6.789, β=-0.438, p = 0.087) on the purpose of continuous use supports H9. SI (t =-8.732, β=-0.334, p = 0.064) had no effect on BT intention, ruling out H10.

Table 10. Measurement level.

Variable Item	Average Variance Extracted	Construct Reliability	Standardized Loading
PE	.848	.854	.886
EE	.804	.911	.903
HM	.881	.854	.833
PV	.755	.808	.824

H	.811	.934	.929
FC	.750	.806	.753
PS	.747	.817	.816
T	.906	.780	.917
PP	.852	.700	.892
SI	.648	.718	.785

Table 2. Discriminant validity amongst variables.

	PE	EE	HM	PV	H	FC	PS	T	PP	SI
PE	1.000									
EE	.352	1.000								
HM	.249	.303	1.000							
PV	.210	.236	.676	1.000						
H	.720	.148	.100	.021	1.000					
FC	.151	.152	.625	.471	.254	1.000				
PS	.017	.032	.498	.591	.473	.646	1.000			
T	.143	.427	.831	.656	.006	.555	.483	1.000		
PP	.507	.013	.220	.422	.545	.003	.152	.060	1.000	
SI	.117	.188	.472	.167	.225	.370	.409	.689	.466	1.000

Table 3. Path coefficient and level of significance.

Variable Item	Beta	t-value	p-value	Decision
PE-BI	-.831	-10.278	.082	Not supported
EE-BI	.138	2.254	.025	Supported
HM-BI	-.234	-4.067	.069	Not supported
PV-BI	.641	8.790	.000	Supported
H-BI	.907	10.482	.000	Supported
FC-BI	-.707	-7.570	.078	Not supported
PS-BI	.640	8.443	.000	Supported
T-BI	.999	9.457	.000	Supported
PP-BI	-.438	-6.789	.087	Not supported
SI-BI	-.334	-8.723	.064	Not supported

Note: Critical t-values. *p<.05*

4. Discussion

We found a link between BT willingness and trust, habitus, perceived security, price value, and effort expectancy. We found that trust influences willingness and intention to adopt BT (supporting the H8 hypothesis). This matches most other studies (Merhi et al., 2019; Slade et al., 2013). Trust is a key ingredient in all construction contracts. If practitioners must use BT on their projects, they must be assured that BT is trustworthy.

The willingness of practitioners to use/adopt BT was found to be significant (supporting hypothesis H5). The findings of this study suggest that perceived security influences practitioners' willingness to use/adopt BT (accepting hypothesis H7). This result contradicts other recent IT studies (Chen et al., 2020; Kwateng et al., 2018; Hujran et al., 2020), which never integrated security with emerging technology adoption. Those considering BT need assurances that unauthorised access and data theft are prevented. This is vital. Moreover, our findings show that price value influences willingness to adopt BT (accepting hypothesis H4), which is supported by previous research (Kwateng et al., 2018; Merhi et al., 2019).

As a result, prospective users of emerging technologies will never be satisfied with their experience if the perceived benefits outweigh the financial costs. This finding confirms that professionals in construction projects prioritise BT price over other factors. Finally, the willingness to adopt and use BT influenced effort expectancy (accepting hypothesis H2). Several previous studies found effort expectancy to be a barrier to BT adoption (Merhi et al., 2019; Kwateng et al., 2018). However, in the study by Chen et al. (2020), the outcome supports theirs. As a result, practitioners perceive BT as simple to learn and apply on their construction projects.

5. Conclusions

Using the UTAUT 2 model, the paper examined the effects of users' intent to adopt Blockchain technology on their construction projects. This study filled a gap in the literature by focusing on Blockchain adoption on construction projects in Imo State, Nigeria.

Perceived security, trust, privacy, social influence, and performance expectancy were examined theoretically and empirically in relation to users' behavioural intentions to adopt blockchain technology. The findings reveal five major influences on a user's willingness to adopt Blockchain technology. For example, expectancy of effort and trust. They describe a situation where a user feels comfortable using Blockchain applications because practitioners and clients trust each other. The model produced stable results that supported most of the proposed constructs. The study's findings add to the existing literature by revealing the willingness to adopt Blockchain technology. From a consumer perspective, this study adds to the body of knowledge on how people view common technology in construction.

As this paper focused on Blockchain technology, future research studies will need to expand the model with additional constructs to provide a more detailed view. Further research could examine the direct and indirect effects of normative values on usage behaviour. This study also did not examine the moderating effect of certain characteristics, which could theoretically alter the model's relationships. Future studies may also test the model in new locations, helping to generalise the findings.

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ID 29

Systematic Literature Review on Sustainable Construction Strategies for the Development of Affordable Housing

Traci-Lee Ferlito[1*], Innocent Musonda[1], Motheo Meta Tjebane[1], Adetayo Onososen[1]

[1] Centre of Applied Research and Innovation in the Built Environment
Department of Construction Management and Quantity Surveying, University of Johannesburg, South Africa
t.ferlito@gmail.com

Abstract

The building industry plays a critical role in attaining sustainable development. Despite its substantial contribution to nation-building, the construction industry has a significant environmental impact in both industrialized and developing countries. Even though sustainability is a global issue, developing countries must approach it differently than developed countries, and alternative strategies must be embraced and implemented. In this research, SLR was performed to understand sustainable construction strategies for the development of affordable housing. Using the PRISMA model, we selected and analyzed 22 papers published between 2011 and 2021. The publications were sourced from ScienceDirect, Scopus, Emerald Insight, Sage Journals and Engineering Village through conferences and journals. The systematic review indicates using affordable, locally sourced building material as a sustainable, affordable housing development strategy.

Keywords
Construction, Housing, Systematic Literature Review, Sustainable, Sustainability.

1. Introduction

Due to reasons such as human population increase, natural catastrophes, and conflict, global housing demand has reached unprecedented levels. This is especially true in developing nations, which have been subjected to disproportionately high demand due to their inherent fragility. Many existing approaches to housing delivery in poor nations continue to rely on inefficient and unsustainable building technologies and execution procedures. As a result, affordability and sustainability have become critical issues in the international development debate over housing the poor in developing nations in order to satisfy long-term sustainable development goals and housing demands (Bruen et al,2013).

The building industry plays a critical role in attaining sustainable development. Despite its substantial contribution to nation-building, the construction industry has a significant environmental impact in both industrialized and developing countries. Land degradation increased energy consumption, which has resulted in pollution in recent years (Du Plessis, 2007). The rate of urbanisation is increasing exponentially. Slums and informal settlements are among the challenges facing urban housing policymakers globally. The number of informal housing inhabitants increased from 689 million to over 880 million in the space of 24 years. This drives the need for infrastructural growth (Cheah et al, 2020). Furthermore, implementation is critical in South Africa, where sustainable construction principles are little known (Marsh, 2020). When well-planned and managed, cities produce value, which is defined as the total of all economic, social, environmental, and intangible circumstances that can improve citizens' quality of life in meaningful and tangible ways (Un Habitat; 2020).

Sustainable development creates a one-of-a-kind social, psychological, and physical environment in which people's behavior is harmoniously adjusted to improve the present and provide for the future. Many countries are unaware of the need of environmentally friendly building. Some writers blame a lack of sustainable building design training and education, a clear conceptualization of sustainability, a clear argument for sustainability advantages, and a lack of long-term sustainability perspective on a lack of sustainable building design training and education (Ganiyu, 2016:). The lack of a precise evaluation instrument to analyze building design, as well as the unwillingness of construction industry practitioners, have all been identified as hurdles to the adoption of sustainability in construction.

Sustainable houses remain at a high rate of need among the citizens. Affordable housing is a basic requirement for human well-being and a fundamental human right. The construction of affordable housing is promoted as a tool to alleviate concentrated poverty, enhance access to opportunity, and improve affordability for many populations viewed as necessary or desirable to a community (Muazu et al, 2011). This becomes a challenge for the government and the built environment to provide the public with other infrastructure such as energy and water in a healthy and adaptive climate (Li et al., 2019). The housing sector is a major consumer of global energy and a contributor to CO2 emissions. Heating and hot water provision among private households account for 40% of the total energy consumption and 25% of greenhouse gas emissions, while 54% of electricity is used to run homes (Adabre et al, 2019).

It is crucial for the construction industry's future and its environmental impact. In Africa, green architecture is viewed differently. It looks at traditional construction methods, energy-saving, and promoting material reuse in a variety of ways. Due to expense, governance, and a lack of technology, it is environmentally cautious and mindful of waste management. Despite these obstacles, numerous institutions are attempting and making success.

Research on sustainable construction strategies for affordable housing development is relatively low in the South African context. Most research has focused solely on sustainable construction (Aigbavboa et al, 2017; Oke et al, 2017; Mashwama et al, 2020) and affordable housing (Butcher, 2020; Othman et al,2011; van Niekerk, 2018) separately. The study of (Massyn et al, 2015) looked at the economics of providing well-located housing in the inner city of Cape Town, South Africa. Moreover, (Ndlangamandla et al, 2019) looked at sustainable construction practices used in developing self-help housing and upgrading informal settlements that are believed to affect the natural environment negatively. An investigation and interrogation are required to implement sustainable practices in South Africa properly.

A complete investigation of the link between innovative and sustainable cities is needed, according to studies, with an emphasis on practical applications that might lead to a deeper knowledge of the domains, typologies, and design principles involved (Angelidou, M et al., 2018). The goal is to discover and connect all three pillars of sustainability: social, economic, and environmental sustainability. In terms of research, sustainability in house development is still in its infancy in South Africa. South African research on this area appears to be underexplored in their efforts. Many articles discuss sustainability in terms of its environmental, social, or economic implications, but few examine it in terms of all three and how they interact and are implemented. Articles like (Masia et al, 2020) focus on energy, water, and resource efficiency, even though there are numerous new technologies and approaches to quantify sustainability. The most notable difference in this study and others is that it will use a mixed-method approach.

2. Review Method

To understand the state-of-the-art strategies on sustainable construction for the development of affordable housing prioritization, a Systematic Literature Review (SLR) was adopted from (Rouhani et al, 2015) and (Lenarduzzi et al, 2021). The SLR method allows researchers to probe into existing scholarly articles. The advantage of an SLR is that it provides transparent and explicit protocols by which researchers search for and assess the field of studies relevant to a specific research topic. It has been widely used in business and management (Tian et al, 2018). For this study, the review protocol was developed jointly by the authors of this paper. In contrast, the corresponding author identified and selected the primary studies following the specified protocol. All the steps of the protocol are described below in this section. The review protocol for the study was designed collaboratively by the authors of this work. This is to help systemically to identify and select the primary papers according to the protocol. The section below describes all the steps of the SLR.

2.1 Research question

Defining and describing sustainability implementation is not a new problem. Over the years, different approaches, methods, and methodologies have been proposed to describe sustainable construction implementation practices. However, little research explains how the strategies enable sustainable construction in the development of affordable housing. As a result, aligned with this paper's overall purpose and research questions, the systematic literature review set out to synthesise existing knowledge of SSCI and answer the research questions. The SLR research questions that we intend to answer in this research are as follows:

RQ1: What are effective strategies for the implementation of S.C. in the South African Construction Industry?

2.2 Search String and process

Mathematical sets and database logic are built on the foundation of Boolean operators. They link your search terms together to narrow or extend your results set. AND, OR, and NOT are the three basic Boolean operators.
The benefits of using Boolean operators are:

- To narrow down a search, especially if your topic has several search terms.
- To link together disparate pieces of data to locate exactly what you're looking for.

Search strings were applied to ensure the availability of relevant publications to grab the most relevant and updated information related to the topic. This SLR concentrated on searching in scientific databases because that is the major research result compared to just in books and reports. Databases allow researchers to see how many times an article was cited. Keyword and search strings were conducted on Emerald Insight Engineering Village, Sage Journals, ScienceDirect and Scopus to retrieve relevant articles for the SLR. The following sources and search strings have been selected to perform the SLR search process:

Table 11: Search databases and strings

Database	Website	Search String
Emerald Insight	https://www.emerald.com/insight/	sustainable construction strategies for the development of affordable housing
Engineering Village	https://www.engineeringvillage.com	Sustainable Construction Strategies for the Development of Affordable Housing
Sage Journals	https://journals.sagepub.com/	sustainable construction strategies for the development of affordable housing
ScienceDirect-Elsevier	https://www.sciencedirect.com	sustainable construction strategies for the development of affordable housing
Scopus	https://www.scopus.com	TITLE-ABS-KEY (sustainable AND construction AND strategies AND for AND the AND development AND of AND affordable AND housing)

2.3 Inclusion and exclusion criteria

The inclusion and exclusion criteria were devised and strictly followed by authors to select primary studies. This is to be used to exclude studies that are not relevant to the research questions. This inclusion criteria were meticulously curated to obtain the most up-to-date, influential, topic-relevant, and correct data in order to provide the best contribution and dissemination of information in the field of sustainable construction. The table below shows the defined inclusion and exclusion criteria.

Table 12: Inclusion and Exclusion Criteria

Criteria	Assessment Criteria
Inclusion	research articles relating to the sustainable construction of affordable housing
	The publications made between 2011 and 2021
	Publications that are written in English
	Peer-reviewed publications
	Publications which are conference papers or journal articles
	subject areas of Social Sciences, Environmental Sciences and Engineering
	Open Access publications
	Papers that are not entirely written in English

Exclusion	Papers from newspapers, blogs and technical reports
	Publications where the full paper cannot be Located
	Papers not within a selected discipline
	Papers not within the 10-year range

2.4 Data analysis

Atlas.ti is a qualitative research tool that allows you to code and analyze transcripts and field notes, as well as write literature reviews, create network diagrams, and visualize data. We may use Atlas.ti software to query data and analyze qualitative data in a systematic and transparent manner. Questions can be asked and answered rapidly with data that would otherwise be buried. There will be no educated guesses. Another advantage is that the results can be double-checked by a third party, ensuring that they are completely accurate. As a result, the information added to scientific and human knowledge will be of higher quality (Friese, 2019).

Following the results of each section above, the initial hits were exported to Atlas.ti. After removing the duplicates, all titles and abstracts were screened to select the relevant studies based on the inclusion and exclusion criteria. The selection of the papers was made to check the comparability of studies by reviewing the abstract. After removing studies that met the exclusion criteria during the initial screening, the full text of the remaining studies was assessed against the inclusion criteria, and any differences were discussed, and a consensus was reached. A flow chart of the study selection procedure is presented in Figure 1.

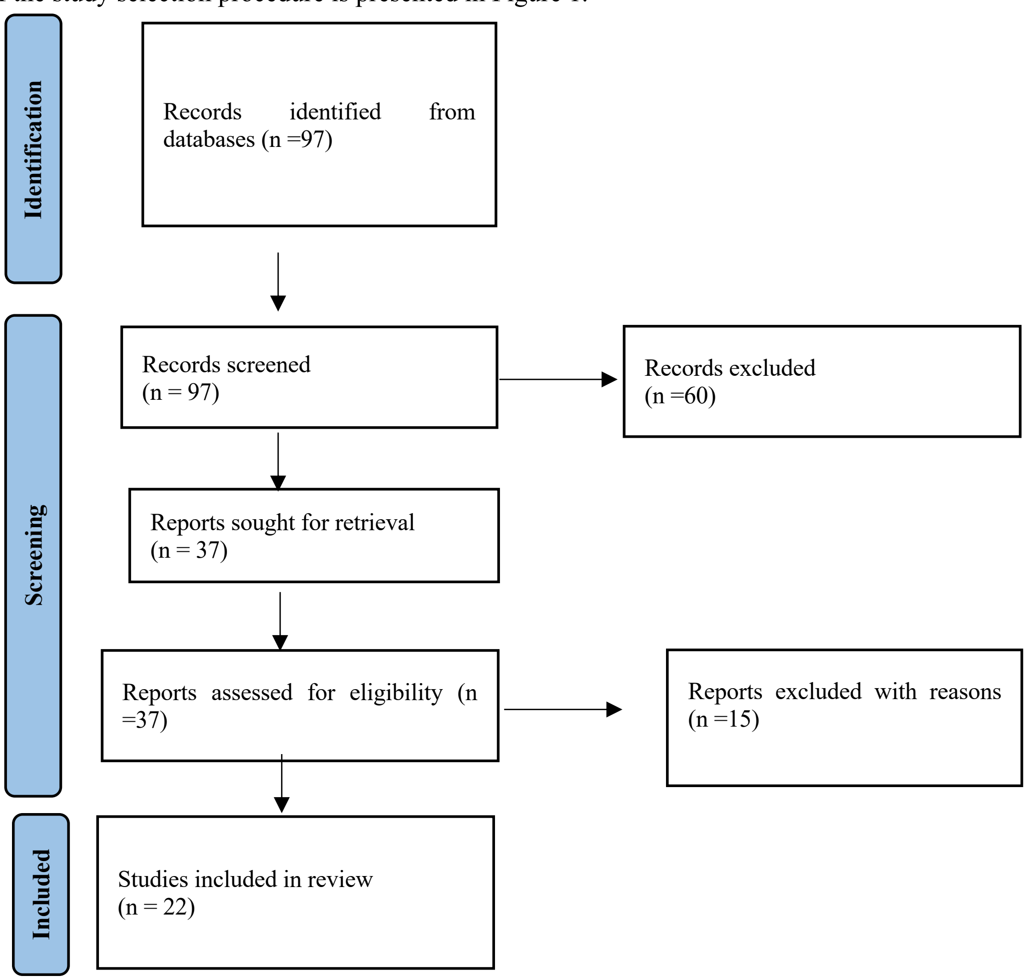

Fig. 8: PRISMA Model

Source; (Page, 2021)

3. Results

3.1 Descriptive Classification

Figure 2 up to figure 5 show the descriptive information of the 22 publications. Figure two shows the annual publications made. The highest number of papers were published in 2020, with five publications. Figure three shows the publications made per country. Australia and Nigeria have four publications each. Ghana with two publications. Seven countries have one publication each. Figure four shows the publication type. Of the 22 publications, 16 publications were journal articles, while six were conference papers. Figure 5 shows the research method. Most publications were Qualitative in 10 publications. Quantitative was used in 5 publications, literature review in 5 and mixed methods in 2 publications.

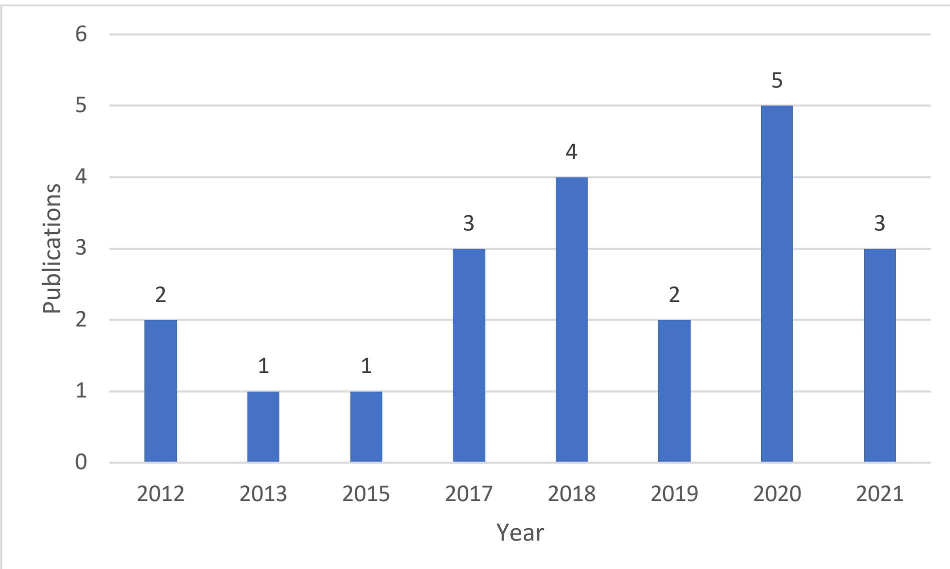

Fig. 9: Number of publications made per year

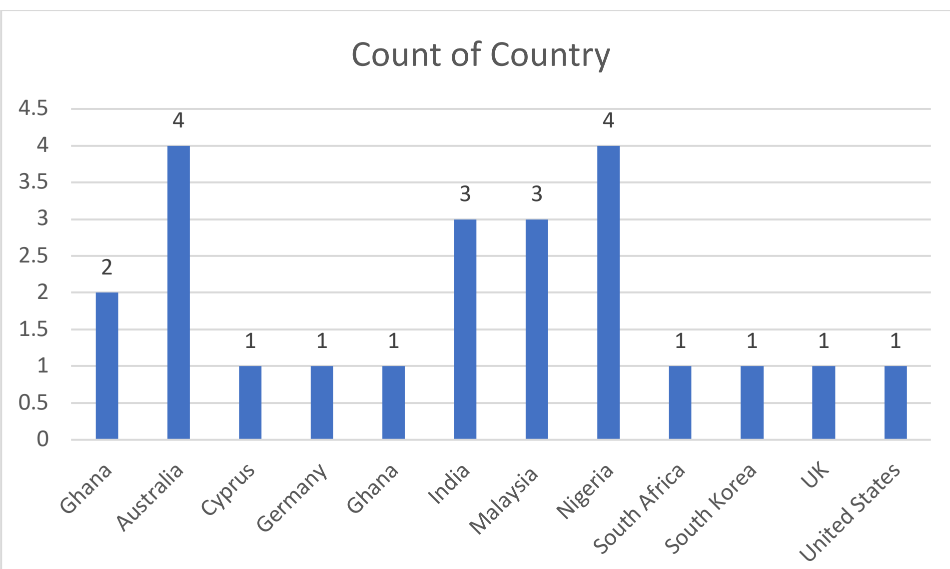

Fig. 10: Publications made per country

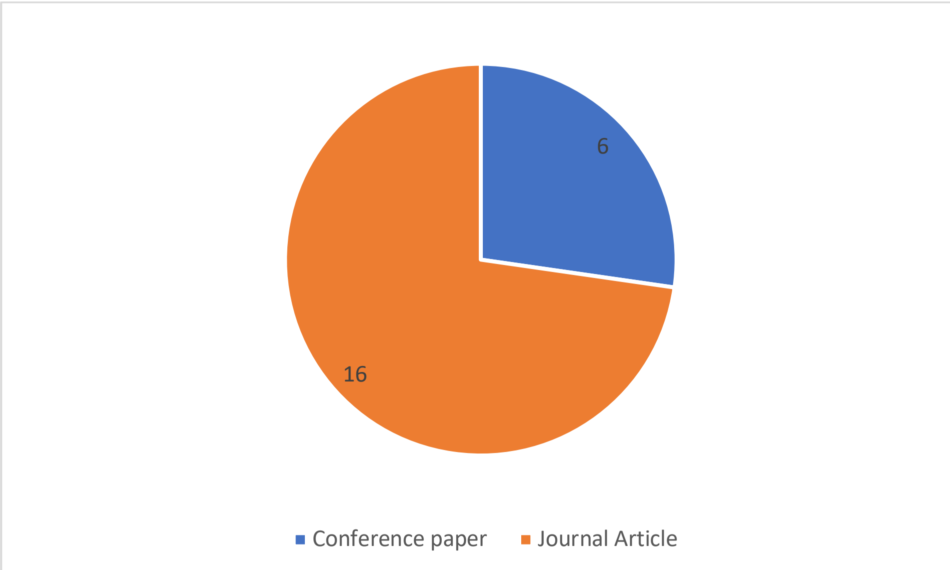

Fig. 11: Selected publication type

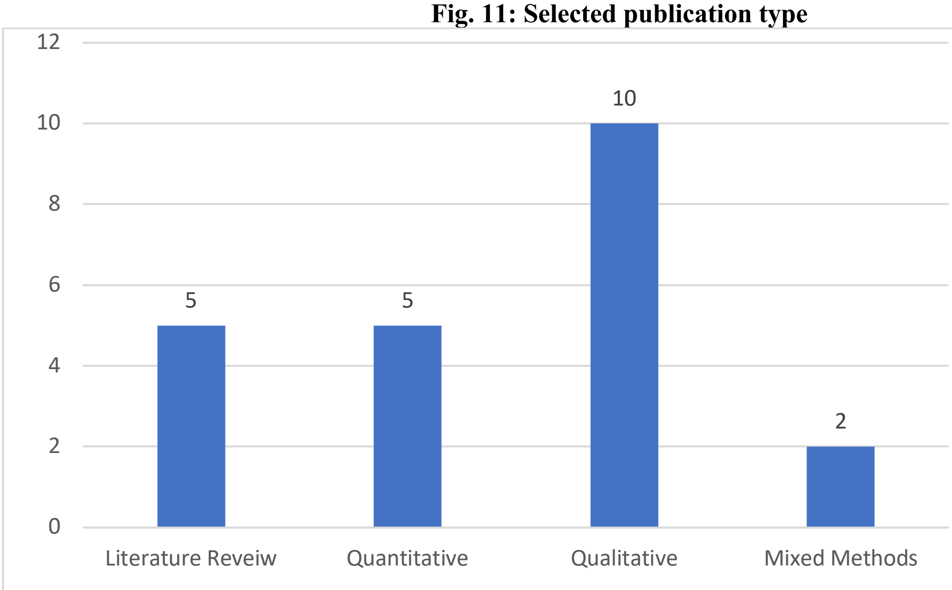

Fig. 12: Research Method

3.2 Thematic Analysis

From the thematic analysis of the publications, it was found that four papers suggested using affordable locally sourced material as a strategy. Moreover, most publications cited partial government finance and the policy response to social housing needs as the second most cited strategy of sustainable construction development of affordable housing.

Table 13: Thematic Analysis

Main Finding	Reference
Using affordable, locally sourced building material	(Ugochukwu et al, 2015), (MacAskill et al, 2021),(Abdul et al, 2018),(Hashim et al, 2012),(Kulshreshtha

	et al, 2020),(Georgiadou, 2012),(Mohammed et al, 2017),(Oluleye et al, 2020)
Offsite construction	(MacAskill et al, 2021), (Nanyam et al, 2017)
Self-build co-housing	(Scheller et al, 2018)
Usage of energy-efficient resources	(Scheller et al, 2018), (Michael et al, 2020), (Georgiadou, 2012)
Increasing public knowledge and awareness	(Scheller et al, 2018), (Dave et al, 2017), (Musonda et al, 2020)
Setting up an appropriate maintenance management plan	(Hashim et al, 2012), (Bilal, 2019)
Government partial finance	(Ortiz et al,2018), (Cronin, 2013), (Morris et al, 2019), (Bilal, 2019), (Mohammed et al, 2017),(Oluleye et al, 2020)
The policy response to social housing needs	(Michael et al, 2020), (Gilbert, 2020), (Georgiadou, 2012),(Feather, 2019),(Mohammed et al, 2017),(Oluleye et al, 2020)
Functional designs for housing and urban infrastructure	(Obianyo et al, 2021), (Morris et al, 2019)
A better understanding of population dynamics	(Obianyo et al, 2021)
Evolution of integrated approach to sustainable housing development	(Obianyo et al, 2021)
Polices of finance with private institutions	(Dave et al, 2017), (Bilal, 2019), (Mohammed et al, 2017)
Investment in research and development	(Dave et al, 2017), (Gilbert, 2020), (Georgiadou, 2012)
Making land urban affordable	(Butcher, 2020), (Georgiadou, 2012), (Feather, 2019), (Mohammed et al, 2017)
Controlling land development and construction through vertical integration	(Butcher, 2020), (Gilbert, 2020)
Directing investors and users into sustainable housing developments	(Butcher, 2020)
The government leading role in shoring up the monopoly of property investors in affordable housing	(Butcher, 2020), (Morris et al, 2019)
Appropriate building design and building services supply	(Cronin, 2013), (Georgiadou, 2012), (Bilal, 2019)
Increasing stakeholder and user participation and communication	(Cronin, 2013), (Musonda et al, 2020), (Oluleye et al, 2020), (Adabre et al, 2020)
Use decision-making techniques and tools	(Georgiadou, 2012), (Adabre et al, 2020)
Development of a housing development model	(Bilal, 2019)
Development of smart technology sustainable housing units	(Musonda et al, 2020)

Discussion

From the figures above we can deduce the following:

- Figure 2 demonstrates that the bulk of sustainability-related publications were released in 2020, indicating that sustainability is becoming more important and on people's minds than ever before.

- The countries with the most publications in the field of sustainability are depicted in Figure 3. The countries with the most publications were Australia and Nigeria, each with four. With two publications, Ghana ranks in second, followed by the rest of the countries with one apiece. This indicates that Australia and Nigeria are countries that are placing a high importance on sustainability and its implementation with the other countries slowly following suite.

- Figure 4 depicts the various types of publications. According to the publications reviewed, journal papers are the most widely published. Sixteen of the twenty-two pieces are journal articles, while just six are conference papers. Journal articles include more material about a subject or discipline than conference papers, which are limited in length. Journals enable for additional research and knowledge to be gathered.

- Figure 5 shows the 22 articles most utilized research methods. Ten were qualitative, five were quantitative, five were literature reviews, and two were mixed approaches. The qualitative method was the most popular since it is simple to comprehend and discover themes and patterns. The data collection procedure is also adaptable, useful, and thorough.

Four papers advised using economical locally obtained material as an approach, according to the publications utilised. Furthermore, most media mentioned partial government financing and policy responses to social housing requirements as the second most cited option for long-term affordable housing creation.

Conclusion

Sustainability is no longer a choice but a necessity. Even though sustainability is a global issue, developing countries must approach it differently than developed countries, and alternative strategies must be embraced and implemented. In this research, SLR was performed to understand sustainable construction strategies for the development of affordable housing. To do this, 22 publications from between 2011 and 2021 were collected and thematically analysed. From the SLR descriptive analysis were able to see that 2020 had the highest number of publications with three papers. The study also found Australia and Nigeria to have the highest number of publications. This suggests that these countries are taking sustainability in construction into consideration. Sixteen of the 22 papers were journal articles, while five papers were literature reviews. Eight papers cited the thematic analysis using affordable, locally sourced building material as a sustainable, affordable housing development strategy. Future research should combine the knowledge gained from the literature review with primary data collected. Future studies should address the limitation on the number of databases used to screen publications

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ID 30

AgiBuild: A Proposed Framework for Agile Building Adaptation Project Management Based on Literature Review

Pearl Li Ng[1], Malik Khalfan[1,2], and Tayyab Maqsood[1]

[1] RMIT University, Melbourne, Australia
[2] Plymouth Business School, Plymouth, United Kingdom
s3817516@student.rmit.edu.au

Abstract
The Agile Building Adaptation (AgiBuild) framework is the adoption and adaptation of the large-scale agile framework for building adaptation projects. The agile methodology is proven to drive innovation by focusing on adaptation to change and user centricity. Similarly, the authors envision that the AgiBuild framework can fundamentally change the way that buildings are re-designed, refurbished, and operated. The AgiBuild framework is developed from the need of the building adaptation industry to manage uncertainties, overcome communication barriers, and improve innovation. In this study, a literature review of Agile and its impact on building adaptation projects was undertaken. Based on this systematic literature review, this paper defines the AgiBuilt framework and provides its benefits and barriers to implementation. A key finding of the literature review is that leadership influence, and adequate training form the key foundation for the implementation of the AgiBuild Framework. In defining the AgiBuild framework, the paper described its components and how its implementation is likely to proceed. The authors propose that by adopting the AgiBuild framework, the industry can transform itself into a highly innovative and user-centred industry to improve productivity and performance of the construction industry.

Keywords
Agile project management, Agile construction, Building adaptation, Built environment, Scaling agile

1. 1. Introduction

Commercial buildings play an important role in our built environment and our economy. The construction, operation and maintenance of a building will have both an immediate and long-term impact upon our environment as well as the occupants of the building. With that in mind, the value of commercial building activities in Australia as of 2025 is estimated to be approximately 43.2 Billion AUD (Granwal 2021). Specifically for the fit-out market, it is forecasted to have a growth of more than 14% by 2026.

At the time of writing, the world is facing the Coronavirus (COVID-19) pandemic. The COVID-19 pandemic has caused economic and social disruptions. At the same time, it was also observed that there is acceleration of emerging trends such as flexible work arrangement and increasing demand for e-commerce. In addition to the uncertainties and transformation within the macro environment of the commercial building industry, the lack of coordination and integration of planning across various stakeholder groups in the industry also exacerbate the challenges experienced in the built environment industry (Coleman 2017). Other challenges include resistance to change and low productivity, predictability and profits (Sawhney et al. 2020).

These challenges and issues prompt the need to relook at the way projects are managed in the construction and building sector. Farmer (2016) suggests that the industry needs a transformational change to overcome these challenges. Furthermore, a recent report by the Australian Infrastructure Audit claimed that key industry players need to perform major reforms to improve the way we plan, finance, construct, maintain and operate these building

(Coleman 2017). A new way of working is required for the built environment industry to be more adaptable to change due to uncertainties, and to drive communication and coordination.

The challenges experienced by the built environment industry is not unique. Similar to the built environment sector, the Information Technology (IT) industry also finds it challenging to cope with on-going changes, such as new and emerging technology, as well as dealing with communication breakdown when working across multidisciplinary teams. To cope with these challenges, the agile ways of working is introduced to the software industry. The agile ways of working has strong focus on adaptation to change, flexibility and human-centred design. It is proven to be effective to promote adaptation and coordination.

2. Research Objectives and Methodology

The objectives of this research were to define and describe the Scaled Agile framework for building adaptation projects based on a detailed literature review of the Scaled Agile concept. The framework aims to combine and bring together the synergies between agile and building adaptation, so that it can be used as a guideline for construction professionals to apply agile practices in their daily work. The first stage involves developing the framework based on systematic literature review to identify the key components of the framework. The second stage refines the initial framework through expert interviews.

2.1 Stage 1: Systematic Literature Review

To achieve the research objectives, the following thematic areas were selected for literature review and analysis: (1) Agile practices at scale; (2) Advantages, disadvantages, success factors and barriers to apply agile at scale; (3) agile project management in buildings and construction; and (4) human-centred design in buildings and construction. Systematic literature review is undertaken to review, evaluate and analyse these for thematic areas. Systematic literature review was chosen as it provides an overview of previous studies in the chosen area and allows the authors to identify areas that are yet to be explored or under-explored (Webster & Watson 2002). In fact, systematic literature review is the foundation of any research projects (Esa, Halog & Rigamonti 2017).

The first step of this literature review was to define the problem that would be studied, that is "How can the concept of Agile at Scale be utilized in the buildings industry to improve adaptability, innovation and productivity?". The objective of the review was defined as to identify the recent developments of Agile concepts in the software industry and how are they being used. The following step was to review those research that used the concepts of Agile at scale within the non-software industries, including the building and construction industry. To conduct this literature search process, the authors performed the following search strategy steps: (1) Choose the database source; (2) Choose keywords and search criteria based on the thematic aresas defined; (3) Apply backward and forward search as required; and (4) Evaluate the appropriateness of the literature subset (Cocchia 2014).

Various search filters were applied that resulted over 200 papers in the area of agile at scale, which is relevant to the first two thematic areas; close to 100 papers in the area of agile construction; and approximately 90 papers in the area of human centered design in construction. As this is a fast-emerging field, the search filters and selection of papers were done carefully. Noting that there are a few "buzzwords" that are present in the industry, the authors also take into consideration the use synonyms when performing the search, for instance *Scrum* is occasionally being linked to *Agile*; and *design thinking* and *user-centred design* are used interchangeably with *human-centred design*. Through comprehensive reviews of relevant literatures, the different components of a Scaled Agile framework for the building adaptation projects are identified and articulated.

2.2 Stage 2: Expert interviews

The second stage of the framework development involves refining the framework by using empirical evidence collected through expert interviews. These ten experts, via their professions and professional commitments, are highly knowledgeable regarding the agile transformation, human centered design and construction management. Data were collected through ten unstructured interviews that lasted between 30 to 60 minutes. The authors started the interviews by providing a brief explanation of the various components of the framework, followed by interviews with the participants. Exploratory follow-up and non-directive probing questions were asked to ensure that the interviewees are not directed towards the perspectives of the authors (King 2004). The notes taken during the interview were analysed to identify themes that emerged.

3. Literature Review

This paper documents the overview of scaling agile and it's application in building adaptation projects. A framework, known as AgiBuild, is developed based on literature review to convey the purpose and direction to apply scaled agile practices in building adaptation projects, portray how various elements interact to produce the desired outcomes and provide a structure in which industry professionals can adapt based on their projects. This section presents the literature review on agile project management and agile at scale. The next section i.e. the *Results* section will present the proposed AgiBuild framework. Each component of the framework is elaborated and serves as a guideline for industry professionals to manage uncertainties, drive innovation and improve collaboration.

3.1 Agile project management and practices

Agile management practices originate from the software industry. Developed in 2001, the agile manifesto advocates for four values: (1) Individuals and interactions over processes and tools; (2) Working software over comprehensive documentation; (3) Customer collaboration over contract negotiation; and (4) Responding to change over following a plan (Beck et al. 2001). Denning (2019) describes that the agile ways of working has strong focus on customer value, adaptation, iterative and incremental delivery as well as continuous improvement.

The concept of agile emerged due to the shortcomings experienced in traditional software development process. The traditional approach involves sequential steps and having all the requirements defined upfront (Ciric et al. 2018). However, such practices may not be practical to allow the team to be flexible and make rapid adjustments. The agile approach is said to allow teams to manage changing requirements to keep up with the continually changing technology and business requirements (Ciric et al. 2018; Larson & Gray 2010). Some of the fundamental difference between the traditional and agile is that the traditional methods assume predictability, attempt to minimise changes and exert control on schedules (Bergmann & Karwowski 2019; Vinekar, Slinkman & Nerur 2006).

Agile is an umbrella for a vast variety of practices. Not all these practices are mandatory and some of them can be applied independently. Agile advocates for iterative and incremental development. A sprint, an iteration or a cycle is a basic unit of work with a fixed timebox that lasts from around one to three weeks (Srivastava, Bhardwaj & Saraswat 2017). Most traditional project management methods involve a project scope that outlines the work that needs to be done (Fashina, Abdilahi & Ibrahim 2020). This is often represented as a product backlog when APM is implemented. The product backlog contains the requirements, features or functionalities that are useful to the end user or customers (Larson & Gray 2010; Srivastava, Bhardwaj & Saraswat 2017). Other practices worth mentioning include release planning, product road-mapping, Kanban, planning poker, team estimation, common work area, agile / lean user experience (UX) and many others. Of the agile practices, the top five practices are the daily meetings, retrospectives, sprint / iterative planning, sprint / iteration reviews and short iterations (Digital.ai 2021).

At the time of writing, agile practices have become a mainstream, cutting-edge approach applied in many industries, especially those in fast pace, competitive markets (Ciric et al. 2018). The key benefits that were observed include the ability to manage changing priorities, provide visibility and allow alignment between business and IT stakeholders.

It is important to note that APM is not a method on its own. In fact, there are many distinct APM methods that can be applied in different organisations or teams. Some of the common or popular APM methods are Scrum, Extreme Programming (XP), Crystal Clear, and other (Larson & Gray 2010). Of these methods, Scrum is the more popular methodology (Sarpiri & Gandomani 2021). Scrum, like other agile methods, are designed to manage uncertainties and changes in requirements. The three main roles in Scrum are the Product Owner, Scrum Master and development team (Gandomani et al. 2019). The Product Owner ensures that the objectives of the project are met and the Scrum Master is responsible for resolving any challenges at the team and organization level. The Development team consists of team members with distinct, specialised skills such as the programmers and others. This cross functional team plays an important role in delivering the end product that satisfies the needs of the customers (Larson & Gray 2010; Srivastava, Bhardwaj & Saraswat 2017). The Scrum development process starts with defining the product backlog, followed by the sprint backlog. Within the Scrum framework, the Product Owner will shape the product backlog. Together with the Development team, the sprint backlog will be formulated. Once the sprint starts, the development team will gather every day to discuss about the work that they have done. At the end of the sprint, the Scrum team performs a sprint review and a retro.

3.2 Scaling agile

Most agile methods, including Scrum, are catered for small, co-located team with no more than ten team members. However, the benefits of agile methods for small teams have encouraged organisations or teams to adopt agile methods for large programs with multiple teams (Uludag et al. 2018). The idea of using agile methods on larger projects with bigger team size is known as *Scaling*. Xu (2009) further elaborates agile approaches, when applied on large program, will pose risks associated with communication and interaction. There are few frameworks that were developed to guide larger teams to apply agile. Examples of framework include Scrum of Scrums (SoS), Scaled Agile Framework (SAFe) and others (Kalenda, Hyna & Rossi 2018). The 15th State of Agile report, SAFe, is the most popular framework across large enterprises. Kalenda, Hyna and Rossi (2018) identified eight common scaling agile practices and they are Scrum of Scrums, Communities of practice, Scaled sprint demo, Scaled requirements management, Scaled Retrospective, Feature teams, and Undone department. Some of these large scale agile framework also include the scaling of roles such as Area Product Owners (APOs) and Chief Product Owners (CPOs) (Putta 2018).

The benefits of agile in software development has inspired the applications of APM in non-software projects. Examples of application include real estate, education and services. Some of the benefits observed include improve team communication and collaboration, high productivity and output quality as well as ongoing feedback and continuous improvement (Ciric et al. 2018). Following an increase of participation in the agile movement, many studies have been conducted to explore the application of agile in construction in isolation. As a result, the aim of this paper is to bring together a framework that allows agile practices to be embedded in building adaptation.

4 Results

4.1 Framework overview

With the increase application of APM, the built environment sector also has the opportunity to improve innovation and be more efficient (Owen & Koskela 2006). The AgiBuild framework is a conceptual framework which serves as an intermediate theory that outline all possible resources related to agility and create a logical connection between APM and building adaptation projects. It can be used as a guideline for construction professionals to plan, design and deliver built environment projects more effectively and efficiently, especially in a market environment that is constantly changing. Modelled after the concept of Scaled Agile framework, the AgiBuild framework is also intended to be scalable to accommodate building adaptation projects that are of different sizes and complexity. There are three organisational levels in this framework: Teams, Programs and Portfolios. The framework contains the people, tools and processes on the application of agile. With reference to the expert feedback on the framework, all the experts agreed that this framework is relevant and could be applied in building adaptations in general, but one expert argues that this may not be relevant due to the unique nature of the industry.

4.2 Component analysis

4.2.1 Agile foundation

The core values and principles of the AgiBuild framework will be adapted from the Agile Manifesto to suit the built environment sector. Studies were performed to examine the relevancy of the agile values and principles in various construction projects. Diepersloot (2019) suggested that while these values are relevant, slight change in terminologies should be considered to better suit the building and construction industry. The authors suggest using the adapted version found in the Disciplined Agile Delivery (DAD) in the AgiBuild, where the terms in *italic* are the modified terms: (1) Individuals and interactions over processes and tools; (2) Working *solution* over comprehensive documentation; (3) *Stakeholders* collaboration over contract negotiation; and (4) Responding to change over following a plan.

The values above take a holistic lens where the solutions could be defined as a functional system (e.g. electrical, piping), a deliverable (e.g. a P&ID diagram) or a work package. Given the complex stakeholder ecosystem in construction, stakeholders collaboration, including customer, regulators, contractors and others, need to be considered. Another important concept in scaled agile is user centricity. In the context of building adaptation projects, this includes anyone who will be using the building such as the staff, a visitor, or a service provider. The project teams need to have a multidisciplinary approach involving psychology, physiology, engineering, building physics and health to understand the complex interactions between humans, buildings, and their environment (Darby et al. 2019). Interviews with industry experts suggest this this is an important component of the framework and should be applied in projects where necessary.

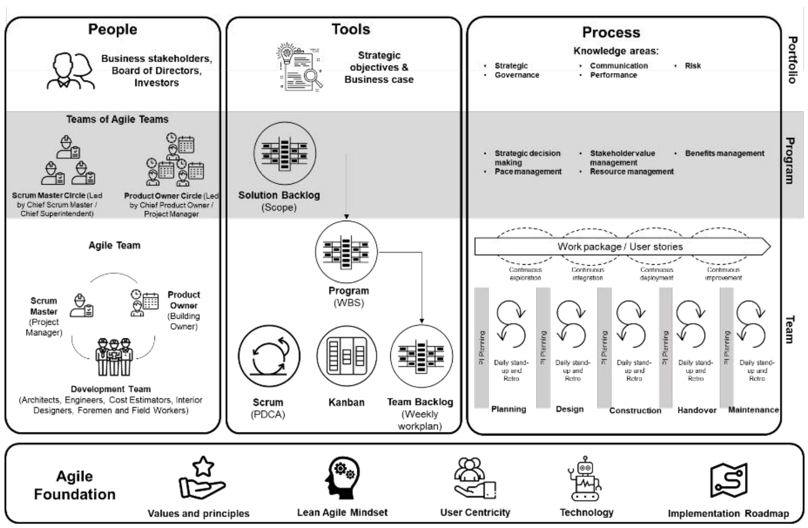

Fig 13: The AgiBuild Framework

The technology component was newly added to the framework after the interviews with industry experts. The industry experts suggested that digital transformation and digital tools such as Building Information Model (BIM) are changing the way building and construction organisations execute their projects, and the availability to technology tools is a potential enabler for this framework (Gless, Hanser & Halin 2017; McArthur & Bortoluzzi 2018; Sawhney et al. 2020; Tomek & Kalinichuk 2015). The Implementation Roadmap is another key element for agile to be applied in the built environment sector. Pareliya (2018) recommended to educate building and construction professionals with agile methodology to drive adoption.

4.2.2 People

Stakeholder management is crucial for the success of a project, more so in retrofit projects. Retrofit project involves a wider group of stakeholders, such as tenants and facility managers, who have contractual relationship such as lease contract, split incentives and others (Liang, Yu & Guo 2017). At the Teams level, Layton (2015) suggested that the Scrum roles can be adapted for the construction ecosystem. The Product Owner role can be represented by the Building Owner, who will be responsible for making decisions on behalf of the end users and occupants. The Superintendents or Project Managers can occupy the role of the Scrum Master by not only facilitating the daily coordination of resources and tasks, but also helping the team to remove any impediments. The agile development team is made up of skilled team members such as architects, interior designers, engineers, and others. When the team gets larger, a consideration is to include roles such as Scrum of Scrum Master and Chief of Product Owners. They will take a lead role in coordinating the multiple agile teams (Belling 2020; Berntzen, Moe & Stray 2019). At the Portfolio level, the key roles would be the portfolio executives who assume the responsibilities in exercising authority over the organization (Liang, Yu & Guo 2017). One of the experts also suggested the portfolio executives to play a role in organising the contractual agreements that will empower team members to undertake agile roles.

4.2.3 Tools

The strategic objectives and business cases are established by the portfolio executives and stakeholders. They will impact the development backlogs at the subsequent levels (Knaster & Leffingwell 2020). The program backlog contains the upcoming work orders that are required to address the user needs and deliver business values (Knaster &

Leffingwell 2020). A visualised version of the program backlog allows organisations to assess the gaps in achieving the organisation goals and the effort required to achieve the targets. Zilberova, Tomashuk and Bobkina (2019) suggested that the program backlog needs to take into account resource workload and customers' requirements to achieve the highest possible efficiency. Overall, in terms of the tool, all experts agreed that having a simplified Kanban board allows the team to visualise responsibilities and drives communication.

4.2.4 Processes

This portion of the framework was revised based on the mix opinions from different experts. One of the experts suggested to keep the processes flexible to allow this framework to be scalable. He also suggested to incorporate elements from the PMBOK's portfolio and program knowledge areas as part of the framework. At a team level, the framework proposed the team to have a planning session, with agile practices embedded, prior to starting any work. Another recommended agile practice is the daily Scrum meeting where the team gathers to identify their daily work plans and challenges (John 2018; Knaster & Leffingwell 2020). Most of the experts pointed out that the daily scrum is encouraged for most construction projects, and in fact, has taken place in the execution phase in most of the construction or building adaptation projects today.

5 Limitations and Future Work

Due to limited time and scope of work, this agile framework proposed in this paper is developed solely based on previous literatures and expert interviews. A follow-up study is required for the proposed framework to be validated. One possible direction of future work is also to prototype the framework on a building adaptation project and gather feedback from research participants. In addition, it would be advantageous to quantify the effectiveness of the framework in reducing delay, enhancing coordination, and managing risks. As this is an emerging field, it is also essential to consider the skills required within the future workforce for this framework to be applied successfully.

6 Conclusion

The construction and built environment sector are pivotal for the advancement of civilization. While there are a lot of developments and evolution processes within the industries, the built environment sector faces major challenges such as lack of growth and innovation. In addition, building adaptation projects often experiences poor coordination, fragmentation and inefficiencies. Agility, a concept that originates from the software industry, has the potential to facilitate a flexible, responsive process, especially dealing with fragmented activity changes. In this paper, the authors have identified the linkages between agile project management and building adaptation project management. Using the systematic literature review and expert interview approaches, the AgiBuild framework and its key components are identified. While agile principles and practices have been partially applied on some construction projects, the application of agile in building adaptation is still an emerging field. Partnerships between various entities such as academic institutions and industries are required for the future workforce to be well-equipped for the implementation of the AgiBuild framework.

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Collaboration as a Multifaceted Skill Set in Construction Education

Saeed Rokooei[1], Mohsen Garshasby[2]

[1] Mississippi State University, Starkville, MS 39759, USA
[2] Mississippi State University, Starkville, MS 39759, USA
srokooei@caad.msstate.edu

Abstract

Collaboration is a key element in many programs, especially those with common themes with other disciplines. The collaboration concept in recent years has been a focal point in educational models for multidisciplinary programs. A similar situation also exists in the professional environment. The construction industry is a broad industry with numerous interactions with trades, developers, engineers, and designers. Likewise, construction programs incorporate subject modules in their curricula that are shared with other relevant programs such as civil engineering, architecture, and business. The intertwined nature of several topics in construction makes collaboration an effective approach for content delivery. The collaboration takes place in various forms and different capacities. This paper addresses the collaboration efforts in two major courses between the Building Construction Science and Architecture programs at Mississippi State University. A quantitative method was used to explore both majors' students' perceptions toward the different aspects of teamwork and collaboration. The result indicated that different components of the collaboration system, such as teammates, instructors, content, and tools, were perceived at different levels by students. The findings of this study not only provide insight on nuances of collaboration but also help construction educators and administrators to better design and develop collaborative environments and control factors that impact the efficiency of such educational realms.

Keywords

Collaboration, Construction, Education, Architecture.

1. Introduction

In recent decades, the role of collaboration in the construction industry and education has become increasingly more important. In construction education in particular, due to the necessity of today's industry work environment, having the ability to work with other disciplines is critical. Research suggests simulating real-world experience for construction students can significantly help students develop their skills while in school prior to entering the job market. In Mississippi State University College of Architecture, Art, and Design, two of eight studio courses in Building Construction Science (BCS) and Architecture (ARC) curriculum are collaborative studios. In these studios, BCS and ARC students work alongside each other to complete the group projects defined in the studio. As part of this effort, students develop their communication skills to prepare for industry standards and eventually deliver projects to the client. An important aspect of this collaborative effort is for students in both disciplines to understand the challenges faced in the other discipline as well as learn effective communication and collaboration tools and technics. Students also research various project delivery methods to analyze the benefits and disadvantages of each method and finally choose one to utilize for their project. In the first collaborative studio, which happens during the second year of the curriculum, BCS and ARC students collaboratively work on a design/build project to design, develop, and construct real-life products and deliver to clients. The teams consist of 10-12 students divided into subgroups of designers, general contractors, and fabricators. During this process, the BCS students are fully immersed in the iterative process of design and ARC students begin to realize the challenges of constructing a real-life full-scale project. In the second collaborative studio, which happens during the third year of the curriculum, BCS and ARC students collaboratively work on designing and further developing a commercial size building to propose a comprehensive solution to a design issue. ARC students focus on the aspect of schematic design and design development and presentation while BCS students focus on using technology -- as members of a multidisciplinary team -- on aspects of estimating, scheduling, site planning, logistics, and so forth.

2. Background

Collaboration, as defined in a seminal study by Wood & Gray (1991), takes place when a group of autonomous stakeholders of a problem domain is involved in an interactive process, using shared rules, norms, and structures, to act or decide on issues related to that domain. Thomson et al. (2009) further elaborated this notion stating that collaboration requires negotiations among the parties involved to jointly create rules and structures for mutually beneficial relationships. Collaboration is not defined in the same way across different disciplines (Thomson et al., 2009; Bedwell et al., 2012). Within the construction industry, collaboration has been widely discussed lately. BIM-based Construction Networks (BbCNs) is a new term coined which entails the teams, comprised of members from several specialist organizations, to undertake BIM-related tasks on BIM-enabled projects (Oraee et al., 2017). Within this context, fostering collaboration is a top priority for construction project managers. On the other hand, research in the past decades identified gaps in educational paradigms, which lead to inconsistency with the constantly evolving needs of the industry, particularly with respect to collaboration and building information modeling (BIM). A recent study on improving collaboration in construction employed action research (A.R.) approach to investigate the role of participants in a construction project (Connaughton & Weller, 2013). The results highlighted the importance of effective collaboration within the framework of action research. In a cross-national study, multiple universities across Turkey, the United States, Israel, and Brazil developed a course, "International Collaborative Construction Management," to investigate the efficacy of collaborative paradigms in construction education (Soibelman et al., 2011). The course was developed over three years and required students to collaboratively develop construction schedules, cost estimates, risk assessment plans, and so forth. The study argued that the traditional skills and education style of engineers and construction managers did not prepare them to successfully address globalization issues (Soibelman et al., 2011). Therefore, there was a need to devise more innovative approaches to construction education to keep up with the present needs of the industry. Research from the early 2000s also indicated that due to globalization, academic institution, industry professionals, and corporations highly benefited from the advantages of collaboration and development of students who were trained in multicultural teams with international content (Steele & Murray, 2000; Bradner & Mark, 2002). It is also worthwhile to note that industry internationalization has been accompanied by revolutionary changes in engineering practices, management, and the structure of collaborative groups (Doerry, 2003). Therefore, adequate training and preparation for students in construction fields is essential. Findings from later studies also indicate the necessity of collaboration skills to succeed in today's rapidly evolving, complex, and multidisciplinary construction workforce (Ozbek & Clevenger, 2017). Also, the construction industry increasingly seeks employees with demonstrated collaboration and teamwork skills (Valdes-Vasquez & Clevenger, 2015). Therefore, the development and implementation of collaboration skills and paradigms in construction education have become increasingly important.

The international demand and emphasis on sustainable approaches and the necessity to improve efficiency and address present needs require new educational approaches to Architecture, Engineering, and Construction (AEC). A comprehensive study in 2011 examined the current AEC educational environment to provide a baseline solution to cope with the complexity of this challenge (Becerik-Gerber et al., 2011). The study looked at 101 U.S. AEC programs concentrating on emerging topics of Building Information Modeling (BIM) and sustainability and investigated how educational innovations of distance learning, multidisciplinary collaboration, industry collaborations, were incorporated to develop core competencies in those two subject areas (Becerik-Gerber et al., 2011). This research highlighted the disparities in reviewed educational programs and suggested realignment to develop the future workforce that will lead the AEC industry transformations. A recent study on collaboration and coordination modules for BIM education at the Illinois Institute of Technology indicated the significance of BIM education and the necessity of collaboration in a shared knowledge network (Bozoglu, 2016). The study discussed that the challenges reside in the classic gap between academic vision on disciplinary principles and the industry needs for specific application competency. On the other hand, the heart of BIM is an effective collaboration (Du et al., 2020). Several studies looked at the ways that collaboration in BIM-related courses impacted student learning through peer pressure. Zhao (2021) examined the existence of peer pressure in BIM collaboration and explored its effect on student learning outcomes. In this study, the researcher designed four pedagogical scenarios to simulate different degrees of peer pressure and found a positive relationship between the level of peer pressure and the student learning outcome (Zhao, 2021). Other studies explored innovative ways to implement collaboration in virtual worlds in construction education. In a study by Ku & Mahabaleshwarkar (2011), the researchers proposed the concept of building interactive modeling to complement the capabilities of BIM with social interaction to enhance collaboration information and knowledge sharing. This is even more critical since back in the late 2000s, almost fifty percent of the AEC industry was using BIM, and twenty percent of non-users were planning to adopt it within the next two years (Construction, 2009). The authors also discussed that through using virtual worlds, building interactive modeling will leverage participants' knowledge to better lead the management and collective decision-making. Given the nature of the construction industry with qualities like fragmentation and the need to communicate over a distance in large-scale projects, researchers looked at solutions in the education sector to prepare students for working in such a context. A study by Soetanto et al. (2012) reported on an industry-sponsored project that implemented an innovative learning approach that consisted of a distanced collaboration between students from different disciplines from two institutions in the U.K. and Canada. While the study utilized empirical work entailing interviews and surveys in different stages of the project, the findings revealed the impact of disciplinary training on the development of effective virtual collaboration (Soetanto et al., 2012). To further elaborate the underlying reasons for the enhanced efficiency, Soetanto et al. (2012) argued that there are attitudinal requirements that facilitated successful multidisciplinary working including willingness to accept other ideas, levels of trust, a preference to working in teams, the ease to establish relationships with others in the team, which are dependent on the culture at functional, organizational and national levels. These aspects could be more easily acquired through experiential learning provided by collaborative environments as opposed to the process of knowledge transfer in traditional lecture sessions (Soetanto et al., 2012). Additionally, it is noteworthy to mention that the changing operational environment and increasing competition in the higher education sector played an important role in promoting the introduction of new pedagogical approaches to teaching and learning, including Problem-based Learning (PBL), which is at the core of the collaborative industry and educational environments. PBL revolves around student activities; students learn more effectively from the activities they undertake and experience first-hand, rather than attending seminars and listening to traditional lectures in classrooms (Soetanto et al., 2012).

3. Methodology

The main purpose of this study was to investigate the effect of collaboration as a multifaceted skill between two groups of Building Construction Science (BCS) and Architecture (ARC) students. The participant population included 125 students (BCS: 91 and Arc: 34) who were engaged in two of eight studio courses in the BCS and ARC curriculum in Mississippi State University College of Architecture, Art, and Design in 2021. In these studios, BCS and ARC students worked alongside each other to complete the group projects defined in the studio. Upon the completion of data collection, all the data were combined into a data model, uncompleted responses were deleted, and standard imputations were applied, organized, and analyzed with statistical software SPSS. The questionnaire consisted of two sections. The first section was designed to collect the demographic profile of students. The second section focused on obtaining information regarding different features of collaborative studios in BCS and ARC programs. In all relevant questions, if the participant was a BCS student, the collaborator major was Architecture, and vice versa. The survey was distributed on paper to increase the rate of return. The obtained data were collected, cleaned, and modeled, and descriptive analyses were performed to explore the constructs related to the research questions.

4. Results

The first section of the survey was designed to obtain demographic information. The questions were based on five-point Likert scales ranging from very low (1) to very high (5). Table 1 provides demographic information of students. Participants were asked to what extent they considered their teamwork with their collaborator major students successful. Fifty-six of the students believed their teamwork with the collaborator was successful. The percentages of the consideration of both BCS and Arch groups are shown in Figure 1.

Table 1. Demographic Information

		BCS	Arc
Gender (%)	Male	91.2%	47%
	Female	8.8%	53%
Expected Final Grade (out of 100)		87.47	89.70
Hours spent per week		16.67	18.78

In the next section, participants were asked to specify the impact of several pre-defined factors on the success of the collaborative studio. Those factors included shared understanding of the perspectives, commitment to participate, mutual benefits, trusting relationships, effective communication, diversity, working at the same time in the same place, complementary skills, regular feedback by teammates, and regular feedback by professors. A five-level Likert scale (1: Very Low; 5: Very High) was used to rate the factors. The weighted average of each score (out of 5) is shown in Figure 2.

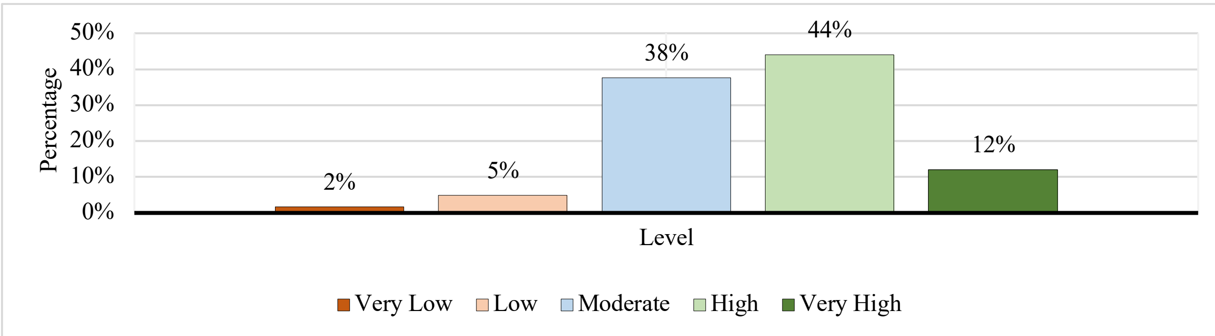

Figure 1. Percentage of success level of teamwork with collaborators

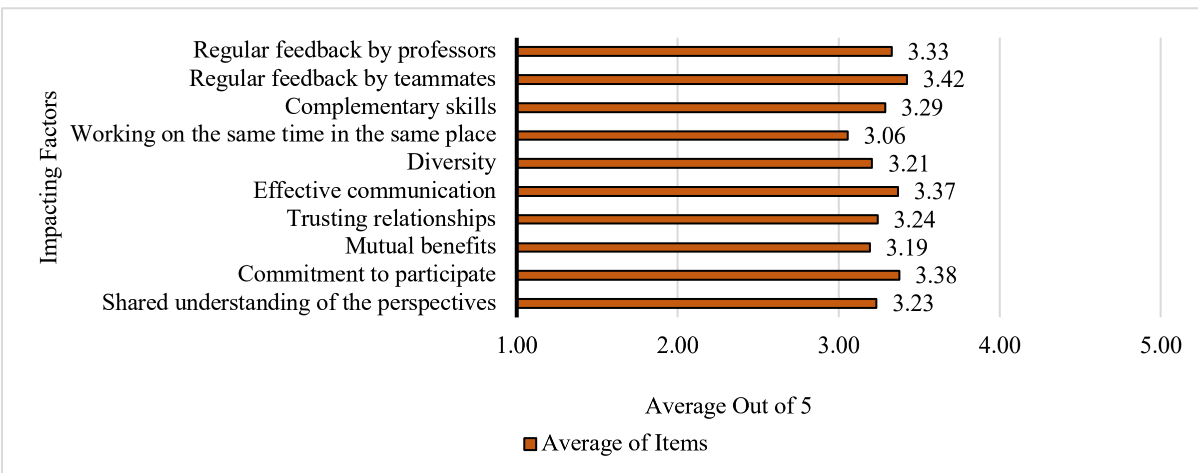

Figure 2. Weighted average score of factors impacting the success of the collaborative studio

The participants were also asked to what extent they learned from teammates in their own major or their collaborators in their collaborative studio. Figure 3 shows that in the "High" and "Very high" levels, the percentage of "learning from own major" was higher than that of "collaborator". The survey participants were also asked to what extent they learned from both majors' instructors in their collaborative studio. As shown in Figure 4, the majority of students expressed a high rate of learning from their own instructors in the collaborative studio rather than collaborator

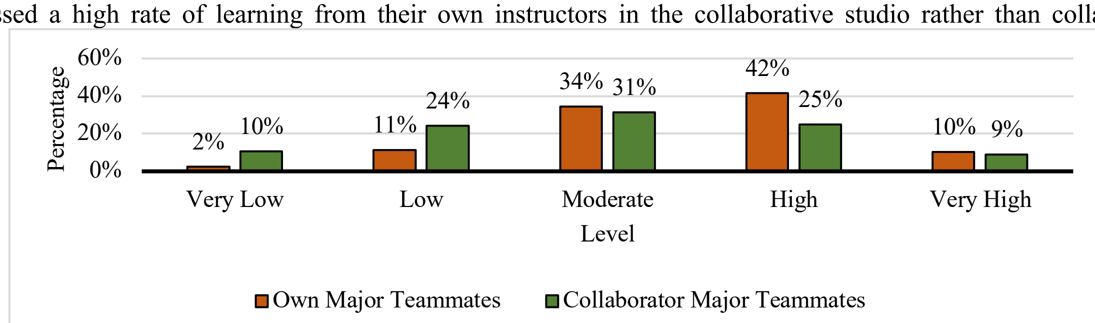

Figure 3. Percentage of learning levels from collaborators

professors. In another section, participants were required to specify their preference for asking questions or discussing issues with their own or collaborator instructors in the collaborative studio. Figure 5 shows that students preferred to ask their questions or discuss issues with their own major instructors instead of collaborator instructors.

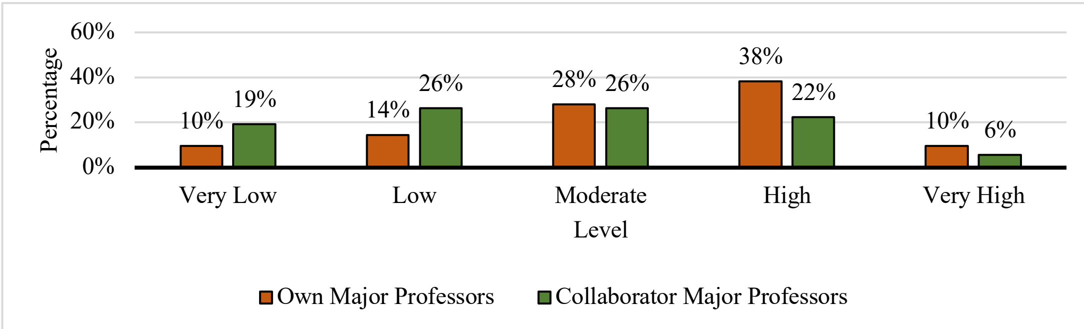

Figure 4. Percentage of learning levels from instructors

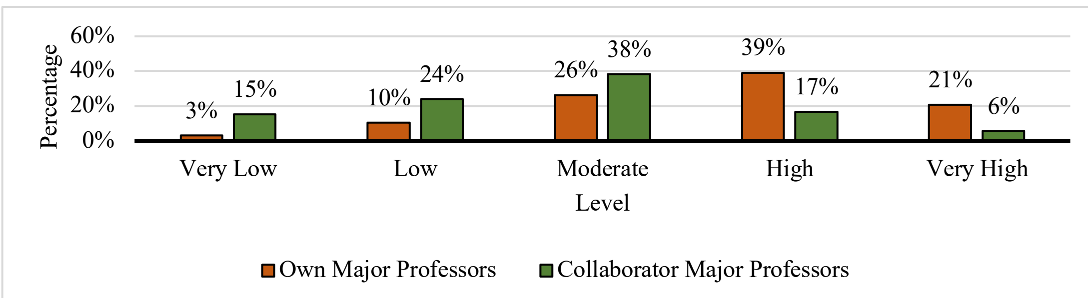

Figure 5. Percentage of discussion preference levels

Students were also asked about their evaluation for the quality of communication (timeliness, clarity, politeness, etc.) with their team members in the collaborative studio. Figure 6 shows that most of the students had better communication with their major teammates rather than the collaborator teammates. The results also showed that 6% of students evaluated the low quality of communication with their team members in the collaborative studio. The survey participants were also asked about the rate of the usefulness of collaborative studio and its content to all students, including their own major and collaborators. Based on the results, students shared a similar opinion based on the five-point Likert scale ranges. As shown in Figure 7, more than 54% (High and Very High) of both groups of BCS and ARC students believed the collaborative studio is equally useful for both majors' students.

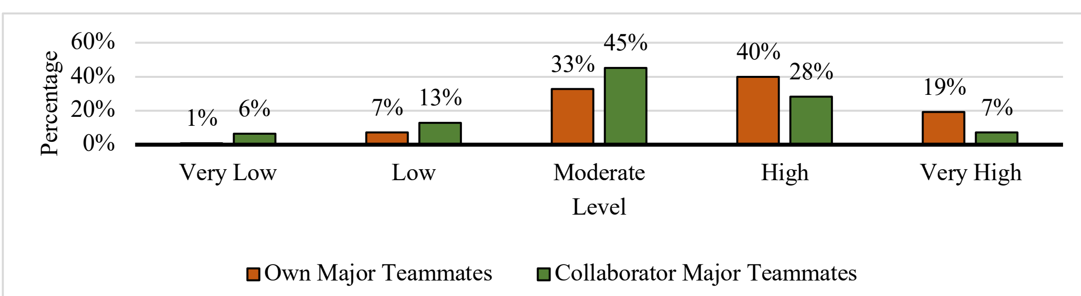

Figure 6. Percentage of communication quality levels

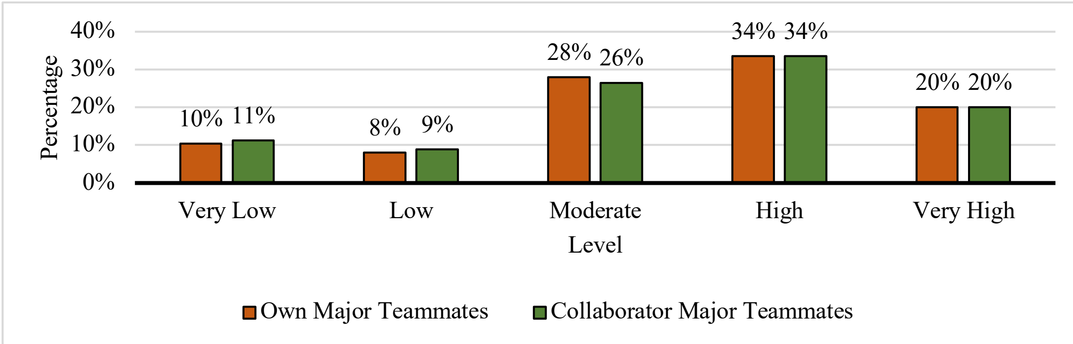

Figure 7. Percentage of perception about the collaborative studio

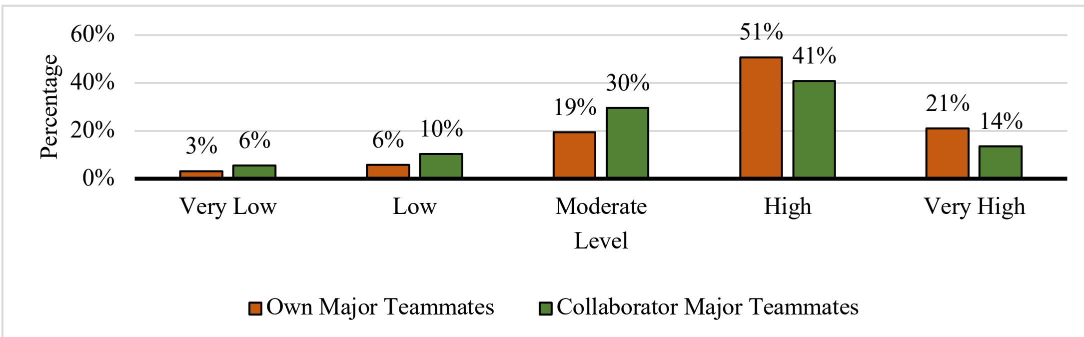

Figure 8. Percentage of student performance level impacting the success of the student's projects

The survey participants were also asked about the performance of the members in the collaborative studio that impacted the success of the student's projects, as shown in Figure 8. As the figure implies, both BCS and Architecture students believed that the performance of both majors' members in their collaborative studio highly impacted the success of their projects/assignments, although the percentage of their own major teammates was higher in the "high" and "very high" levels. The next question examined students' satisfaction with both groups' performances. As Figure 9 shows, the satisfaction with the performance of the own major teammates in the collaborative studio in "High" and "Very High" levels was higher than that of collaborator teammates. Finally, participants were asked about their willingness to take another collaborative studio with their current one versus another major. Figure 10 represents the extent to which students were willing to have another collaborative studio. Two groups of BCS and ARC students shared similar opinions on having another collaborative studio with their current one or another major from art or engineering.

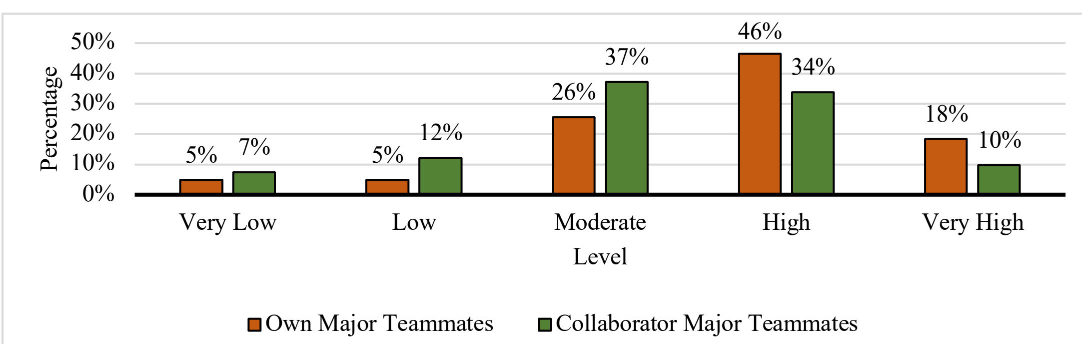

Figure 9. Percentage of overall satisfaction level

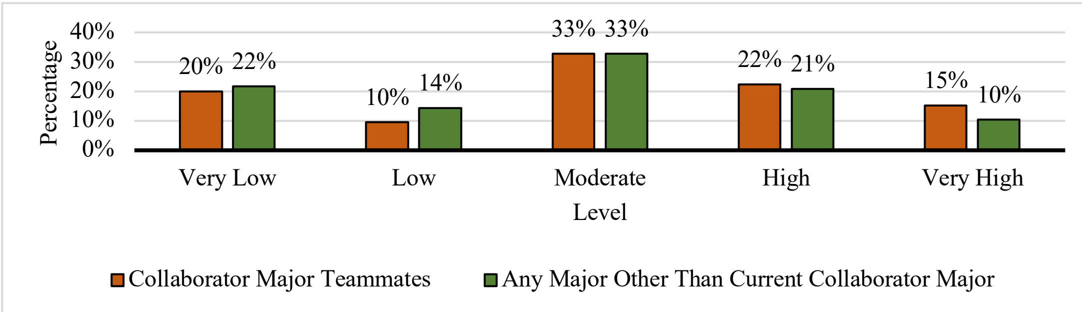

Figure 10. Percentage of willingness to take another collaborative studio

5. Discussion

To conduct this study, the literature review and discussion with the educators identified various factors to better understand the different features of collaborative studios in BCS and architecture programs. Then, the related questionnaire was responded to by 125 students. In this group, 73% were studying BCS, and 27% were architecture major students. As shown in Table 1, the average of females' studying hours per week was greater than male students' (Male=16.66 hours, Female=19.04 hours). Also, the expected final grade of architecture major students was higher than BCS (BCS=87.47, Architecture=89.70), and the average studying hours per week of architecture students was higher than BCS students (BCS=16.67, Architecture=18.78). The results showed that more than 56% of students considered a high rate of successful teamwork with their collaborator major students, and less than 7% believed the teamwork with their collaborator major students was not successful. In addition, the results showed that the learning rate, the quality of communication, the performance of the following members in the collaborative studio impacted the success of student's projects, and satisfaction with the performance of own major teammates in the collaborative studio was more than corresponding numbers in collaborator group. For example, 52% of students reported a high level of learning with their own major teammates. Additionally, 59% of students reported a high impact of quality of communication with their own major teammates. In contrast, just less than 8% expressed that the rate of quality of communication was low. A similar pattern was discovered for collaborator teammates. Additionally, students believed that the collaboration student was equally useful for both majors. Also, students stated that the course content is highly useful for both sides. Furthermore, the results indicated that students generally considered a high rate for both majors' performance on the success of projects. In other words, students, on average, did not distinguish between the impact of both majors' students' performance on the success of their projects. Another notable point from the results was the preference of students for interactions with their instructors. In this section, the difference between the percentages of "High" and "Very High" levels of "own major" was higher than those of "collaborator." This means students preferred to communicate with their own major instructors, even though other instructors were available to them.

6. Conclusion

This study was an attempt to look at two collaborative studio courses between ARC and BCS programs at Mississippi State University and explore aspects associated with collaboration as a multifaceted skill. The findings of this study, consistent with existing research, supported the efficacy of collaboration in overall success from the students' perspective in AEC educational programs. The findings also highlighted the importance of communication in overall success. Therefore, efforts should be implemented to enhance the communication between students of each discipline with the other as well as the collaborator professors. In future research, it may be helpful to conduct a more detailed interview with a select group in order to further explore the fine details and nuances in students' perception. In spite of the apparent anticipation that collaboration should always result in a higher rate of success, the findings of this study suggested that students' perceptions does not always agree with that. Possible reasons include the lack of efficiency in communication leading to unsuccessful collaboration, improper team dynamics, the project scope, presence of external entities or industry partners and so forth. Also, it is evident that the results may have changed if the population included students in other disciplines where collaboration framework was different. For future research, certain measures should be taken to investigate specific dimensions of projects defined in collaborative courses and explore how different modules of a project might induce or discourage collaboration. Additionally, exploration may entail how and to what degree different kinds of assignments could be better completed in a collaborative effort or as an individual effort. Other factors to be considered in future is the size of the collaborative teams, the make-up of the team (number of students from each discipline), the time needed to complete the project and so forth.

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ID 33

Challenges of Sustainable Construction Projects Delivery

Salma Ahmed[1] and Sameh El-Sayegh[2]

[1] American University of Sharjah, United Arab Emirates
g00043157@aus.edu

Abstract
As the construction industry plays a significant role in the growth of a country socially and economically, it is also considered a crucial contributor to environmental degradation. This has led to the development of several sustainable construction initiatives around the world. However, this uptake of sustainable construction comes with its fair share of challenges. This research sets out to identify the most significant challenges of sustainable construction projects delivery. Literature review was conducted to extract a list of the most cited challenges, thirty-three were shortlisted and used to create a questionnaire survey that was then distributed among construction professionals within the United Arab Emirates (UAE) to gather their perceptions on the significance of each of these challenges. Eighty-two questionnaires were returned and used for analysis. The Relative Importance Index was calculated in order to rank the challenges. The five most significant challenges were: owner's unwillingness to pay, client's funding issues, cost overruns due to tight schedule plans, lack of early involvement of construction professionals and lack of contractual incentives for the contractor. This research suggests increasing the levels of integration, investing in innovation and advanced technological systems as well as relinquishing traditional management practices to better achieve sustainability criteria among the main recommendations to overcome these challenges.

Keywords
Sustainability, Challenges, Construction Management, Sustainable Construction Practices.

1. Introduction

Sustainable construction has been gaining a lot of attention over the past years. It comes as a response plan to the significant quantity of natural resources and massive quantities of waste produced by construction activities (Zuo et al., 2012). In fact, a recent study done in China has shown that the construction demolition waste has reached an estimate of 1.55 to 2.4 billion tons (Hao et al., 2020). Similarly, the carbon dioxide emissions resulting from construction activities are among the highest rates in Gulf Cooperative Council countries (Al-Saleh and Taleb, 2010). Not only does sustainable construction mitigates these environmental impacts, but studies have also shown that sustainable buildings reduce energy consumption and improves the indoor air quality as well as thermal comfort for the occupants (Baird and Field, 2013)

The two most famous environmental rating systems that are available in practice are LEED in the US and BREEAM in the UK (Nguyen and Altan, 2011). Countries around the world have similarly have developed several initiatives to promote sustainable construction practices. For instance, in the UAE, specifically in Abu Dhabi, the Estidama Pearl System was launched in 2008 in an attempt to localize the definition of sustainability and incorporate sustainable criteria that satisfy the cultural, climatic and financial settings in the country (Mezher et al., 2011). Furthermore, in 2014, Dubai Municipality introduced the green building initiative to impose sustainable construction on all buildings (Small and Mazrooei, 2016).

However, the delivery of sustainable construction projects is accompanied with several challenges that impede their success. Lam et al. (2009) concluded that the three most critical barriers to sustainable construction were additional costs, delays and lack of competent suppliers in the market. Similarly, a study done in Kuwait has revealed that lack of awareness and government support were the most significant barriers that hinder the implementation of green practices in the country (Alsanad, 2015). Other challenges that were highlighted from literature included longer time during preconstruction phase, difficulty in selection of skilled contractors as well as owner-related barriers and gap existence between actual project delivery and policy formulation (Hwang and Ng, 2013; Tafazzoli et al., 2020; Alqadami et al., 2020).

Therefore, the aim of this research is to evaluate the challenges associated with sustainable construction projects delivery with evidence from the construction professionals in the UAE. The UAE had been selected as the construction industry in the country is booming with expansive measures of sustainability being implemented in construction projects throughout the country. In order to achieve this aim, the following objectives must be met:

1. Identify key challenges in the delivery of sustainable construction projects
2. Measure the relative importance and rank each of the identified challenges

This paper provides invaluable insight into the main challenges accompanied with sustainable construction projects delivery. It also provides recommendations in order to overcome the most significant challenges in an attempt to increase the success rate of sustainable construction projects delivery.

2. Materials & Methods

The first step was to identify the challenges of sustainable construction project delivery. This was done primarily through literature review. A comprehensive list of 33 challenges was developed. A questionnaire was then structured to get the perceptions of construction experts in the UAE. The questionnaire consisted of two sections. The first section was to gather general information about the respondents' profile such as years of experience. The second section was to get the perception on the significance of each risk. A Likert scale of 1-5 was adopted where 1 indicated very low significance and 5 indicated very high significance. The questionnaires survey forms were distributed among construction professional within the UAE construction industry and the completed responses were received online. 82 responses were collected out of a total 200 surveys sent. 12% of the respondents had more than 20 years of experience and 61% of the respondents worked in local companies while 39% worked in international companies. The Relative importance index was then calculated for each challenge using Equation 1 (Aghimien et al., 2018; El-Sayegh et al., 2018).

$$RII = \frac{\sum_{i=1}^{5} w_i x_i}{\sum_{i=1}^{5} x_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (1)$$

Where;
w_i is the weight assigned to the ith response; w_i=1,2,3,4,5 for i=1,2,3,4,5 respectively
x_i is the frequency of the ith response
i is the response category index=1,2,3,4,5 for very low, low, average, high and very high significance respectively.

Post computing the relative importance index, each of the identified challenges will be ranked in order to determine the top 5 challenges associated with the delivery of sustainable construction projects which will then help generate recommendations to overcome these challenges and possibly improve the delivery of sustainable construction projects.

3. Results

3. 1 Challenges of Sustainable Construction Projects Delivery

Thirty-three challenges of sustainable construction projects delivery were collected from literature review and categorized into 7 categories according to Ahmed and El-Sayegh (2022) who used factor analysis to cluster the challenges as shown in Figure 1. The first category is financial which includes all monetary challenges, the second category includes all challenges associated with the uniqueness of the sustainable materials and technology. While the third category is contractual which includes incentives, risks and reward sharing as well as involvement and co-ordination among team players. The fourth category deals with all design challenges associated with sustainable construction. The fifth category emphasizes the lack of experience in terms of skilled workforce to conduct sustainable construction projects. The sixth category includes the regulations and approvals required for sustainable construction projects and the last category is limited organizational awareness towards sustainable construction.

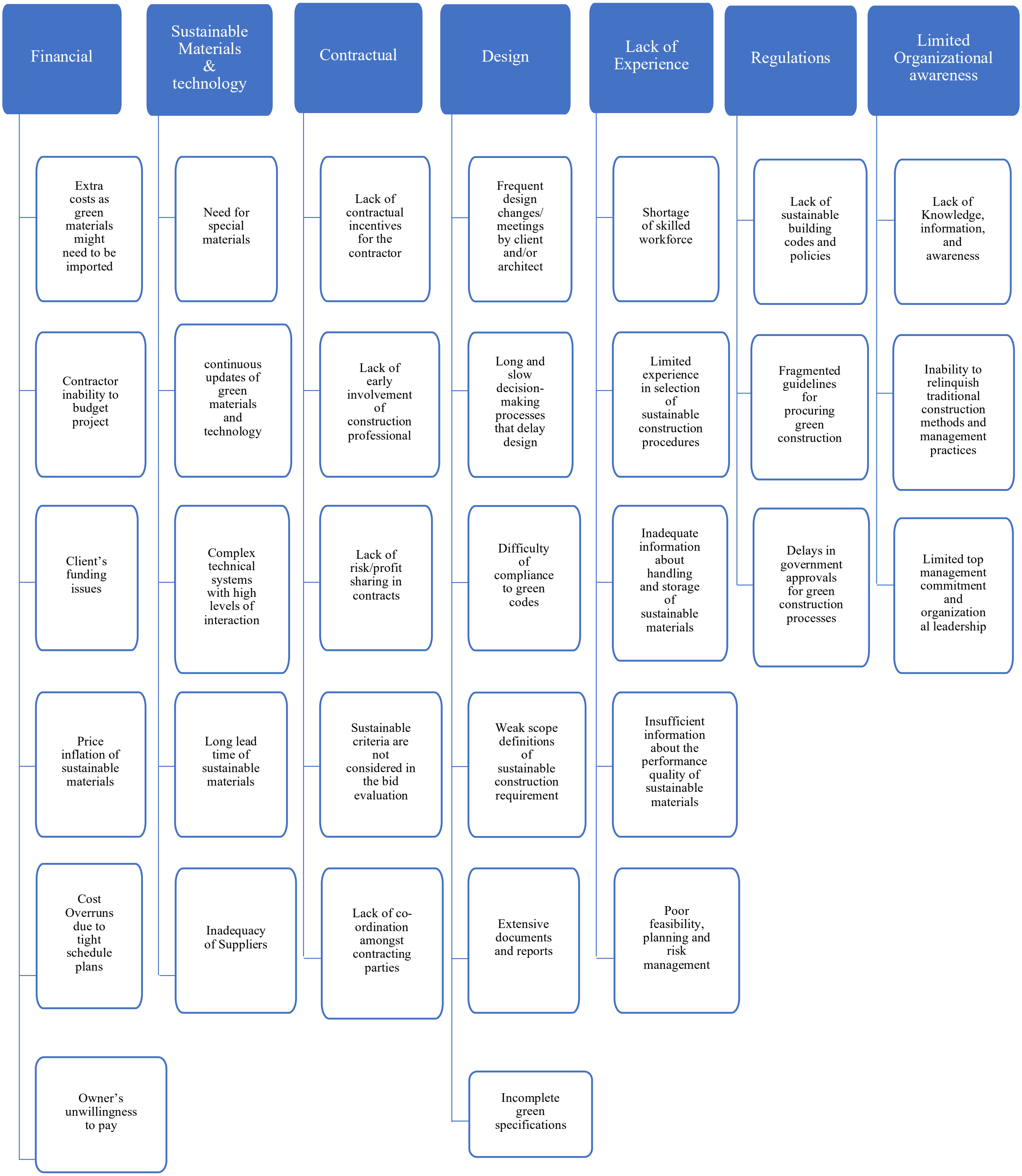

Fig. 14. Challenges of Sustainable Construction Projects Delivery

3. 2 Significance of The Challenges

Based on the survey results, the relative importance index was calculated for each challenge. The challenges were then ranked according to their RII. The results are presented in Table 1.

Table 14. RII and Rank of Sustainable Construction Projects Delivery

Challenges	RII	Rank
Owner's unwillingness to pay	4.23	1
Client's funding issues	3.88	2
Cost overruns die to tight schedule plans	3.87	3
Lack of early involvement of construction professionals	3.85	4
Lack of contractual incentives for the contractor	3.80	5
Additional costs as green materials might need to be imported	3.78	6
Frequent design changes/meetings by client and/or architect	3.77	7
Sustainable criteria are not included in the bid evaluation	3.76	8
Shortage of skilled workforce	3.70	9
Inability to relinquish traditional management practices	3.68	10
Contractor's inability to budget project	3.66	11
Lack of co-ordination among contracting parties	3.65	12
Long and slow decision-making process that delay design	3.63	13
Lack of risk/profit sharing in contracts	3.62	14
Need for special materials	3.62	15
poor feasibility, planning and risk management	3.62	16
Limited top management commitment and organizational leadership	3.60	17
weak scope definitions of sustainable construction projects	3.59	18
Limited experience in selection of sustainable construction projects	3.59	19
Inadequacy and unreliability of suppliers	3.55	20
Price inflation of sustainable materials	3.54	21
Delays in government approvals for green construction procedures	3.54	22
Lack of knowledge, information and awareness	3.49	23
Complex technical systems with high levels of interaction	3.45	24
Insufficient information about performance quality of sustainable materials	3.44	25
Incomplete green specifications	3.38	26
Inadequate information about handling and storage of sustainable materials	3.32	27
Long lead time of sustainable materials	3.29	28
Difficulty of compliance to green codes or certification	3.24	29
Lack of sustainability building codes and government policies	3.23	30
Continuous updates of green materials and technology	3.22	31
Extensive requirements for documentation and reporting	3.17	32
Fragmented guidelines for green procurement	3.15	33

4. Discussion

The results have revealed that 3 out of the top 5 challenges of sustainable construction projects delivery belong to the financial challenges category. The most significant challenge which is the owner's unwillingness to pay has been emphasized by Taffazoli et al.(2020) who also added that funding issues arise in sustainable construction due to poor cost and schedule planning. Furthermore, literature review has also concluded that tight schedule plans are not always the perfect strategy when conducting sustainable construction projects as they require more time than traditional ones and trying to enforce those tight plans will only lead to cost overruns (Hwang and Ng, 2013). This matches the results of this paper as cost over runs due to tight schedule plans is the third most significant challenge. Other financial challenges that were collected from literature included price inflation of sustainable materials (Hwang et al., 2017), additional costs of green materials especially if they are not available in the local market as they might need to be imported (Hwang et al., 2017), as well as the inability of contractors to properly budget the project due to their unfamiliarity with sustainable construction (Zou et al., 2007). Indeed, this is closely related to the lack of awareness about sustainable construction procedures which is one of the most cited challenges in literature (Aghimien et al., 2019) as well as the limited experience of contractors and consultants when dealing with sustainable construction projects (El-Sayegh et al., 2018). It is indeed essential to invest more in innovation and technological research to explore more of sustainable construction practices.

The 4th and 5th most significant challenges are lack of early involvement of construction professionals and lack of contractual incentives for the contractor which belonged to the contractual category. In fact, Suprapto et al. (2016) highlighted that contractual incentives such as risks and profit sharing motivate contractors to perform better in construction projects. Moreover, Korkmaz et al. (2010) stated that sustainable construction projects demand a higher level of integration that allows for early involvement of construction professionals, better communication and collaboration amongst stakeholders as these projects are more complex than traditional ones and comprise of a lot of interdependent technical systems. Other challenges that belong to the contractual category include the lack of sustainability criteria in the bidding evaluation which was highlighted by El-Sayegh et al. (2020) as traditional contractor selection methods that rely solely on lowest price methods need to be updated. In fact, Opoku et al. (2015) stated that the delivery of sustainable of construction projects require organizational awareness and top management commitment to be able to relinquish traditional management practices and implement sustainability measures.

Other challenges that were collected from literature include design challenges and sustainable materials. Al-Hajj and Hamani (2011) explained how weak scope definitions and incomplete green specifications might impede the successful deliver of sustainable construction projects. As this may lead to frequent design changes that may prolong decision making processes that further delay the design phase (Ayman et al., 2020). Additionally, sustainable materials are unique and are not readily available everywhere (Aghimien et al., 2018; Asaad and El-Sayegh, 2021). They also have long lead time that delays the approvals process and hence delays construction activities. Besides, there are limited number of suppliers with sufficient experience in how to handle and store these sustainable materials which adds another challenge to the delivery of sustainable construction projects (Lam et al., 2009; Qazi et al., 2021).

The least significant challenges according to the results of this paper belong to the regulations challenges category that included fragmented guidelines for green procurement as well as lack of sustainable building codes and policies. In fact, AlSanad (2015) stated that sustainability codes are constantly being updated which makes it challenging to deliver sustainable projects that comply to the continuously changing codes and policies. Similarly, Bohari et al. (2017) explained that the green procurement guidelines that are available in practice are fragmented and are missing invaluable information such as the effectiveness of the different delivering methods in accomplishing sustainability criteria.

5. Conclusions

As the projects in the construction industry grow more in size and complexity, they become more liable for the emission of greenhouse gases and environmental pollution. This has therefore, encouraged the shift towards sustainable construction. However sustainable construction comes with complex challenges that are different from tradition construction. Which necessitates the need to further explore these challenges to be able to come with up recommendation that can help overcome them and achieve more successful sustainable construction projects. Thirty-three challenges were identified from literature review and built into a survey to measure the significance of each of the identified challenges. The top five challenges according to perceptions of construction professionals in the UAE are: owner's unwillingness to pay, client's funding issues, cost overruns due to tight schedule plans, lack of early involvement of construction professionals and lack of contractual incentives for the contractor. These results highlighted the fact that financial challenges are the main challenges in sustainable construction. Additionally, the results also emphasized the need for higher levels of integration and advancement in technological research to increase the success rate of sustainable construction projects, as well as the need for top management commitment to relinquish traditional management practices.

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ID 36

Decision Tree Analysis in Project Risk Management: A Systematic Review

Aynur ZAKU[1], Furkan UYSAL[2]

[1] Social Sciences University of Ankara, Ankara, Turkey
[2] Social Sciences University of Ankara, Ankara, Turkey
aynur.zaku@student.asbu.edu.tr

Abstract

The most critical step repeated at each process in risk management is "decision making." Decision trees, part of artificial intelligence, have been used in an integrated manner with different methods in decision-making under uncertainty in recent years. The main reason for this is the need to quantify uncertainty in project risk management and the need for a flexible decision-making process in project management. This article aims to determine which project risk management processes the appropriate methods are used more frequently and determine the literature gap. In this context, literature review and bibliometric analysis methods were used. The results indicate that the integrated use of related risk assessment methods has increased in the last five years. The methods were most frequently used in quantitative risk analysis, qualitative risk analysis, and risk identification processes. It has been determined that the number of studies conducted on risk monitoring and control processes is very few compared to the number of studies on other risk management processes.

Keywords

Project risk management process group, decision tree, event tree analysis (ETA), fault tree analysis (FTA), bow tie analysis

1. Introduction

Risks are associated with uncertainty where either the output of an event or the event itself cannot be forecasted. According to Chapman and Ward (2003), uncertainties in project management come from estimates, the basis of estimates, design and logistics, objectives and priorities, relationships between project parties. Researchers have proposed several project risk management methodologies to manage these sources of uncertainties. ISO 31000, Prince 2, and PMBOK guide are commonly used methods (Řeháček, 2017). Moreover, these different methods were compared and contrasted in various aspects (Karaman and Kurt 2015; Chin *et al*. 2012, Obrová and Smolikova 2013). As a result, several tools are proposed to select the best suitable approach for selecting project risk management methodology in the built environment, such as Forbes *et al*. (2008). Among all proposed methodologies, Project Management Institute's (PMI) Project Management Body of Knowledge (PMBOK) has been widely accepted and used by construction management practitioners. PMBOK defines project risk as "an uncertain event or condition that, if it occurs, has a positive or negative effect on one or more project objectives" (PMI, 2017). These uncertainties have to be managed through seven processes. PMI's project risk management processes start with planning a project risk management plan and continue with identifying risks, performing qualitative and quantitative risk analysis, planning risk responses, implementing risk responses, and monitoring risks. As stated by Forbes *et al*. (2008), the whole process depends on the identification of risks, since determining the risky event and associated uncertainty starts with identification. Evaluating the identified risks is another major component of risk management using qualitative and quantitative techniques.

Even though project risk management literature has been widely studied, there are very few numbers of systematic reviews based on PMI's process groups. For example, the chronological development of risk assessment techniques and models in construction risk management has been proposed by Tesfaye *et al.* (2016), and risk modeling techniques with fuzzy logic are given by Rezakhani (2012). Bahamid (2017) compiled studies on risk management in construction projects in developing countries, and Xia *et al.* (2018) examined risk management in construction projects in an integrated framework with stakeholder management. A systematic review on new and emerging tools in project risk management could serve researchers and practitioners to see the gap in the literature.

When the PMI's project risk management processes are considered, the essential step repeated at each process is "decision making." In a project, we move forward by deciding whether to continue the project or not, the project timeline, identifying and prioritizing risks, and the strategy to be executed. However, we also want to know our options and possible consequences before deciding to make the right decision. Decision trees have been developed to schematize choices, branches, and outcomes to facilitate decision-making between different options. However, decision-making has a complex structure as it includes many parameters, and it does not seem possible to answer all problems with a single method.

Since there are scarce resources in terms of systematic reviews on project risk management and decision making is a complex process, decision trees are selected as the primary subject matter of this paper. Therefore, a systematic review is conducted for decision trees in project risk management, and literature gaps are determined based on PMI's seven project risk management processes.

2. Methodology

This paper used literature review and bibliometric analysis as the primary search method. A three-phase search process was followed as a starting point for a comprehensive literature review. The first phase included searching and filtering the keywords determined after expert opinion. The second phase included finding the related literature on the decision trees with the article abstracts' analysis. The final phase included finding the general trends and literature gap in the literature. The general flow of the research is shown in Figure 1.

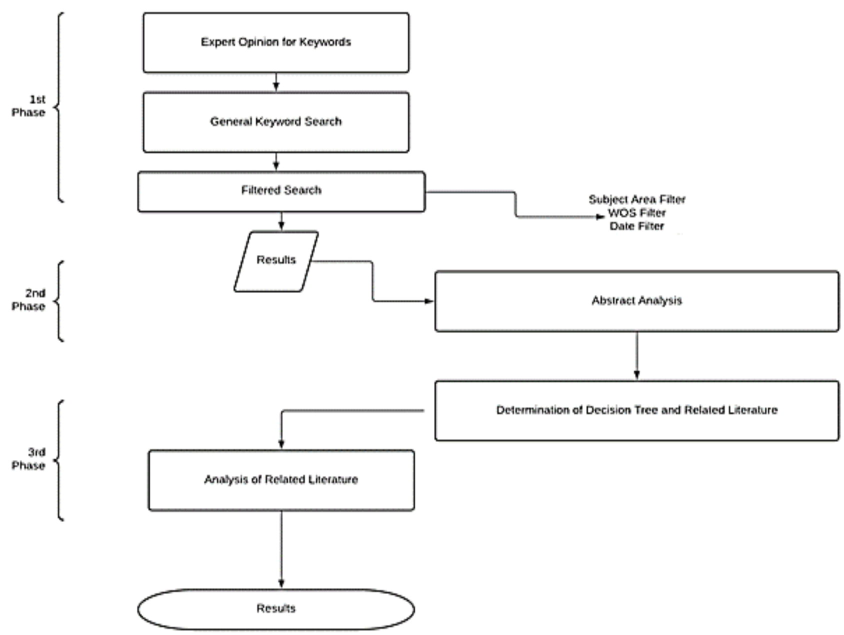

Figure 15. General Flow of Research

This study determined the target information source of scientific articles registered in the Web of Science (WOS) database. ***In the first phase*** of the research, the keywords were determined after expert opinions. Five key experts who have academic publications on project risk management and have experience at least five years in construction were asked to determine the most suitable keywords related to project risk management. Eleven keywords were selected, and a search was conducted with these eleven keywords.

Table 15. Keywords Determined After Expert Opinions

No	Key Words
1	“risk management” AND “project*” AND “decision tree”
2	“project management” AND “risk*” AND “decision tree”
3	“risk plan*” AND "project*" AND “decision tree”
4	“risk identif*” AND "project*" AND “decision tree”
5	“qualitative risk” AND “project” AND “decision tree”
6	“quantitative risk” AND “project” AND “decision tree”
7	“risk strategy*” AND “project*” AND “decision tree”
8	“risk response*” AND "project*" AND “decision tree”
9	"risk control" AND "project" AND " decision tree"
10	“risk monitor*” AND “project” AND "decision tree"
11	"ETA" OR " FTA" OR " Bowtie" OR " fault tree" OR "event tree" AND "project*"

Article search was carried out in article topic in WoS using the keywords given in Table 2. These searches were filtered with the below methods;

- # of articles without filter: Refers to the number of articles in search results before any filters are applied.
- # of articles: Refers to the number of articles after the article filter is applied.
- # Date filter: Refers to the number of articles after the date filter is applied (The articles published between 2012 and 2021 are included).
- SCI-Expanded and SSCI Index: Refers to the number of articles after the WoS Index filter is applied (The articles indexed in SCI-Expanded and SSCI Index are included).
- WoS Category: Refers to the number of articles after the WoS Category filter is applied. (Engineering Civil and Construction Building Technology categories included).

Table 16. 1st Phase of Keyword Search

# of Articles without Filter	# of Articles	# Date Filter	SCI and SSCI Index	WoS Category
131524	114351	53421	43899	502

In the second phase of the research, all 502 article abstracts, titles, author names, and sources are downloaded for further analysis. The keywords project, decision tree, fault tree, and event tree were searched separately in the abstracts. Since the bow-tie analysis includes both ETA and FTA analysis, no additional searches were done for this keyword. The number of articles obtained is also shown in Table-3.

Table 3. 2nd Phase of Research: Abstract Analysis

# of Articles-1st Phase	“Project” filter	“Decision Tree” filter	“Fault Tree” filter	“Event Tree” filter
502	159	36	121	34

- # of articles-1st phase: Refers to the number of articles obtained from 1st phase of the research
- “Project” filter: Refers to the number of articles after the word “project” filter is applied.
- “Decision Tree” filter: Refers to the number of articles after the words “decision tree” filter is applied.
- “FTA” filter: Refers to the number of articles after the word “FTA” filter is applied.

- "ETA" filter: Refers to the number of articles after the word "ETA" filter is applied.

The abstracts of the articles shown in Table-3 were analyzed and divided into two categories within the scope of project risk management processes (articles not within the scope of project risk management were excluded). In this context, 39 articles for Decision Tree Analysis and 37 articles for ETA and FTA were determined for further analysis.

In the third phase of the research, a total of 75 identified articles were reviewed and classified one by one according to the seven process groups of the PMI's project risk management process. If research can be categorized in more than one process group, each process group is counted separately. Obtained results were analyzed in 3 stages. Decision trees and project risk management processes in the first stage; ETA, FTA, bow tie analysis, and project risk management processes in the second stage; all tree analysis and project risk management processes in the third stage. The number of articles by year is graphed to see the trend of decision trees in Project risk management processes. Finally, to determine and show the gap in the literature, the phases in the project risk management processes in which decision trees are used are quantified and delivered on a radar chart.

3. Results

3. 1 First Stage Results

In the ten years between 2012 and 2021, the number of articles using decision trees in project risk management is 39. The distribution of the articles within the scope of project risk management by years is given in Figure 2.

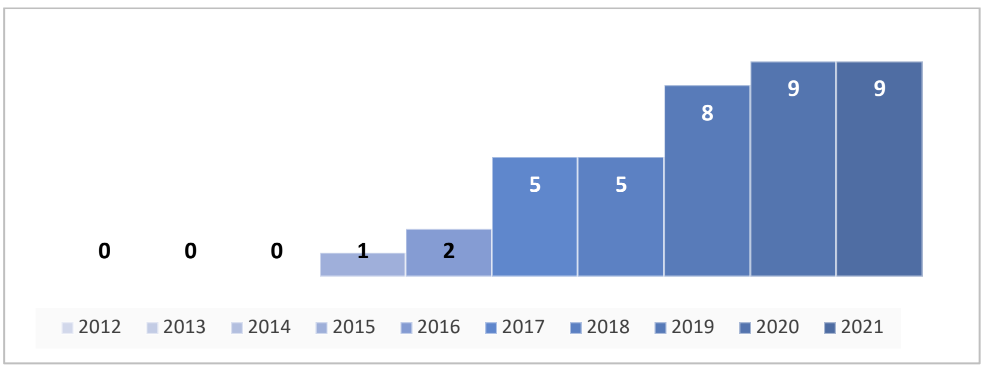

Figure 2. Number of Publications using Decision Tree Analysis in the Project Risk Management Process

As shown in Figure 2, while only three articles were published between 2012 and 2016, the number of studies has started to increase since 2017. The main reason for this increase is the increasing prevalence of machine learning methods and integrated studies of decision tree analysis with these new methods. The most frequently used methods integrated with decision tree analysis are as follows: Naive Bayesian (Hassan *et al.*, 2021; Liang *et al.*, 2021; Ahmad *et al.*, 2020; Gondia *et al.*, 2020; Lu *et al.*, 2020; Hu *et al.*, 2019), Bayesian Network (Ahmad *et al.*, 2020; Hu *et al.*, 2019), Analytical Hierarchy Process (AHP); (Maceika *et al.*, 2020; Maceika *et al.*, 2021), which ensures that not only objective factors but also subjective factors are considered in the decision-making process. Gong (2021) and Khazali *et al*. (2019) used a fuzzy logic and decision tree together. Compernolle (2019) and Chen (2017) use Monte Carlo Simulation () in construction projects. Welkenhuysen *et al*. (2017) used Techno-economic simulator PSS (Policy Support System) with Monte Carlo Simulation. Optimization and decision trees are used by Abreu *et al*. (2018) and Niederleithinger *et al*. (2017). Kameshwar (2020) used three separate decision trees for bridge restorations. The integrated use of machine learning with decision trees has increased in project risk management in recent years: The artificial neural network (ANN) (Arbab *et al.*, 2021; Gondia *et al.*, 2020; Shin, 2019; Guerrero *et al.*, 2018), Random Forest (RF), (Arbab *et al.*, 2021; Zhang *et al.*, 2020; Hu *et al.*, 2019; Poh *et al.*, 2018; Liang *et al.*, 2020), Support Vector Regression (SVR), (Arbab *et al.*, 2021), Support Vector Machine (SVM), (Hassan, 2021; Liang *et al.*, 2021; Zheng *et al.*, 2021; Poh *et al.*, 2018), Gradient Boosting Decision Tree (GBDT), (Zheng *et al.*, 2021; Shin, 2019; Liang *et al.*, 2020), K-nearest neighbors (KNN), (Hassan *et al.*, 2021; Zheng *et al.*, 2021; Mahmoodzadeh *et al.*, 2021; Steineder *et al.*, 2019; Poh *et al.*, 2018), J48 Decision Tree (Ahmad *et al.*, 2020; Khazali *et al.*, 2019; Hu *et al.*, 2019). Lin *et al.* (2019) used Classification and regression tree (CART), chi-squared automatic interaction detection

(CHAID), and quick, unbiased efficient statistical tree algorithms (QUEST) methodologies together. Gunduz and Lutfi (2021) used the CHAID and CRT models when deciding whether to bid on the projects or not. Rinaldi *et al.* (2020) used a decision tree-based machine learning algorithm. Howick *et al.* (2016) used the decision tree integrated with the mixed OR method. Real option (RU), which has more financial use than its application in engineering design analyzed with a binomial decision tree Ajak *et al*. (2015), Tang *et al*. (2017), and Ihm *et al*. (2019) studied with a trinomial decision tree. Other methods in which decision trees are used integrated into project risk management are as follows: Comparative analysis, gradient decision tree boosting- GDTB (Gong *et al*. 2021), Chi-square automatic interaction detection decision tree analysis (Cottrell *et al.*, 2019), Matrix analysis of HVAC system, Cost estimation methodology (Cho *et al.*, 2018), scenario analysis (Wang *et al.*, 2016) and operation analysis (Otsuki *et al.*, 2017).

Figure 3; 39 reviewed articles are classified according to PMI Risk Management Process Groups.

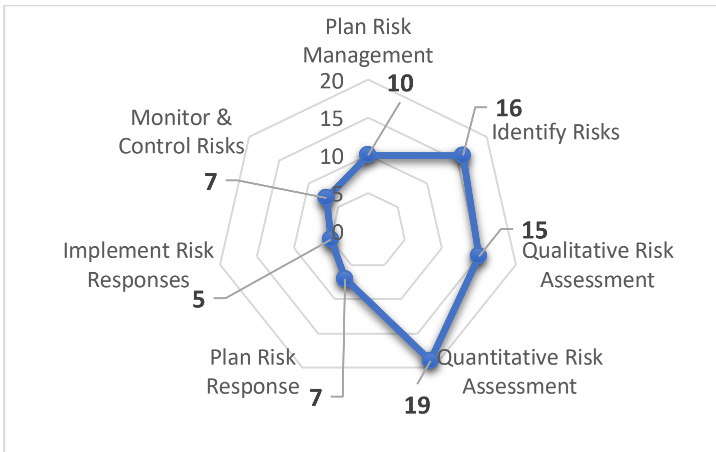

Figure 3. PMI Risk Management Process Groups of the Articles in the First Stage

When integrated methods, including decision tree analysis, are classified according to PMI Risk Management Process Groups, it is seen that studies mainly belong to the risk identification and qualitative and quantitative risk analysis process groups. The number of studies on monitoring and controlling risks is less than other processes. Very few recent studies emerged in plan risk management, plan risk responses, implement risk responses, and monitor and control risk process groups.

3.2 Second Stage Results

Thirty-six articles published on project risk management processes in this analysis stage were analyzed. The distribution of the articles handled within the scope of project risk management by years is given in Figure 4.

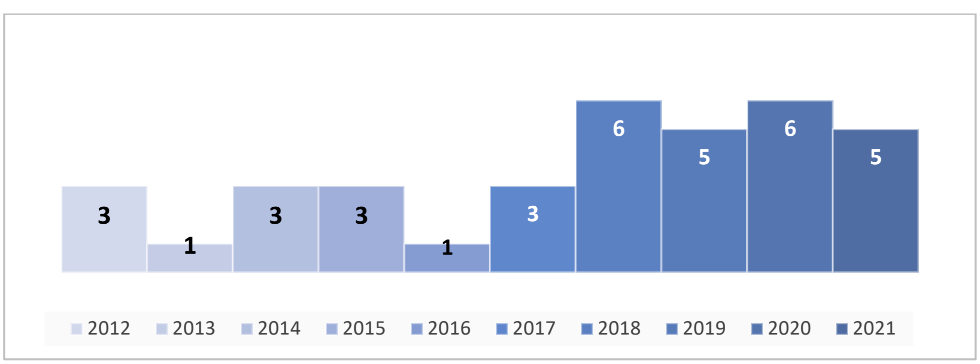

Figure 4: Number of Publications using ETA, FTA, Bow-Tie Analysis in the Project Risk Management Process

Fault tree analysis (FTA) is a risk assessment method used to estimate the probability or frequency of a particular hazard event that may occur. Qualitative or quantitative risk assessment can be made using Boolean algebra's diagram to define the hazard. Event tree analysis (ETA) is a risk assessment method that evaluates the consequences of a hazardous event. A diagram is created over the scenarios of a particular event. The method in which the questions of what can cause a hazardous event and what will happen if a hazardous event occurs together are evaluated together is called the bow-tie analysis. In other words, bow tie analysis combines ETA and FTA. In project risk management, ETA, FTA, and bow tie analysis methods have increased significantly in the last five years.

The most frequently used methods integrated with decision tree analysis are as follows: Fuzzy logic in integration with FTA and ETA (Abad *et al.*, 2020; Alipour-Bashary *et al.*, 2021a; Krechowicz, 2020; Nasirzadeh *et al.*, 2019; Shoar and Banaitis, 2019; Alipour-Bashary *et al.*, 2021b; Hsu *et al.*, 2020; Chen *et al.*, 2018; Ardeshir *et al.*, 2014; Gierczak, 2014; Abdelgawad *et al.*, 2012; Abad *et al.*, 2019; Marzouk and Mohamed, 2018; Marhavilas *et al.*, 2020; Shahhosseini *et al.*, 2018; Shoar *et al.*, 2019). The second most common method used in integration with FTA and ETA is the Bayesian network (Zhou *et al.*, 2018; Chen *et al.*, 2015; Leu *et al.*, 2015), but Guan *et al.* (2020), Zhang *et al.* (2014 and 2019) used fuzzy logic and Bayesian methods together with ETA and FTA. Ardeshir *et al.* (2014) and Marhavilas *et al.* (2020) preferred AHP with fuzzy logic. Another method integrated with ETA and FTA is Monte Carlo simulation (Vileiniskis *et al.*, 2017; Shoar *et al.*, 2019; Gernay *et al.*, 2016; Abdelgawad *et al.*, 2012). Zhang *et al.* (2019) used fuzzy fault tree analysis, fuzzy weighted index, and a risk response matrix in the designed model. On the other hand, Krechowicz (2020) used a Fuzzy set, fault tree analysis (FTA), artificial neural network (ANN), rough set (RS), cloud model (CM), and Bayesian network (BN) together for all phases. Marzouk *et al.* (2018) propose a framework with a new integrated system comprising fault trees, artificial neural networks, and analytical network processes.

Heravi et al. (2015) used ETA for conflict management for changes in construction projects project participants Liu *et al.* (2015) used fault tree analysis to evaluate project skill risks of project teams. Song *et al.* (2012) used ETA with alternative dispute resolution (ADR) techniques. Tsai *et al.* (2018) proposed the decision-making support system of risk management from risk efficiency with FTA. Aljassmi (2013) used a fault tree with defect management, and Zhang (2021) used it with optimization. Figure 5 is obtained when the 36 reviewed articles are classified according to PMI Risk Management Process Groups.

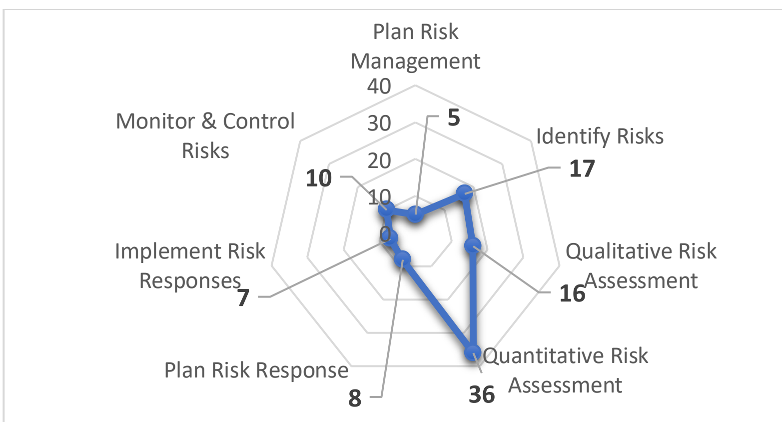

Figure 5: PMI Risk Management Process Groups of the Articles in the Second Stage

As shown in Figure 5, ETA, FTA, and Bowtie Analysis were mainly used to quantify risks in PMI project risk management processes. Unlike decision tree analysis, integrated models using these methods and including all stages have also been proposed. ETA, FTA, and bow tie analyses are often used to identify risks and the qualitative analysis of risks, with the quantitative analysis of risks.

3.3 Third Stage Results

In the third stage, 39 articles, including decision tree analysis and 36 articles including ETA, FTA, and Bowtie analysis (75 articles in total), were grouped according to project risk management processes. Project risk management processes in various fields such as tunnels (Liang *et al.*, 2021; Leng *et al.*, 2020; Sharafat *et al.*, 2021; Zhang *et al.*, 2019; Ardeshir *et al.*, 2014; Zhang *et al.*, 2014; Gierczak, 2014), Public-Private Partnership (PPPs), (Zheng *et al.*, 2021; Marzouk *et al.*, 2018), contracts (Gunduz and Al-Ajji, 2021; Hassan *et al.*, 2021; Zheng *et al.*, 2021; Poh *et al.*, 2018; Siu *et al.*, 2018; Turner *et al.*, 2017; Marzouk *et al.*, 2018) in construction technologies and civil engineering projects were evaluated. The distribution of the articles handled within the scope of project risk management by years is given in Figure 6.

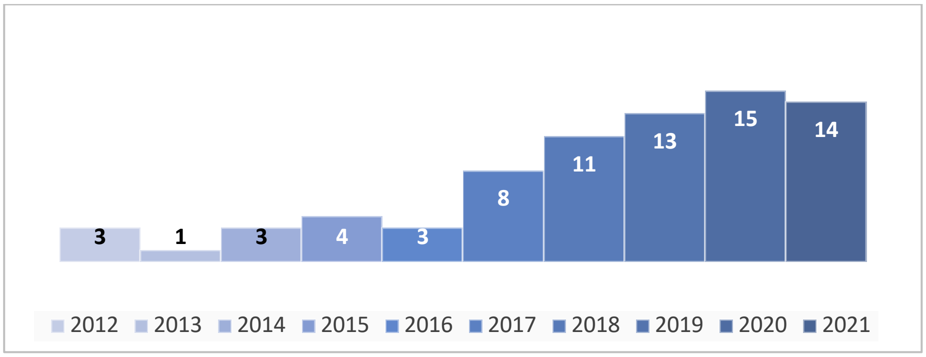

Figure 6: Number of Publications using DT, ETA, FTA, Bow-Tie Analysis in the Project Risk Management Process

When the distribution of 75 articles by year is examined, it is seen that 81% of them were published in the last five years. This ratio indicates an increasing interest in using decision trees with hybrid methods in project risk management. Figure 7 is obtained when the 75 reviewed articles are classified according to PMI Risk Management Process Groups.

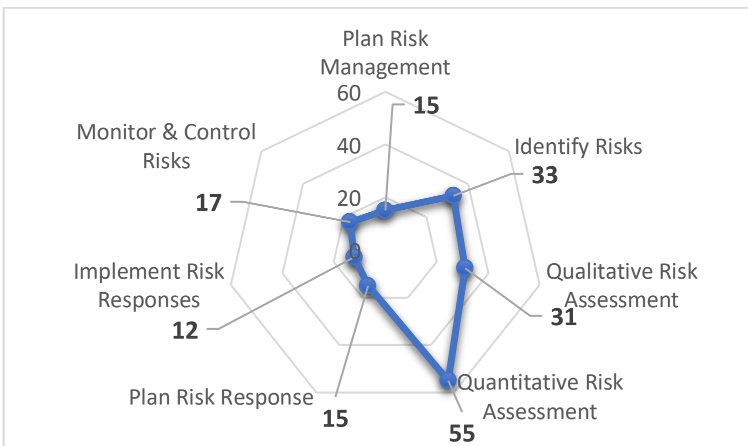

Figure 7. PMI Risk Management Process Groups of the Articles (Two Stages together)

Considering the PMI's process groups, the vast majority of the papers are published in the context of the quantitative risk analysis process group.

4. Discussion

The "decision-making" step is critical in each project risk management process. Decision trees, used as decision-making tools, provide ease of use as they schematize options about choices and possible outcomes. However, traditional decision trees deal with discrete values, are insufficient for uncertain situations, and can analyze a limited number of features with good performance. Most risk factors associated with a project are not independent and have causal relationships. There is an increasing interest in risk assessment methods that focus on this relationship between risks to increase the effectiveness of risk management (Guan *et al*., 2020). Easy integration of decision, event, and fault tree analyses with other methods lead to an effective project risk management methodology.

92% of the research with decision trees in project risk management has been done in the previous five years. In recent years, this ratio shows the increasing interest in using both decision trees and fault/event trees in project risk management processes. When the 39 articles on decision trees were analyzed, it is seen that the most research was on the quantitative risk analysis (n=19) process. However, the number of processes for identifying risks (n=16) and qualitative risk analysis (n=15) is close to the number of quantitative risk analysis processes. The most important reason for this is that the stages of identifying, evaluating, and prioritizing risks are generally handled and used together. However, after the risks are evaluated, the number of studies carried out during the planning risk strategies (n=7) and executing risk strategies (n=5), as well as the control and monitoring of risks processes (n=7), is considerably less than the number of other processes. This shows that planning, executing and control and monitoring of risks have high research potentiaş. In the 39 reviewed articles, including decision tree analysis, the number of processes for planning risk management and identifying and assessing risks constitute 75% of the total project risk management processes. The number of processes for planning responses to risks, implementing risk strategies, controlling and monitoring risks constitute 25% of the project risk management processes.

When project risk management processes analyzed the 36 reviewed articles on ETA and FTA, the most research was on the quantitative risk analysis process (n=36), more than the sum of risk identification (n=17) and qualitative risk analysis (n=16) processes. The number of processes for controlling and monitoring risks is higher than decision trees. The most important reason for this is event tree analysis. Because ETA evaluates controls against the risks that may occur if an event occurs. The least researched process in the articles on ETA and FTA is the process where the project risk management is planned (n=5). In 2 articles, integrated models, including all project risk management processes, were preferred (Zhang *et al.*, 2019; Krechowicz, 2020). In the 36 articles reviewed, the number of processes for planning risk management and identifying and evaluating risks, similar to decision trees, constitutes 75% of the total number of project risk management processes. The number of processes for planning responses to risks, implementing risk strategies, controlling and monitoring risks constitute 25% of the project risk management processes. However, the number of quantitative risk analysis processes alone corresponds to 36% of the total number of processes. This ratio shows that FTA is preferred most frequently in quantitative risk analysis. The majority of the findings indicate that project risk management researches are oriented to quantitative and qualitative risk analysis steps. There are less number of researches in project risk planning, executing and control and monitoring steps.

Limitations of the study is twofolds. First,this study aimed to find research potential based on previous literature researches that can help new researchers in project rist management and only WoS database is used for analysis. Second, the full research articles are filtered from search results. Conference preceeding could be added to the research results. A more comprehensive study could be done with more keywords and more databases.

5. Conclusions

Flexibility and high costs increase the importance of project risk management in the built environment. The use of decision trees, a tool for decision-making under uncertainty, has risen in recent years. According to the results of the bibliometric analysis, it has been determined that the integration of decision trees with methods such as machine learning and fuzzy logic has increased the use of decision trees significantly in the last five years. When the PMI's seven processes related to project risk management are analyzed, the decision tree is mainly used to identify risks and the qualitative and quantitative risk analysis processes. The least amount of study processes are where risk strategies are implemented and risk management is planned. Articles on project risk management generally concentrate on the risk identification and risk assessment phases. Since project risk management is a cyclical process, the planning and implementation of risk strategies and less handling of monitoring and control processes appear as the weakest link in project risk management

For further research, bibliometric analyzes on project risk management in sectors other than construction will reveal the application differences between industries, and good practice examples can be integrated. According to the analysis it is seen that there is a gap in the literature, especially in implementing risk responses, plan risk management, plan risk responses phases. This analysis with decision trees can be repeated with several quantitative risk management methods such as AHP, machine learning, or fuzzy logic.

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Building Information Modelling Mandates and Government Efforts: A Systematic Review

Motheo Meta Tjebane[1], Innocent Musonda[1], Adetayo Onososen[1]

[1] Department of Construction Management and Quantity Surveying, University of Johannesburg, Johannesburg, South Arica
motheometa@gmail.com

Abstract
While much advocacy has been given to adopting BIM in the built industry, the mandate or effort adopted by the government holds different implications towards disposition to adoption. This is imperative as resistance to change on BIM adoption is hinged by implementation strategies adopted by the government between national contexts. A review of government efforts is important to bring the strength of diverse mandating strategies for future national efforts from governments yet to adopt BIM. Research studies have sought to produce a holistic review of the increasing BIM publications to establish the development trend. The studies have used different Scientometric reviews, bibliometric reviews, or systematic literature reviews(SLR) to show the trends. Although BIM adoption differs across firms and countries, these studies regularly take a global view of development. Few studies use a two-phase literature review to look at BIM mandates worldwide. This paper aims to present a two-phase bibliometric analysis and systematic literature review of BIM mandates and government efforts in the construction industry to investigate the current state of BIM across regions. The study used publications made between 2011 and 2022 using the Web of Science. Vosviewer was used to analyse the bibliometric data while AtlasTi was used to analyse and code the SLR data. The review findings revealed that the African continent lags in publications and governments' efforts to make BIM mandatory. The results of this study should be used to establish a BIM mandate roadmap for developing countries and their governments in the future.

Keywords
Building Information Modelling, Bibliometric Review Government, Mandate, Systematic Literature Review

1. Introduction

Governments have increasingly recognised the potential of BIM in recent years and have implemented related legislation in the worldwide construction industry(Chang *et al*2017; Liao *et al*2020). Moreover, governmental efforts are a vehicle for construction stakeholders to take BIM adoption efforts seriously through policies. Furthermore, while the government remains the largest client for projects, it is expected that they will lead the way for other investors to follow (Olanrewaju *et al*2020). BIM (Building Information Modelling) is a set of technologies and solutions that allows for the three-dimensional (3D) representation of geometric and non-geometric (functional) aspects of building elements (Demian and Walters, 2013; Murphy *et al*2013; Lee *et al*2020). According to Bryde et al. (2013), not only does BIM include software that enables geometrical modelling and data entry, but it also incorporates project management tools and processes. It is a centralised platform for integrated design, modelling, asset planning, and collaboration. It offers all stakeholders a digital depiction of a building's attributes over its entire life cycle, promising significant efficiency gains (Miettinen and Paavola, 2014). Its goal is to promote collaboration among many stakeholders in the architectural, engineering, and construction (AEC) industry and productivity and management throughout the life cycle (Jiang *et al*2021). With the global construction industry's growing needs and the world drive toward BIM adoption and implementation, construction professionals must quickly catch up and begin using BIM in their projects, recognising that BIM adoption benefits all project stakeholders (Mehran, 2016). This is through the implementation of government policies and strategies.

While other studies have examined BIM mandates (Pereira *et al*2021; Hussein *et al*2021; Khan *et al*2021; Mansuri *et al*2021); this study adopts a mixed review through bibliometric and systematic literature review on BIM mandates worldwide to further extend the body of knowledge. A mixed literature review is a traditional method for identifying current trends and research gaps in a body of knowledge. They do not critically analyse the studies making trends on the BIM mandate and the government's efforts. BIM mandates are important as it is an initiative by government to drive industry uptake and implemnetaion of BIM across all levels of the AEC industry (Oti-Sarpong *et al*2020).

This study provides a literature overview of BIM mandates and government efforts worldwide through a literature review. The first phase is a qualitative Scientometric literature review to identify emergent trends of the BIM mandates in this field. The second phase is a quantitative systematic literature review (SLR), which provides a reliable and resilient strategy for selecting the most appropriate contribution across a large field of research. Two phases were employed in the literature review to increase the validity and reliability of the data sources(Alwan *et al*2017). The rest of this paper is structured as follows. Section 2 elaborates on the research methodology used in this study. Section 3 provides an in-depth analysis of the literature review findings of BIM mandate efforts of the various governments. Finally, section 4 concludes the findings and presents further studies concerning governance issues of BIM mandates.

2. Methodology

Figure 1 depicts the research approach used in this study. Bibliometric analysis and SLR were used in combination. The first phase was conducting a bibliometric analysis. Bibliometric analysis is one technique for visualising bibliometric networks to synthesise science mapping, which identifies unique disciplines, scientific domains, and research frameworks using large bibliographical datasets and large bodies of literature(Chen and Song, 2019). The Web of Science Core Collection database is recognised as the most valuable and high-impact data collection and the most dependable database for bibliometric studies (Rojas-Sola and Aguilera-García, 2020). Vosviewer, a text-mining tool, explored a wide range of bibliometric networks for bibliometric analysis (Morelli and Ignacio, 2021). The tool includes citation relationships between publications, co-authorship networks between scholars, and keyword co-occurrence relationships (Safura Zabidin *et al*2020; Turatto *et al*2021).

The second phase was conducting the SLR from the final 16 documents used in the bibliometric analysis manual selection and elimination. SLR was used to undertake critical analysis and objective appraisal of the literature by methodically searching, sorting, and finding articles (Palka *et al*2018). This included determining and choosing the right search keywords and discovering and extracting relevant research studies based on the inclusion and extraction criteria (Rashmi and Kataria, 2021). Any article not written in English was excluded. This is because English is one of the most spoken languages worldwide and is used for communication in the business, policy and academic world (Nunan, 2003; Jenkins, 2013). The classification and coding approach of the SLR of the articles was conducted using Atlas.ti These reviews are especially useful for doing in-depth analyses of cutting-edge research and integrating the findings into a specific topic (Abu *et al*2021).

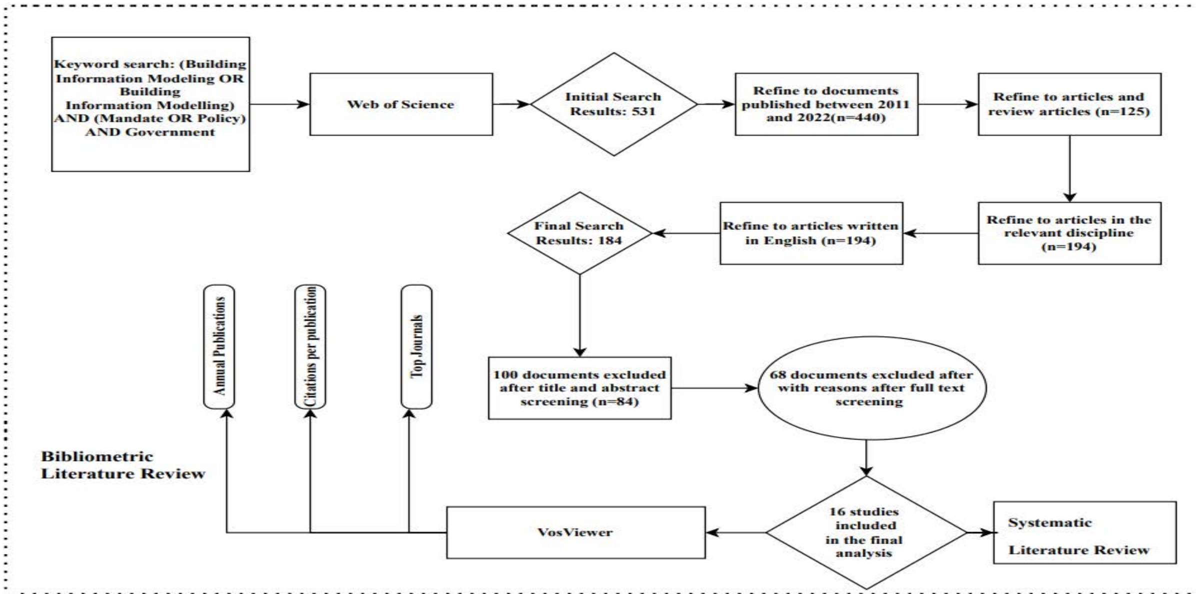

Fig. 16. Research Methodology.

3. Results

The bibliometrics analysis is results are shown in the section below. The current state and evolution of knowledge surrounding the issues of BIM, government, and mandates were examined using several bibliometric features of all the publications acquired.

3.1 Bibliometric Analysis

3.1.1 Annual Publication and Citations

Figure 2 below depicts the annual evolution of publications and citations. Between 2011 and 2021, the number and kind of publications were evaluated. This topic's relevant publications were published in 2017. There is an upward trend in studies related to BIM mandates and policies. In 2021, the highest number of publications was found, with six totalling 149 citations. Therefore, the subjects under analysis in the current paper are of current and high interest in the scientific community. This could indicate that a large amount of the data acquired is trustworthy, enhancing the quality of the analysis performed in this research. Similarly, between 2015 and 2021, there was a noticeable increase in citations.

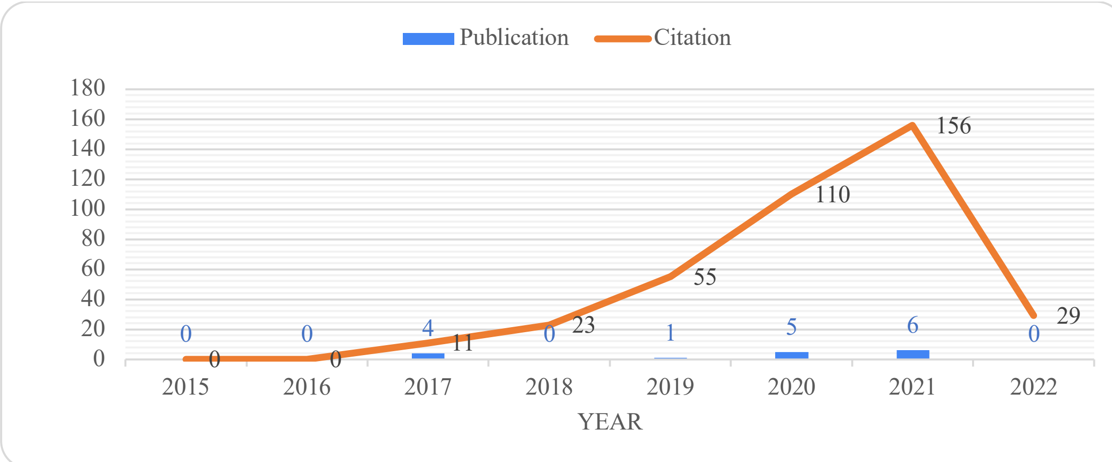

Fig. 2. A number of publications and citations.

3.1.2 Citations per publication

A researcher's influence in an area is measured by the number of citations they receive. Table 2 lists the top 10 publications from the identified 16 in government efforts in BIM mandates and policies with the most citations, according to data extracted from the Web of Science database. Li et al's publication had the most citations (106) and the most average citations (26.5). The publication looks at the BIM and Blockchain intergration in the built environment and the construction industry.

Table 2. Top ten contributing publications in the relevant field

Authors	Total Citations	Average citations per year
Li *et al*	106	26.5
Alwan *et al*	94	18.8
Dainty *et al*	75	12.5
Chang *et al*	31	6.2
Juan et al	26	5.2
Babatunde *et al*	15	7.5
Qin *et al*	11	3.67
Doan et al	12	4
Liao *et al*	6	2
Bouguerra *et al*	2	1

3.1.3 Citations per Journal

Journals are publicly accessible and provide a platform for publishing research. Peer-reviewed journal papers are likely to continue as an important means of disseminating research findings. Table 3 shows the journals with the most prestigious publications. The most cited journal is the Journal of Cleaner Production and Automation in Construction (94 citations), followed by Building Research and Information (68 citations), and the Journal of Civil Engineering and Management (68 citations) (35). The journals with the most documents (2) are the Journal of Civil Engineering and Management, Journal of Construction Engineering and Management, and Sustainability, while the others only have one publication.

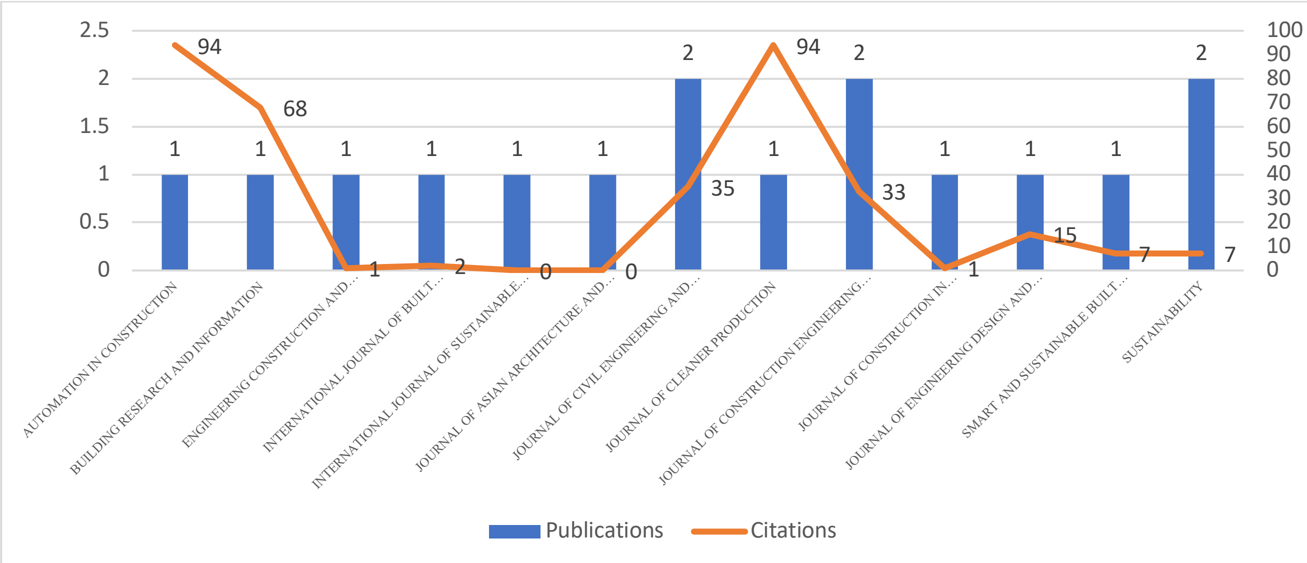

Table 3. Contributing journals having maximum publications

4. Discussion and Conclusion

This study presented a two-phase bibliometric review and systematic literature review of BIM mandates using BIM publications from the Web of Science. The bibliometric overview identifies the publication trend, country, author, and journal source. The SLR identified the mandates around the world. Table 4 is a literature review summary of the various governments' BIM mandates and policies. Table 4 shows a summary of BIM mandates and policies.

Table 4. BIM Mandates and policies

Country	Government Effort	Source
Australia	The government has mandated BIM for all government-funded projects, resulting in a major increase in BIM usage in Australia. Currently, as of 2021, BIM is being widely used on projects in Australia and by Australian consultants working on overseas projects	Babatunde *et al*2020; Bouguerra *et al*2020; Karampour *et al*2021; Jiang *et al*2021
Brazil	Government to mandate BIM in the year 2021. On April 3, 2020, decree 10.306 / 2020 was finally issued, requiring the mandatory use of BIM in the construction of direct or indirect work by entities or bodies belonging to the federal public administration	Jiang *et al*2021
Canada	To maintain consistency in the BIM implementation process, a national BIM strategy, standards, guidelines, protocols, and technical codes were planned to be developed. According to the NATSPEC report 2021, the Canadian government is now considering whether to mandate or encourage BIM processes in public procurement procedures and is polling industry players	Doan *et al*2020
China	Governments and the private sector in China have promoted BIM heavily. In May 2015, the government published standards for BIM usage and adoption. Every year china holds seminars to train industry players on BIM.	Chang *et al*2017; Qin *et al* 2020; Wang *et al*2021
Colombia	The government is working on BIM-adoption strategies for public construction. The Colombian government is also part of the Latin America BIM network since 2019, which aims to increase productivity under BIM	Murguia *et al*2021
Denmark	The Industry Foundation Classes (FC) certification provided the foundation for BIM implementation. Denmark was a pioneer in defining BIM classification standards, which helped boost BIM adoption across Europe. In 2007, the Danish government launched a digital construction programme requiring BIM in all public building projects.	Karampour *et al*2021; Jiang *et al*2021

Finland	In 2007 the government-mandated BIM adoption to all construction projects. Currently, BIM is at 100% uptake in Finland. In addition, BIM sessions (training) for specific usage are scheduled regularly, based on the profession and activity.	Jiang *et al* 2021
France	Since 2017, the government has mandated BIM in all public-sector projects. Because of the fragmentation of the player types, primarily SME's, the construction sector in France remains quite heterogeneous in terms of digital technology and BIM integration. Thus, in 2019, BIM reached 66% of overall adoption in France. More specifically, 42% of architectural agencies are implementing BIM practices in 2020.	Liao *et al* 2020b ; Jiang *et al*2021
Germany	Since 2015, a policy has been in place to manage the digital design, construction, operation, and maintenance activities across all project types. BIM was only mandated in all public infrastructure projects in 2019.	Liao *et al* 2020b; Jiang *et al*2021
Hong Kong	It is required as from 2018 BIM on capital work projects.	Jiang *et al*2021
Italy	The Italian government financed a project to create a standardised national BIM library that included Italy's construction companies, three universities, and building component manufacturers' groups. This was implemented in 2019.	Karampour *et al*2021; Jiang *et al*2021
Japan	The government published BIM guidelines in 2013. This was first done in government projects as a pilot then gradually infiltrated into the industry. However, the private sector is currently the driver for BIM adoption in Japan.	J uan *et al*2016 ; Bouguerra *et al*2020 ; Jiang *et al*2021
Mexico	The government is developing BIM adoption strategies for the construction of public infrastructure.	Murguia *et al*2021
Netherlands	In 2011, the government mandated that all central government departments implement BIM.	Jiang *et al*2021
Norway	Following the government's commitment to BIM adoption in 2010, a slew of public-sector initiatives were launched in its support. Statsbygg, a Norwegian key adviser and public administration company, authorised the usage of BIM, and by 2010, all of its projects were using BIM models based on IFC and IFD.	Karampour *et al*2021; Jiang *et al*2021
Peru	The government created a national BIM Steering Committee for BIM usage in public projects	Murguia *et al*2021
Singapore	The government put in place mandatory BIM submission. The mandate came into place in 2015. The government is using a top-down approach to enforce organisations to use BIM	Juan *et al*2016;Bouguerra *et al*2020; Liao *et al* 2020a ; Qin *et al*2020; Liao *et al* 2020b ; Jiang *et al*2021
South Korea	The government has included BIM adoption in all public sector projects since 2016	Liao *et al* 2020b; Jiang *et al*2021
Spain	The government has included BIM adoption in all public sector projects since 2018	Liao et al, 2020b; Jiang *et al*2021
Sweden	In 2015 the government-mandated BIM was used in all investment projects	Jiang *et al*2021
Taiwan	The Taiwan government is planning to enact a BIM-based submission model for building permits specifically for architectural firms	Juan *et al*2016
United Kingdom	In 2011, the government issued a mandate. BIM was made mandatory on all public-financed projects under the Government Construction Strategy, resulting in a major increase in BIM usage in those countries. The UK government developed the UK BIM Task Group to support clients and the supply chain through active collaboration between government departments, business, academia, and real estate clients, which is why the UK government encouraged client usage of BIM. This was a top-down approach that resulted in widespread adoption. Since 2016, all government-funded public projects must use at least Level 2 collaborative BIM on a four-level scale.	Alwan *et al*2017; Chang *et al*2017; Dainty *et al*2017; Babatunde *et al*2020; Liao *et al* 2020b; Qin *et al*2020; Karampour *et al*2021; Jiang *et al*2021; Li *et al*2019
United States	the government mandated in 2007 a BIM-adoption policy for public construction through the National BIM policy, which has led to a significant increase in BIM adoption in those countries. The implementation of policies was largely driven by other players in the industry, which is a bottom-up approach.	Bouguerra *et al*2020; Babatunde *et al*2020; Juan *et al*2016; Liao *et al* 2020b; Karampour *et al*2021; Jiang *et al*2021
Vietnam	Government BIM roadmap in 2014 to improve efficiency in the construction industry	Nguyen and Nguyen, 2021

From the Systematic Literature Review, Denmark and Finland were the first countries to implement BIM mandates in 2007. Furthermore, the only African country cited was Nigeria as a case study in both analyses. This is in terms of research and not BIM mandate. As a result, government encouragement might stimulate BIM innovation in the African AEC industry, as seen in industrialised countries. The African AEC sector and government must accept and adopt technologies such as BIM to address infrastructural gaps and prepare for the continent's population growth. The AEC industry will be in greater demand than ever to offer infrastructure facilities.

The analysis was conducted using a dataset collected from the Web of Science search database; as a result, the study may be influenced by the coverage of publications. Furthermore, only records published in English were evaluated; other documents may have been published in other languages. These restrictions may provide fruitful ground for future research. Furthermore, future research should consider using the findings to create a roadmap for BIM mandates in developing countries.

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ID 38

Key Indicators for Successful Value Management Performance in the Built Environment (A Literature Review)

Comfort Olubukola Iyiola[1], and Modupe Cecilia Mewomo[2]

[1, 2]Department of Construction Management and Quantity Surveying,
Durban University of Technology, Durban, South Africa.
Modupem@dut.ac.za

Abstract

This research seeks to identify the indicators for measuring successful value management (VM) performance in the built environment based on literature review. Value management (VM) is commonly considered as a beneficial technique for construction firms to address obstacles in the construction sector, such as resource constraints, delay in delivery, cost overrun, time overrun, project abandonment and complexity. However, despite numerous studies on VM, the indicators for measuring the performance of VM have not been thoroughly investigated. This paper, therefore, discusses the key indicators for measuring successful VM performance in the built environment. A comprehensive assessment and analysis of chosen published journals is fundamental of the research. Journal papers, books, and conference proceedings were all included in the study on indicators for measuring successful performance of VM from different databases including ScienceDirect, Web of Science, Google Scholar, Science Direct, Scopus, etc. The performance indicators were categorized into process performance indicators and outcome performance indicators. The process performance indicators (integration, collaboration, standardization, organizational culture) are categorized as variables that must be considered in order to ensure effective VM practices while the outcome performance indicators are variables that indicates the effectiveness of VM practices. A careful evaluation of the performance indicators of VM studies is expected to enhance VM application and strengthen clients' confidence in their VM investment. The initial step in establishing a robust VM performance model is to identify variables that determines its successful integration. Thus, it is expected that the long pending quest of poor implementation of VM will be solved and successful delivery of construction projects will be enhanced. It will also become a useful reference to value managers, designers, architects and construction organisations for achieving building sustainability through VM practices.

Keywords

Performance Indicators, Value Management, Built Environment

1. Introduction

Value management (VM) is an integrative procedure which aims to maximize the worth of a building development operations from start to finish while also meeting the requirements of the clients (Tanko *et al.,* 2017; Thneibat *et al.,* 2021). Madushika *et al.* (2018), on the other hand, mentioned that VM is a strategy that aims to maintain a balance between cost, duration, and durability when employed. When VM is applied on a project, Aghimien and Oke (2015) found that great economic sustainability may be reached since participants have the opportunity to guarantee that building projects provide opportunities for attaining value for money. This means that a different cost management technique may be used at the lowest feasible cost without jeopardizing the project performance or goal.

Several studies have been carried out on the application and potential of VM to deliver sustainability in construction projects in advanced and developing nations. In the UK, for instance, Lin *et al.* (2011) emphasised the importance of VM for the successful delivery of construction projects to fit a nation's culture and the economy. In US, Luvara, and Mwemezi, (2017) indicated that VM practices have helped to improve the execution of building projects in the building sector. In Malaysia, the use of VM was made mandatory for all government projects by the

Economic Planning Unit of the country (Jaapar *et al.,* 2012). Also, VM has also been implemented by government parastatals in most advanced countries like USA, the UK, Hong Kong, China and Australia, to optimize public projects and achieve the worth of the money invested (Kim *et al.,* 2016; Kissi *et al.,* 2015). The relevance of VM techniques in the construction industry is recognized in this perspective. According to many definitions, the basic goal of VM is to improve the worth of the money. It is done by providing all essential functionalities at the lowest life cycle cost while ensuring the product or resource's quality and performance (Madushika *et al.,* 2018).

The insufficiency of currently available methods and approaches for measuring project success is confirmed in mainstream literature, raising doubts about the value and efficacy of project management (Mir & Pinnington 2014). In order to determine the usefulness of VM in enhancing construction project performance and cost effectiveness, it is necessary to measure its performance in construction projects (Al-gahtani *et al.* 2015). The necessity to quantify the achievements of building projects has necessitate the creation and deployment of a number of variables that determines the performance of VM (Haponava & Al-Jibouri 2009, Madushika *et al.,* 2018). A careful evaluation of the performance indicators of VM studies can help to improve VM implementation and integration and also provide clients more confidence in their VM investment (Lin *et al.* 2011). In the meanwhile, only a few research on evaluating the performance of VM in the built environment for building projects have been done. Lin *et al.* (2011), Al-gahtani *et al.* (2015), and Madushika *et al.* (2018) all conducted studies on performance indicators in the construction sector for measuring VM performance. These studies, on the other hand, are geared toward industrialized countries and have minimal relevance for emerging countries. A developed nation's construction sector differs from that of an unindustrialized nation, just as an industrialized economy differs from an unindustrialized economy. As a result, it is necessary to undertake a study on VM performance metrics in emerging nations as well. According to the literature, VM is applied haphazardly in the majority of developing countries (Oke & Aghimien, 2018; Alshehri, 2020; Ojo & Ogunsemi, 2019). There is no pre-defined strategy for using VM in the construction business, according to Aghimien *et al.* (2018) and Alshehri, (2020). As a result, the goal of this research is to establish the performance indicators for effective VM integration for the successful delivery of construction projects in the built environment. The outcomes of this research will help developing countries improve their VM practices.

2. Research Method

Based on the performance metrics, this study comprehensively assessed the relevance of VM in the built environment. The first step was to choose which papers will be included in this evaluation. The second step entailed creating and implementing precise rules of conduct that outlined how to collect and analyze information from the literature. The third stage involved combining the details that had been analyzed and determining the research findings. Journals and conference papers that highlight VM performance indicators were reviewed and found to meet the inclusion criteria for the study selection.

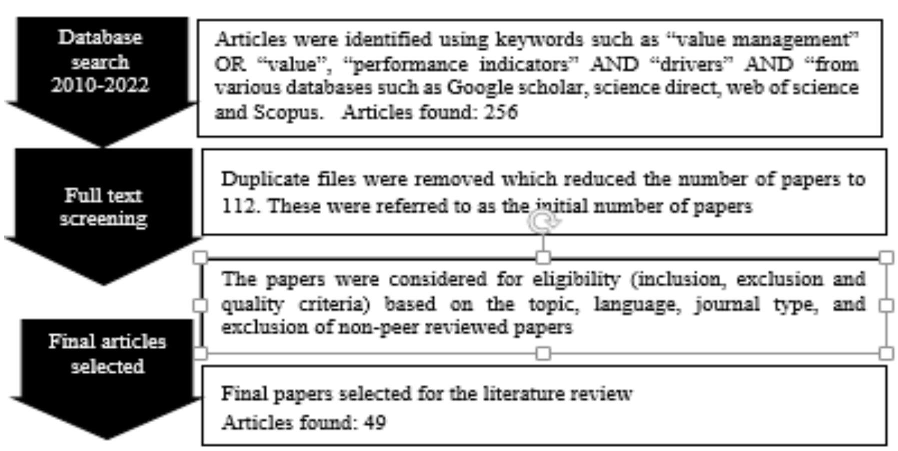

Fig. 1. Steps in the systematic literature review procedure and the resulting number of papers.

3. Results

3. 1 Process Driven Metrics

Table 3 presents the variables that measures effective VM performance through a comprehensive literature review. The process-driven metrics were categorized into; integration, collaboration, standardization, effective organisational culture. The project driven metrics aim to measure and monitor operational performance across an organisation. The process driven metrics offers great opportunities for construction firms to improve their process efficiency and they are extremely important for an organization to create value stream mapping.

Table 2. Process performance indicators

Process Performance Indicators	Variables	Sources
Integration	Early involvement of participants	Cao and Zhang (2011) and Shen and Yu (2014)
	VM action plan	Madushika *et al.*(2018)
	Primary function identified	Lin *et al.* (2011), Jaapar *et al.* (2012)
	Availability of resources	Annamalai and Ganapathy (2021)
	Accelerated decision making	Thneibat *et al.* (2021)
	Efficiency of idea generated	Kinebar *et al.* (2021), Kissi *et al.* (2015)
	Dedicated personnel	Coetzee (2010), Alshehri (2020)
	Communication among participants	Kissi *et al.* (2015)
	Availability of resources	Oke et al. (2018), Shen and Yu (2014)
Collaboration	Information and knowledge sharing	Cao and Zhang (2011)
	Decision alignment	Asri *et al.* (2021)
	Team building activities	Kokkonen and Vaagaasar (2018)
	Interaction among participants	Ferme *et al.* (2018)
	Client's support and participation	Hayatu (2015), Lin *et al.* (2011)
	Active client support	Kineber *et al.* (2021), Tanko *et al.* (2017)
Effective organisational culture	Management participation and commitment	Taghizadeh *et al.* (2012)
	Education and training	Nguyen and Watanabe (2017)
	Risk management	Oke and Aigbavboa (2018)
	Interpersonal relationship	Ekanayake *et al.* (2019)
	Top management support	Owoyemi and Ekwoaba (2014)
	Participants satisfaction	Oke and Aigbavboa (2018)
	Reward and incentive system	Cao and Zhang (2011)
Standardisation	Input of government and its agencies	Kim *et al.* (2016) and Aghimien *et al.* (2015)
	Mandatory VM training for construction professionals	Lin *et al.* (2011), Ojo *et al.* (2021),
	Government commitment to implement VM	Kineber *et al.* (2021), Tanko *et al,* (2017)
	Incorporating VM methods into construction procurement process	Ojo *et al.* (2021), Aigbavboa *et al.* (2016)
	Attendance of policy-makers on constant basis	Madushika *et al.* (2018)
	Effective policies and regulations supporting VM practices	Ojo *et al.* (2021), Madushika *et al.* (2018)

3.2 Outcome Performance Indicators

An outcome performance indicators are specific and measurable characteristics or change that will represent achievement of an effective VM process. These measures are used to determine the extent to which a core function, goal, activity, and services has impacted its intended audience. These measures are usually built around the specific purpose or result that the function, goal, service or activity, is intended to deliver or fulfill. The outcome measures should show progress towards or achievement of an organisations' mission and goals. These indicators are variables that indicates the effectiveness of a VM process.

Table. Outcome performance indicators

Variables	Sources
Reduced construction cost	Lin *et al.* (2011), Jaapar *et al.* (2012), Madushika *et al.* (2018), Oke *et al.* (2015), Algahtani *et al.* (2015), Thneibat *et al.* (2021)
Time management	Lin *et al.* (2011), Kissi *et al.* (2015), Kinebar *et al.* (2021)
Quality management system	Oke *et al.* (2015), Tanko *et al.* (2017), Madushika *et al.* (2018)
Client satisfaction	Kinebar *et al.* (2021), Thneibat *et al*. (2021), Aghimien and Oke (2015), Annamalai & Ganapathy (2021)
Return on investment	Ojo *et al.* (2021), Aigbavboa *et al.* (2016), Aghimien *et al.* (2016)
Risk reduction	Ranesh *et al.* (2012), Nnadi & Ezemerihe (2018), Masengesho *et al.* (2021), Alaqad *et al.* (2015), Hayatu (2015)
Whole life asset management	Jaapar *et al.* (2012), Kissi *et al.* (2015), Aigbavboa *et al*. (2016)
Long-term planning	Alshehri (2020), Lalevee *et al.* (2020), Ojo *et al.* (2021)
Improved project management	Kissi *et al.* (2015), Tanko *et al.* (2017), Oke & Aghimien (2018), Thneibat *et al*. (2021), Ojo *et al.* (2021),
Elimination of delay	Luvara & Mwemezi (2017), Ekanayake *et al.* (2019)
Effective project delivery	Mir & Pinnington (2014), Aghimien *et al.* (2018)
Improved economic quality	Oke *et al.* (2015), Thneibat *et al.* (2021), Tanko *et al.* (2017)
Promoted environmental quality	Carvalho & Rabechini (2017), Yu *et al.* (2018)
Enhanced social prosperity	Oke *et al.* (2015), Thneibat *et al.* (2021), Tanko *et al.* (2017)
Enhanced project functionality	Lin *et al.* (2011), Xiaoling *et al.* (2013), Ochieng *et al.* (2014)
Optimisation of value	Kissi *et al.* (2015), Aigbavboa *et al.* (2016), Lalevee *et al.* (2020)

4. Discussion of Findings

4. 1 Process Performance Indicators

4.1.1 Integration

Integration is the technique of bringing together diverse knowledge, expertise, and technology in order to optimize project results, which is particularly important for assuring the timely completion of construction projects (Olanipekun *et al.,* 2017) and it provides improved value to owners while also maintaining maximum efficiency across all design, fabrication, and construction phases. The studies conducted by Cao and Zhang (2011) and Shen and Yu (2014) recognised the importance of involving professionals in a construction projects. Sabiua *et al.* (2019) maintained that integration process refers to the procedure adopted for improving construction project performance through the syncing of information, process, and people. This opinion recognizes integration as a tool for ensuring operational performance. Annamalai and Ganapathy (2021) described VM integration as a systematic approach in construction for effective role in reducing cost and improving the delivery, functionality or quality of the project. The author described integration process as the level in which VM experts collaborate tactically to handle inter- and intra-organisational operations. This view also recognised that integration occur within and outside the firm. Integration refers to the informal or formal activity of combining information, procedures, and people into a single structure (Kissi *et al.*, 2015; Kinebar *et al.*, 2021; Thneibat *et al.,* 2021). The aforementioned phases of integration can only be achieved through applying different practices necessary for integration (Coetzee, 2010; Alshehri, 2020). Aghimien and Oke (2015) concluded that the initial involvement of construction stakeholders is the most crucial practice for integration. In support of this opinion, Olanipekun *et al.* (2017) discovered that when construction stakeholders and professionals are involved in the early stage of VM, performance will be enhanced. Team colocation on a construction project was identified by Kokkonen and Vaagaasar (2018) to have an important component for integration. The role of VM guarantee that construction firms realise value in their projects while also meeting the expectations of their clients. It also handles the related budget limitations as well as constraint for reducing the additional cost while maintaining project quality and dependability (Aigbavboa *et al.,* 2016). From the foregoing, the success of VM performance is more related to integration.

4.1.2 Collaboration

Collaboration is one of the critical process that have to be fulfilled for ensuring VM performance. In order to improve the performance and delivery of construction projects in the construction industry, collaboration among members of the construction industry has been suggested by scholars (Ferme *et al.,* 2018; Qiang *et al.,* 2021). Also, Ojo *et al.* (2021) affirmed that there is need for enormous collaboration in the building industry due to the difficult, complex, geographically dispersed and multi-organisational nature of the industry. This study affirmed that collaboration entailed the coming together of two or more independent building professionals collaborating to schedule and implement construction project processes to enhance the performance of building projects. Collaboration between professionals is in the form of information sharing, resource sharing, decision alignment, team building activities, knowledge sharing, interaction among participants, improved communication and understanding (Cao and Zhang, 2011; Ferme *et al.,* 2018; Asri *et al.,* 2021). Ojo *et al.* (2021) believed that towards enhancing the performance and delivery of construction projects in building firms through VM, collaboration in the form of cross-sectional team effort is of utmost importance. c6) and Mallett (2017) also confirmed that the sharing of information solely depends on collaboration among construction professionals. Meng (2012) indicated that collaboration provides the opportunity to work jointly across organisation boundaries. Tomelleri *et al.* (2015) stated that collaboration occurs when building professionals agree to harmonize and align their objectives, information and decisions to achieve a common goal. It can be inferred from the above that collaboration entails accepting equal responsibility and commitment to achieve a common goal. Hayatu (2015) further argued that raising clients' knowledge of VM will stimulate its use in more building projects. These characteristics make collaboration crucial in VM process for achieving on-time delivery of the project.

4.1.3 Organisational culture

Organisational culture is one of the major attribute for ensuring VM performance in the building industry. Cadden *et al.* (2013) established that organizational culture is a form of behaviour developed over time by an 252rganization to adapt and solve problems. **Naranjo-Valencia *et al.* (2011) opined that 252rganization culture functions as a business structure that allows the** effortless sharing of information among members of an establishment. Features such as management support, management participation and commitment, and interpersonal relationship should be included in the corporate structure to promote VM. The senior management of the organization must coordinate their processes, strategies, and regulations with the associated project in order to implement VM throughout the organization (Taghizadeh *et al.,* 2012). Organisational culture is influenced by factors such as the organization's structure, the system and procedures by which work is completed, employees' preferences, the organization's customs and beliefs, and management and leadership styles. Moreover, this approach of continual improvement necessitates that manager's act as a genuine leader in the firm, ensuring that all employees participate and become active in all value chain operations (Taghizadeh *et al.,* 2012). Combined standards, beliefs, and assertions involving the way in which employees behave and interact, the way issues are being addressed and how actions are taken, and how roles and responsibilities should be carried out, altogether make up 252rganizational culture (Tedla, 2016). The background and environment of a firm, as well as the people that run and work for it, all have a role in its culture. Good governance necessitates a thorough understanding of the company's culture (Owoyemi & Ekwoaba, 2014). Top management will be better equipped to integrate strategy and accomplish their goals if they comprehend their company structure. The several essential success variables that have been investigated in the area of organization culture includes factors related to managerial involvement, information sharing, personal relations, education and training, rewards and incentive systems, risk-sharing, adequate supervision, employees' participation, and decision making (Ekanayake *et al.,* 2019; Nguyen & Watanabe, 2017; Oke & Aigbavboa, 2018).

4.1.4 Standardisation

This study recognizes the impact of standardization as one of the performance indicator of VM. Standardization in this study was categorized into; input by relevant governmental and local authorities, VM study plan for implementation, clients' enforcement ability to communicate requirements to design team, government commitment to implement VM, and active client's support and participation. This supports the findings of Kim *et al.* (2016) and Aghimien *et al.* (2015), who mentioned that government interest in VM adoption, preparedness, client participation, and public awareness of VM are major performance criteria for VM. According to Kineber *et al.* (2021), the proactive efforts of the US government and its public agencies are enabling to enhance the implementation of VM throughout the US construction sector. When working on building projects for the US and Australian governments, similar VM approval rules are necessary. This demonstrates how government actions can contribute to the adoption and performance of VM in building projects. Kineber *et al.* (2021) also attributed clients' support and active involvement to improved VM performance. Therefore, involving client's and their commitment is paramount to the success of VM. Similarly, policymakers in the construction industry should be prepared to make this a part of organisation culture. The government could control all VM initiatives and regulations because it has the largest significant amount of capital development in the form of property and infrastructure assets (Tanko *et al.,* 2017). As a result, active government support and engagement in the application of VM is crucial (Tanko *et al.,* 2017). The responsibility (i.e. obligatory environmental requirements) for implementing sustainability criteria will be resolved if authorities work with the clients and senior management to clearly define and provide appropriate assistance (i.e. financial rewards).

4.2 Outcome Performance Indicators

This study recognized the outcome performance indicators of VM as the expected benefit or output for adopting VM in the construction industry. The study found that cost saving practice, time-saving practice, clients' satisfaction, quality management, among others, were the major outcome of effective VM performance. Tony and Tam (2013) and Madushika *et al.* (2018) recommended that cost savings is one of the major output for adopting VM in the construction industry. In the same vein, Nnadi and Ezemerihe (2018) ascertained that adopting VM is a valuable strategy for dealing with risks and uncertainties that may arise throughout the construction process, as well as for improving risk response efficiency. As a result, risk consultants are advised to use VM approaches as a strategy to curb the issue of risk for effective project delivery. VM technique, according to Lalevee *et al.* (2020), is effective in integrating sustainable components in the process of developing construction projects, which is one of the outcome of effective VM practices. Quality management was also proven to be a significant output of VM performance. Incorporating VM in the construction sector, according to Xiaoling *et al.* (2013) and Ochieng *et al.* (2014) will increase the quality standard and efficiency. This supports the findings of Oke *et al.* (2015) and Martens and Carvalho (2016), who found that implementing VM effectively enhances the quality of construction projects. In addition, VM is a key contributor to the development of innovative solutions to minimize construction waste and achieve sustainability goals (Kolo & Ibrahim, 2010). The framework was created in response to its requirement to meet sustainability goals by reducing construction waste throughout the design phase. This is because decisions taken early in the design process have a significant influence on the project's long-term viability. Incorporating sustainability into the building process from the beginning and all through the construction process is critical for the success and productivity of a construction project as it enhances decision-making among professionals (Carvalho & Rabechini, 2017; Yu *et al.,* 2018). The qualities of VM, such as the collaboration of professionals with mixed skills and competency ensures an effective job plan, promote high engagement, sharing of knowledge, and efficiency. Better corporate decisions, higher productivity, improved goods and services, improved communication process, cooperation, and decisions that can be backed by all stakeholders are just a few of the benefits of VM. According to Oke *et al.* (2018) and Yu *et al.* (2018), dedication to economic sustainability includes strengthening operating efficiency through effective utilization of resources (human, materials, finance), effective design, and good management, planning, and control; environmental sustainability includes using natural resources, encouraging renewable resources, and protecting the soil, water, and air from contaminations, among other things; and social sustainability includes interdisciplinary collaboration. As a result, VM is a viable and recommended means of achieving sustainability (Kineber *et al.,* 2021).

5. Conclusions

This research has presented the results of qualitative content analysis on key indicators for successful VM performance in the built environment. This study divided the performance indicators into two which are; the process-driven metrics and outcome performance indicators of VM. The process driven metrics which were categorized into; integration, collaboration, standardization, and organisational culture are variables that must be considered in order to ensure effective VM performance while the outcome performance indicators are variables that indicates the effectiveness of VM practices. This article concluded that incorporating all the aforementioned VM attributes (process driven metrics), will ensure the outcome performance indicators that will be derived from the effectiveness of VM practices in the built environment. Thus, it is intended to resolve the long pending pursuit of poor implementation of VM among construction professionals and form a basis to promote VM practices to achieve successful delivery and sustainability of construction projects. Continuous performance measures of VM will help in achieving efficient implementation of VM in construction industry. It will serve as a notable reference for value managers, designers, architects, and construction companies interested in using VM to achieve building sustainability. Furthermore, the outcome of this study can be utilized as a starting point for future VM research investigations. The study is also beneficial to all VM professionals working in the built environment and the findings can be implemented into construction professional's work ethics to improve productivity.

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A Critical Review of Barriers Hindering BIM Integration of Operation and Maintenance Phase in Existing Buildings

James Olaonipekun Toyin[1], Modupe Cecilia Mewomo[2]

[1,2] Department of Construction Management and Quantity Surveying, Durban University of Technology
ModupeM@dut.ac.za

Abstract
Presently, researchers have made clear justices to Building Information Modelling (BIM) capability in new building production and management. Researchers' findings have proven that BIM plays a significant role in building facilities' operation and maintenance (O&M) phase, using information generated during the construction process in the BIM database. However, over 90% of existing residential buildings do not have a functioning BIM. Recently, there has been a growing consideration for BIM implementation in existing residential buildings. Through the critical review of this study, 18 barriers hindering BIM implementation in the existing residential building were identified and systematically grouped under six groups: Documentation Factor, Technical Factor, Personnel Factor, Professional Management Factor, Financial Factor, and Security Factor. The "Data interoperability problem" was identified as the primary barrier hindering BIM adoption in existing buildings that already use FM tools for their management.

Keywords
Existing Building, implementation, BIM, Barriers, operation, and maintenance.

1. Introduction

Don (2017) described facilities operations and maintenance (O&M) as a broad-spectrum encompassing services, competencies, processes, and tools required to assure the built environment will perform the functions for which a facility was designed and constructed. Also, "O&M typically includes the day-to-day activities necessary for the building/built structures, its systems and equipment, and occupants/users to perform their intended function". However, Operations and maintenance are combined into the common term O&M because a facility cannot operate at peak efficiency without being maintained; therefore, the two are discussed as one (Don, 2017).

In this paper, existing buildings could be seen as habitable property (private or commercial buildings) which has been 100% completed, wherein has been occupied or previously occupied.

The BIM model's adoption, implementation, and application were initially designed for new buildings. The tremendous contributions of BIM to the built environment industry have called for its consideration for existing buildings. Loeh et al. (2021) affirmed that the way the BIM model was created and adopted from the design phase. However, it can also be created and implemented from the grassroots for existing buildings.

Decades ago, the idea of Building Information Modeling (BIM) started during the 3rd industrial revolution stage. The focus initially started from the planning and design phase. Wherein advanced to the cost, procurement, and construction phase. It started gaining more attention in the 4th Industrial revolution stage. The further use and adoption of BIM around the lifecycle (LC) of the building could be traced to the benefit acquired in the previous phases in which it has been successfully used (Volk et al., 2014).

Over the years, BIM as an information model has become the central platform for information management in the built environment industry (Hossain & Yeoh, 2018). It has been proven as a platform that grants stakeholders the medium to manage and exchange information throughout the lifecycle of a building concerning its components (Motawa & Almarshad, 2013).

Even though there is a rising trend in BIM adoption within the built environment industries, its use has only been for some new projects in recent years towards O&M of the building phase (NBS, 2016). However, it was noted that most buildings currently existing do not have a functional BIM model. Designing a BIM platform to accommodate existing building data and promote the O&M phase is essential (Hossain & Yeoh, 2018). Moreover, it has been reported by numerous researchers that BIM can function in the O&M phase, which can be used for renovation, defect detection, energy usage analyses, installation and monitoring of firefighting equipment, safety in facility management, demolition, and so on (Hossain & Yeoh, 2018; Wetzel, 2015). Over the years, the adoption of BIM in the design and built environment has received a substantial establishment and has received growing attention for FM and O&M (Cheng et al., 2017; Love et al., 2014; Pärn et al., 2017). FacilitiesNet (2021) reported that for "facility managers, Building Information Modeling database can be a powerful new tool to enhance building's performance and manage operations more efficiently throughout a building's life". Nevertheless, claims have been made frequently since BIM's inception. However, most of the recorded, measurable advantages of BIM are still connected to building design and construction, with little empirical evidence of BIM's benefits in the operations and maintenance phase (Becerik-Gerber et al., 2012; Kiviniemi & Codinhoto, 2014). BIM could be seen as a suitable platform that can handle more extensive and more complicated buildings and can be used in all categories of building types (Becerik-Gerber & Rice, 2010; Kiviniemi & Codinhoto, 2014). Since BIM is seen as a platform for managing reliable building information throughout a building's lifecycle (LIU et al., 2012), it is appropriate to include maintenance and project closeup procedures data information. Information is an essential driving power that supports day-to-day efficient and productive O&M of building facilities (Atkin & Brooks, 2009; Gu et al., 2008; Teicholz, 2013). Yet, the facility management sector is still struggling with information management, primarily due to information's uniqueness and division (Codinhoto et al., 2013; Eastman et al., 2011). Within the built professionals and owner-operated industry, those two fundamental issues are the principal causes of knowledge loss in the construction environment (Kamara et al., 2002). Computerization improves asset means of information capturing and retrieval. However, automated analysis of data and knowledge capturing is inadequate within computer-aided facilities management (Becerik-Gerber et al., 2012; Brian & Brooks, 2009).

The race for efficient and sustainable production in the construction industries has been corroborated in developed and developing countries towards a well-developed and contributory information modeling structure – BIM (Codinhoto et al., 2013; Toyin & Mewomo, 2021a). McGraw-Hill (2008) researched and found out that there is an increase in successful BIM implementation cases in the design and construction phase. Also noted is that the adoption rate of BIM in Europe increased significantly eighteen (18) years ago.

The valuable contribution of the successful implementation of BIM in the construction industry cannot be overemphasized. This has called the attention of prospective clients (Government and Private), who are basically on the ladder to benefit more from the successful adoption of BIM, hence forming part of the fundamental role influencing change in the construction industry (Eastman et al., 2011)

Currently, BIM experts and built professionals are working tremendously to integrate the BIM model into existing buildings' operation and maintenance phases. Thereby allowing existing buildings and facility managers to enjoy the accruable benefit of BIM (Sun et al., 2017).

2. Research methodology

This study adopts a critical systematic review of published articles in conference proceedings, books, thesis, and academic journals on the state-of-art of BIM in an existing building O&M phase. A systematic review enables the researcher to gain more understanding and trends about the topic working on (Faisal Shehzad et al., 2020; Toyin & Mewomo, 2021b; Zhu et al., 2019). The research involves three (3) steps, as shown in figure 1. Step 1: Formulating the research questions: what is the start-of-the-art of BIM in existing buildings? What are the barriers hindering BIM adoption in the Existing building O&M phase?. Those questions were used to formulate the search keywords.; Step 2: article search approach using keywords for drawing out related studies from the databases. The following search condition keywords: BIM FM O&M barriers", "BIM for facility manage", "BIM-FM implementation in old building", 'BIM for the existing building to locate different articles" were repeated in the following databases: DUT online Library A-Z database, Elsevier (Scopus and Science direct), Springer and Google Scholar. The search brought about 157 published papers (n = 157), exclusion of duplicated articles From Endnote database (n= 90), Applied exclusion and Inclusion criteria (Relevance, Missing year of publication and Authors name, etc.) (n=36); Step 3: additional article search using contacted paper references were used to get 20 more relevant papers; Step 4: This is the last step. It involves findings, discussion, analysis of results, conclusion, and suggestions to improve BIM adoption in an existing building.

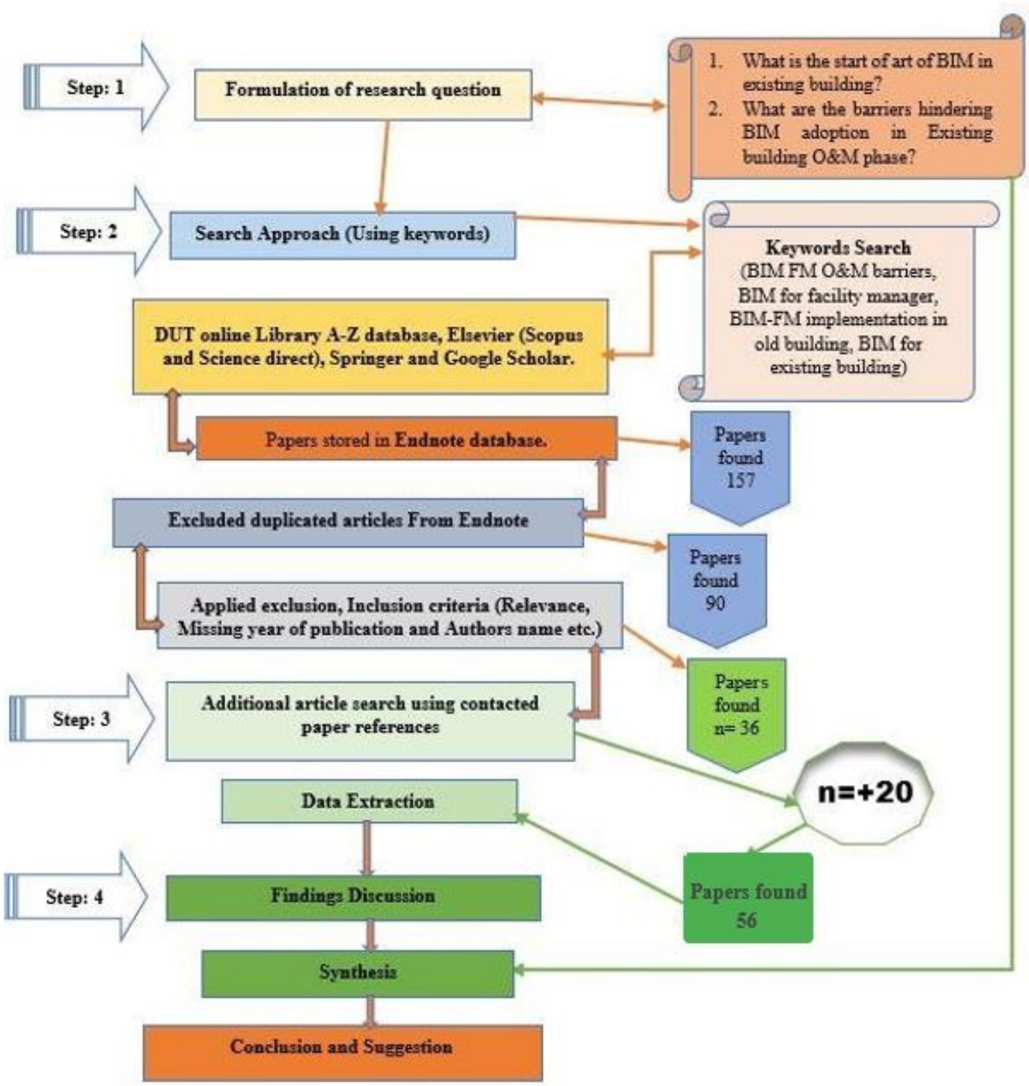


Fig. 17. Review framework

3. Research findings

3. 1 Need for BIM in an existing building

BIM is a revolutionary technology that can improve the construction industry's process and product, owing to its ability to manage information, integration of design, and flexible construction management features (Naghshbandi, 2016; Pniewski, 2011). Moreover, BIM technology aims to create an interactive model of a building facility that the stakeholders or clients could use throughout the project lifecycle (LC). BIM is seen as digital modeling which contains comprehensive virtual information in the representation of a building structure and its component. The required information that could be consulted at any stage of the building LC is contained in the model (Azhar, 2011). Furthermore, Haines (2016) noted that "lifecycle BIM is the practice of creating, maintaining and utilizing building information to manage operations and maintenance of buildings throughout their operational lifecycles". The integration of BIM in an existing building cannot be overemphasized. The use has been justified to some extent in recently completed buildings. Wherein, BIM was adopted throughout its LC (Dixit et al., 2019; Pavón et al., 2021; Zhu et al., 2019). However, various scholars were able to document some vital use of BIM in the O&M phase: Used to store inspections and repairs information history (LIU et al., 2012), help to facilitate locating building elements and components during inspection and management (McArthur, 2015), help to facilitate the incorporation of building facility data into BIM databases and display the drawing of such components (Pärn et al., 2017), BIM enable easy means of scheduling Maintenance work orders (Cheng et al., 2020), to plan maintenance routes (Predictive and Preventive) (Cheng et al., 2020; Wetzel, 2015), used to ease maintenance work processes and effective asset management (Altohami et al., 2021; Loeh et al., 2021).

3.2 BIM for FM: Area of application.

The area where BIM technology is applicable in FM practices, according to Nicał and Wodyński (2016) findings, is linked to: “mobile localization of building resources, Digital asset with real-time data access, space management, Renovation/retrofit planning, and feasibility studies, Maintainability studies, Energy analysis and control, Safety/emergency management” (Becerik-Gerber et al., 2012; Love et al., 2014; Volk et al., 2014). The finding shows that BIM has a promising and crucial role in the O&M phase of building, which invariably will benefit the existing building. The full potential could be realized in the existing building if it is successfully integrated (Toyin & Mewomo, 2021a).

3.3 BIM for existing buildings O&M phase.

Barbosa et al. (2016) find out that “The usage of BIM has been suggested for the documentation of existing buildings in a cultural heritage context”. The building modeling is usually grounded on on-site surveys and historical documents (Pauwels et al., 2008). Revit and ArchiCAD, known as Architectural BIM technology software, was adopted in the architectural heritage framework (Fai et al., 2011; Pauwels et al., 2008). This could be used to generate the likely 3D design of the building. Barbosa et al. (2016) reported that “in many cases, these historical BIMs are mainly constructed with a more theoretical purpose, namely, to study the historical value of any particular building”. (Hossain & Yeoh, 2018) study fundamental that BIM technology software can perform a vital function in existing building O&M phase to project closeup mainly if the existing building O&M phase has been managed using FM tools. The connection of the information in the FM tools to the BIM technology database should be reasonably simple than building managed without FM tools (Fai et al., 2011). In the first scenario, in a BIM database model application, a new building will be designed based on the available historical information generated from the FM application using a BIM application. In the second case, where the FM application is not used to manage the building, A typical in-depth survey would be performed before planning to design the O&M schedule. While carrying out the “survey, the geometrical, constructive, functional, and spatial characteristics of a building are registered” (Barbosa et al., 2016). This could be active through the use of traditional methods, which involves sketches and drawings, photos, manual surveys, written and descriptive analysis, and manual surveys, or “using more technological means, such as terrestrial laser scanning (TLS) and automatic digital photogrammetry (ADP)” (Barbosa et al., 2016; Mateus et al., 2008). Mikhail et al. (2001) explain TLS and ADP: “TSL is a technology that uses laser light to obtain the coordinates of many points in an almost continuous and nearly real-time fashion. ADP allows to accurately relate the geometrical information of an object with a digital image through measurements performed on photographs”. However, 3D points clouds result from TLS and ADP surveys. The likelihood of relying on point clouds models in the BIM database may enable more efficient and high-quality development of reliable building information that may be subsequently used to design a renovation or rehabilitation intervention. “The products of TLS and ADP surveys are 3D point clouds. The possibility to rely on point clouds models (PCMs) in a BIM software environment may allow more efficient and qualitative production of the first layer of building information” (Barbosa et al., 2016). wherein could help plan rehabilitation and refurbishment intervention (Barbosa et al., 2016). In addition, “PCMs allow the capturing of the existing situation in greater geometric detail than what is typically included in a BIM model”. These features attributed to PCMs make it easier to use them for tracking likely hazards in the existing buildings (deformations, cracks, bends). After identifying those hazards and recording them, those characteristics attributed to PCM are critically needed to be integrated into the BIM package, which benefits existing buildings. However, good documentation of those geometric hazards during the O&M phase of the building facility management will aid the planning of an improved renovation plan for the existing building within the lifecycle management schedule of the building. "Likewise, non-geometric components should be documented from the point cloud to the BIM database, as well as the presence of asbestos materials or other hazardous materials, and including potentially dangerous situations (confined spaces, restricted access areas)" (Barbosa et al., 2016).

Despite all the promising advantages of BIM technology for an existing building, the integration and adoption in the existing building O&M phase come with some barriers.

3.4 BIM State-of-art in existing buildings.

The evolutionary progress of BIM technology in new buildings throughout its lifecycle has shown its efficiency in promoting and enhancing construction projects in all areas. Decades ago, its integration of cultural heritage buildings' O&M phase started (Pauwels et al., 2008). This could be traced to the ineffective traditional means used in maintaining those buildings, wherein a large amount of information is lost every year due to improper information documentation. More sophisticated technology such as BIM, which enhances information documentation, was adopted to curb the loss of such historical memories in our society. This act has made "the world heritage virtually accessible for historical research. Numerous disappeared monuments have been reconstructed and digitized under their impulse"(Quintero, 2003). Recently, there has been an increasing interest in adopting BIM for existing buildings (Hossain & Yeoh, 2018). This shows there has been an advancement over the year as to what (Volk et al., 2014) reported.
Barbosa et al. (2016)Outlined how the existing BIM guidelines and standards can be adopted in existing building projects. The lack of proper adoption in this phase is relatively rare due to the limited use of BIM in the O&M phase of the existing building. This could be traced to barriers encountered during its integration. Over the years, researchers have been able to identify some barriers. This study critically reviews those barriers.

3.5 Barriers were limiting the adoption of BIM in an existing building.

This study critically reviews published articles in the area of BIM for an existing building, looking at the barriers hindering its fast adoption. Below are the barriers found in the reviewed articles.

Table 17. Barriers hindering BIM integration in the existing building.

No.	Barriers limiting the adoption of BIM in the existing building.	Reference	Frequency
1.	Lack of comprehensive as-built drawing document.	(Cheng et al., 2020; Fai et al., 2011; Kelly et al., 2013; Kiviniemi & Codinhoto, 2014; Pärn et al., 2017; Teicholz, 2013; Zhu et al., 2019)	7
2.	Unavailability of real cases validating integration of BIM in existing buildings.	(Altohami et al., 2021; Fai et al., 2011; Kelly et al., 2013; Kiviniemi & Codinhoto, 2014; Marocco & Garofolo, 2021; Motawa & Almarshad, 2013; Nicał & Wodyński, 2016; Pärn et al., 2017; Pniewski, 2011; Teicholz, 2013)	10
3.	Data interoperability problem.	(Alvanchi et al., 2021; Barbosa et al., 2016; Becerik-Gerber et al., 2012; Deng et al., 2020; Dixit et al., 2019; Durdyev et al., 2021; Gao & Pishdad-Bozorgi, 2019; Hossain & Yeoh, 2018; Kelly et al., 2013; Kiviniemi & Codinhoto, 2014; Loeh et al., 2021; Motawa & Almarshad, 2013; Naghshbandi, 2016; Nicał & Wodyński, 2016; Pärn et al., 2017; Pavón et al., 2021; Teicholz, 2013; Wetzel, 2015; Zhu et al., 2019)	19
4.	Lack of BIM knowledge, technical skills, and experience among the facility manager.	(Altohami et al., 2021; Becerik-Gerber et al., 2012; Cheng et al., 2020; Dixit et al., 2019; Durdyev et al., 2021; Fai et al., 2011; Kiviniemi & Codinhoto, 2014; Marocco & Garofolo, 2021; Nicał & Wodyński, 2016; Pniewski, 2011)	10

5.	Inadequate compatibility between BIM and existing FM technologies.	(Dixit et al., 2019; Hossain & Yeoh, 2018; Kiviniemi & Codinhoto, 2014; Marocco & Garofolo, 2021; Pniewski, 2011; Volk et al., 2014; Wetzel, 2015)	7
6.	Failure to identify critical information for sustainable operation.	(Cheng et al., 2020; Kiviniemi & Codinhoto, 2014; McArthur, 2015; Pärn et al., 2017; Wetzel, 2015)	5
7.	Handling of uncertainty where building documentation is incomplete.	(Barbosa et al., 2016; Kiviniemi & Codinhoto, 2014; McArthur, 2015; Volk et al., 2014)	4
8.	Lack of best practices and guidelines.	(Fai et al., 2011; Kiviniemi & Codinhoto, 2014; Naghshbandi, 2016; Wetzel, 2015)	4
9.	Lack of effective collaboration between project stakeholders for modeling and model utilization	(Cheng et al., 2020; Deng et al., 2020; Kiviniemi & Codinhoto, 2014; Loeh et al., 2021; Naghshbandi, 2016; Pärn et al., 2017; Pniewski, 2011)	7
10.	Uncertainty of required data.	(Becerik-Gerber et al., 2012; Fai et al., 2011; Kiviniemi & Codinhoto, 2014; LIU et al., 2012; Nicał & Wodyński, 2016; Teicholz, 2013)	6
11.	General lack of Knowledge of software required to use BIM.	(Al-Yami & Sanni-Anibire, 2019; Dixit et al., 2019; Durdyev et al., 2021; Fai et al., 2011; Loeh et al., 2021)	5
12.	Lack of demand and interest by stakeholders and clients.	(Al-Yami & Sanni-Anibire, 2019; Dixit et al., 2019; Fai et al., 2011; Teicholz, 2013)	4
13.	Hardware and software costs.	(Barbosa et al., 2016; Durdyev et al., 2021)	2
14.	Lack of competent BIM experts.	(Becerik-Gerber et al., 2012; Codinhoto et al., 2013; Fai et al., 2011; Hossain & Yeoh, 2018; Kiviniemi & Codinhoto, 2014; Teicholz, 2013; Wetzel, 2015)	7
15.	Lack of clear maintenance policy.	(Alvanchi et al., 2021; Becerik-Gerber et al., 2012; Codinhoto et al., 2013; Kiviniemi & Codinhoto, 2014; LIU et al., 2012; Teicholz, 2013)	6
16.	High cost of training facility managers.	(Becerik-Gerber et al., 2012; Codinhoto et al., 2013; Deng et al., 2020; Durdyev et al., 2021; Hossain & Yeoh, 2018; Kiviniemi & Codinhoto, 2014)	6
17.	Lack of interest/reluctance to change from existing method of maintenance.	(Codinhoto et al., 2013; Durdyev et al., 2021; Kiviniemi & Codinhoto, 2014; Teicholz, 2013)	4
18.	Cyber security/data ownership.	(Becerik-Gerber et al., 2012; Chien et al., 2014; Ghaffarianhoseini et al., 2017; Loeh et al., 2021; Solihin & Eastman, 2015; Sun et al., 2017; Volk et al., 2014)	7

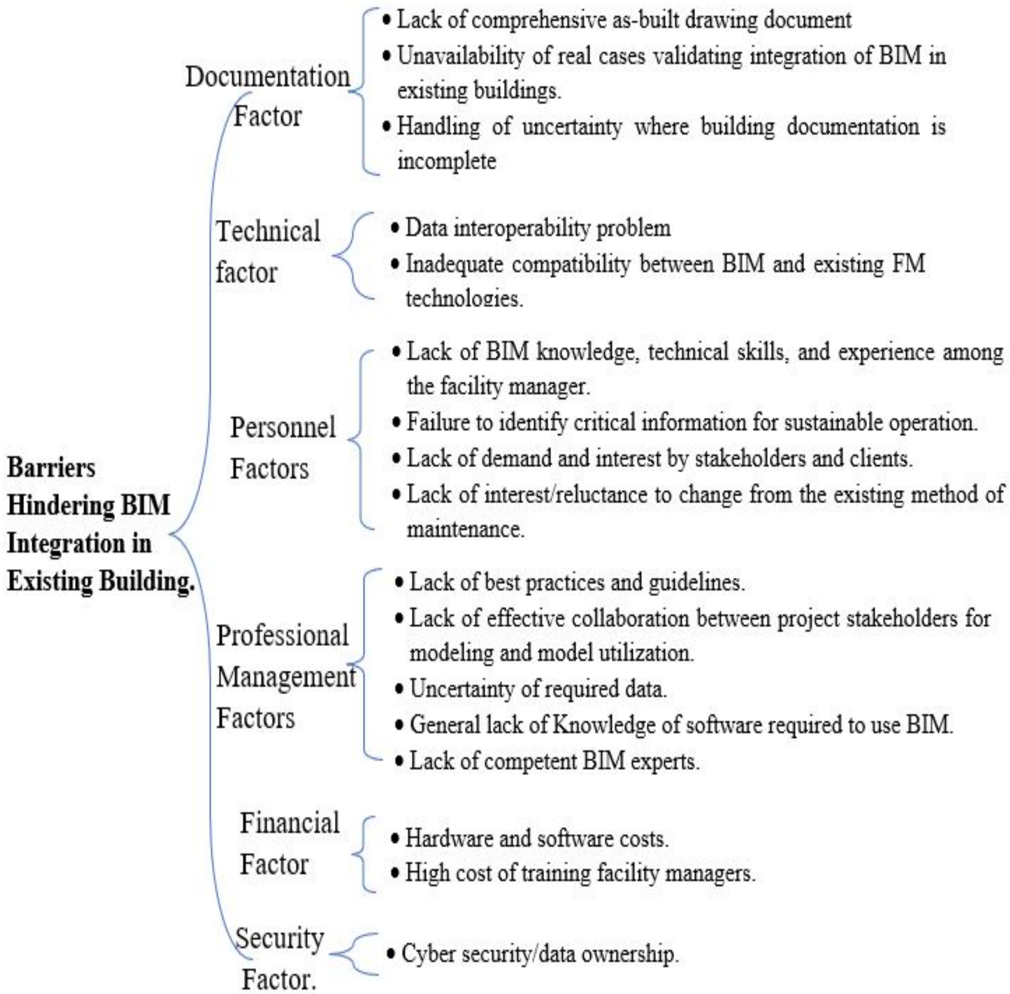
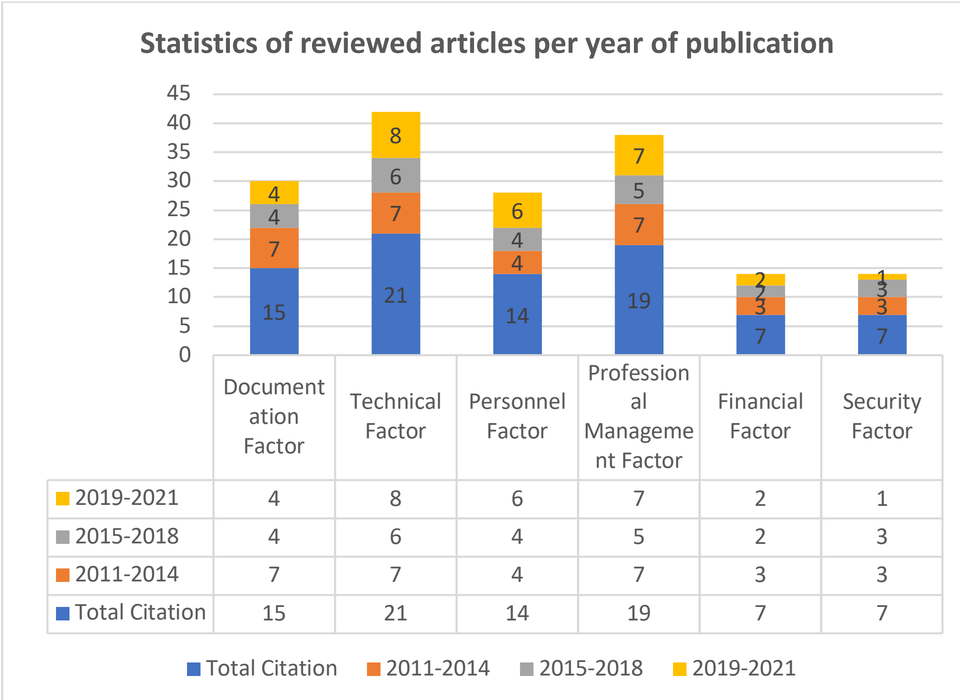


Fig. 2. Classification of barriers hindering BIM integration in existing buildings.



	Documentation Factor	Technical Factor	Personnel Factor	Professional Management Factor	Financial Factor	Security Factor
2019-2021	4	8	6	7	2	1
2015-2018	4	6	4	5	2	3
2011-2014	7	7	4	7	3	3
Total Citation	15	21	14	19	7	7

Fig. 3. Statistics of reviewed articles per year of publication.

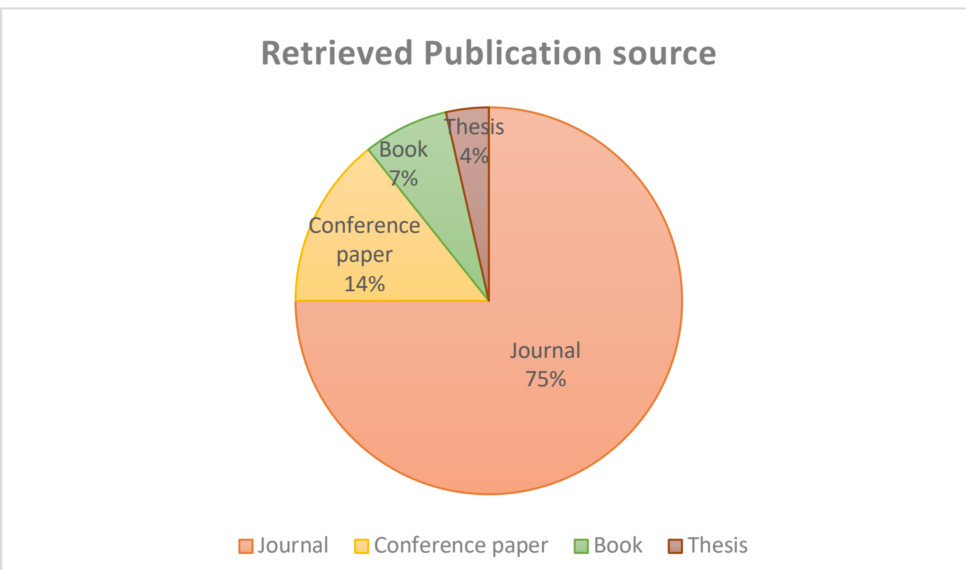


Fig. 4. Retrieved Publication source.

4. Discussion

Fig. 2. shows the systematic grouping of the identified barriers according to their corresponding factors. Al-Al-Yami and Sanni-Anibire (2019); Toyin and Mewomo (2021b) also adopt this grouping in their study. The authors systematically grouped the potential BIM benefit into five groups. Fig. 3. Shows the statistics of reviewed articles per year of publication. Fig. 4. This shows the source which the papers reviewed were retrieved from. The Journal article

used was 75%, and conference paper was 14%, the book was 7%, and the thesis was 4%. All the documents were saved in an endnote.

4.1 Documentation Factors.

Those are the barriers encountered due to improper O&M record-keeping, unavailability of reliable data that provides reliable information or evidence or serves as a record. The following were grouped under this heading: Lack of comprehensive as-built drawing document; Unavailability of real cases validating integration of BIM in existing buildings and Handling of uncertainty where building documentation is incomplete.

4.2 Technical Factors.

BIM technical factors are the challenges faced by or using the BIM software packages. These factors are called BIM limiting factors emanating through inappropriate software use or standard of data available during the integration of BIM in the O&M phase of the existing building. The technical barriers encountered during the integration of BIM in the existing building include data interoperability problems and inadequate compatibility between BIM and existing FM technologies. Interoperability "was defined in the IEEE (1990) glossary as the ability of two or more systems or components to exchange information and use the information exchanged". Kelly et al. (2013) noted the findings of (Lee et al., 2012), which observed that interoperability inefficiencies had caused over a $15.8 billion loss. Wherein $10.6 billion could be traced to the O&M phase. Parallel disintegration between stakeholders in a specific project phase (e.g., building plan, construction, O&M phase) could be affected by the variety of software programs used, contributing to interoperability problems (Howard et al., 1989). Nevertheless, Young et al. (2008) reported that BIM experts are trying to improve interoperability issues. Recently, standards have been put in place to solve the interoperability issues (Marocco & Garofolo, 2021; Pavón et al., 2021). Yet interoperability issue still stands as a top barrier hindering the integration of BIM in the existing building.

4.3 Personnel Factors.

This category of barrier factors involves the whole building production team, including the client. This could be seen as the team member's actions towards BIM integration in the existing building, which are: Lack of BIM knowledge, technical skills, and experience among the facility manager; Failure to identify critical information for sustainable operation; Lack of demand and interest by stakeholders and clients; Lack of interest/reluctance to change from the existing method of maintenance. BIM breaks the conventional method used for building production between multiple built stakeholders and enables the exchange of project information in a single model (Deng et al., 2020). This will directly result in changes in the work process, from conceptual design, data management to the project closeup phase. As a result, the building professionals and construction industry companies will require sufficient time to adjust to the modifications (Sun et al., 2017).

4.4 Professional Management Factors.

Those are the barriers that can be traced to the slackness of the O&M team members in control of BIM integration in the existing building. This could result in the loss of vital information during the documentation. The following barriers were reported: "Lack of best practices and guidelines"; "Lack of effective collaboration between project stakeholders for modeling and model utilization"; "Uncertainty of required data"; "General lack of Knowledge of software required to use BIM"; "Lack of competent BIM experts".

4.5 Financial Factors.

Financial factors are the barriers discouraging BIM implementation, which are cost related. They are mainly cost-incurred during the BIM implementation process for the O&M phase of an existing building. This comprises hardware and software costs and the cost of training facility managers.

4.6 Security Factors.

This is one of the limiting barriers hindering BIM implementation in the existing building. Cyber security and data ownership of BIM data cannot be overlooked in BIM progression (Solihin & Eastman, 2015). Because sharing information allows team members to access project data, cyber security is a problem due to the risk of illegal internet access and copyright breach (Chien et al., 2014).

5. Conclusions, Suggestions, and future research.

The use of BIM in new buildings from the conceptual design phase to construction has been well documented in developed countries. At the same time, its uses for post-construction phase have also gained significant attention. The advancement and benefit of BIM in the new building lifecycle have attracted and drawn the attention of the built professionals and clients to look inward on how to implement this novel technology in an existing building. Limited research has been published in this area of study. Therefore, this study juxtaposes the findings of numerous researchers on the current BIM state-of-art in existing buildings. Basically, this research focuses on a critical review of published articles on the barriers delaying BIM implementation in the existing buildings. The findings show that BIM implementation was first proposed in early 2000 for the Heritage building M&O phase, wherein, a design was generated according to the available structures; this was done in other to retain memories in the society. Also, it was proposed to be used for Residential buildings recently. However, those operations and processes usually come with delays or barriers, which likely discourage the continuous implementation of BIM in the O&M phase of the existing building.

In this study, it was seen that publications on BIM for existing buildings started evolving in 2011. Wherein, 18 barriers were identified. Understanding those barriers made it possible for the author to systematically group them under Six (6) groups: Documentation Factors; Technical Factors; Personnel Factors; Professional Factors; Financial Factors, and Security Factors.

It is recommended that those barriers should be critically investigated and treated accordingly without leaving anyone unattended. This will ease the smooth running and encourage BIM implementation in an existing building.

For further research, this study was limited to highlighting the barriers and discussing the finding. It can be further researched in different regions in other to know more about the barriers peculiar to each region and find a better way of solving them.

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ID 40

Environmental Sustainability Assessment of Wastewater Treatment Processes: Case Study

Fayiz Juem[1], Sarah Sinno[2], Maruf Mortula[3]

[1] American University of Sharjah, Sharjah, UAE

b00088383@aus.edu

Abstract
An environmental sustainability assessment of a wastewater treatment plant (WWTP) operation in the United Arab Emirates (UAE) is presented in this study. Various emissions from the wastewater treatment facility, as well as their environmental parameters, are assessed using OpenLCA, a Life Cycle Assessment (LCA) software. The functional unit is 1 m3 of wastewater. The treatment process showed substantial negative effects on the analyzed categories: global warming, human toxicity, ecotoxicity, and eutrophication. The biggest contributors to global warming are two processes: wastewater transportation, which accounts for about 43% of the entire effect, and bioreactor air blowers, which account for 38% of the total impact. The transportation process, in addition to the filtration anthracite production, are the key contributors to the generation of fine particulate matter. Whereas, in terms of fossil resource scarcity, the operation and maintenance of activated carbon uses up to 0.5 kg of oil per functional unit, accounting for 93 percent of total fossil resource use. Briefly, The main contributors to the environmental impact were found to be the transportation of the wastewater in addition to the production of the materials used in the treatment processes.

Keywords
Environmental Sustainability, Wastewater Treatment Plant, Operational Assessment, OpenLCA Software.

1. Introduction

Wastewater treatment plant is to purify untreated water from a variety of sources such as households, workplaces, labs, and sewerage systems, so that it may be safely disposed or reused. One of the core roles of wastewater treatment systems is to reduce environmental consequences. However, the treatment plant may have environmental consequences. They should be built in such a way that their overall environmental impact is minimized (Bakhit & Eltayeb, 2021). Wastewater treatment plants if not managed efficiently can impose substantial effect on the environment and the human health. Untreated wastewater includes a high concentration of toxins that are hazardous to the environment and humans. Wastewater may contain large amount of Biological Oxygen Demand (BOD), nutrients, organic matter, and bacteria, all of which can cause harm if dumped into the environment without being treated.

The wastewater is usually treated through primary and secondary processes through the wastewater treatment plant. These treatment techniques saved enormous populations from illness; however, society was unaware of the additional environmental expenses involved with water treatment (Corominas et al., 2013). Even though wastewater treatment plants lessen the negative impact of untreated wastewater on the environment, they still have a negative environmental impact of their own due to the use of raw natural resources in their installation and operation (Lopsik, 2013). As a result, while choosing the best technology, not only technical and economic factors must be considered, but also environmental factors (Molinos-Senante et al., 2014). On a local and global scale, poor design, and operation of wastewater treatment plants (WWTPs) can result in serious environmental issues (Sabeen et al., 2018; Xiong et al., 2018). For this reason, sustainability in a wastewater treatment plant is a cause of concern for the researcher (Bakhit & Eltayeb, 2021).

Environmental sustainability assessment is a strategy for quantifying the impacts associated with the product, service, or activity. It is one of the tools that may be used to perform analysis which is based on a thorough knowledge of the process and the collection of reliable data, the collection and assessment of the outputs and possible environmental consequences of a product system. Environmental studies assist in determining the most environmentally friendly process. In this paper, the focus is on the operation mainly and the transportation, to analyze the environmental impacts associated with those processes. The environmental dimension shown to be the most important factor in the sustainability aspect (Omran et al., 2021). Even in developing countries, sustainable wastewater treatment is one of the most difficult issues to solve (Bakhit & Eltayeb, 2021). Wastewater treatment is neither an environmentally friendly nor cost-effective procedure. It uses a lot of energy as well as some chemicals. As a result, an environmental sustainability assessment of the environmental advantages of water conservation and the environmental harm caused by water treatment is necessary. Since the urban areas in UAE keep expanding, the need for new wastewater treatment plants is increasing all around the country, especially with the Environment Vision 2030 (Abu Dhabi) of following more sustainable and environmentally friendly to preserve fresh water, there is a need for basic studies that show the environmental impact of the commonly used wastewater treatment methods in UAE. The study will represent a case study of one of the new wastewater treatment plants to be built in the UAE and could be used as a benchmark for future work to be compared with other case studies of wastewater treatment plants using different treatment methods, this way a clearer vision of the most environmentally friendly treatment method could be provided for further development.

The goal of this study is to evaluate the environmental impacts of a wastewater treatment plant in the United Arab Emirates. The research is being carried out in order to evaluate the impact of the processes used in the proposed wastewater treatment plant for future comparison with other processes and a basis for future decision making for the most sustainable wastewater treatment processes with the least environmental impact. It is important to note that due to the data limitation, the scope of the environmental sustainability assessment in this project is limited to the processes and operational aspect of the wastewater treatment plant. The impact assessment will be limited to the transportation of the wastewater, the energy used by the equipment to operate the WWTP, and the main materials that will be used/changed frequently. There are substantial environmental impacts remains from the waste residuals management within a wastewater treatment plant. This led to several studies focused on the reuse of waste sludge to minimize the environmental consequences (Kaakani et al., 2017; Mortula, 2006). However, this remains outside the scope of this paper.

2.Methodology

The environmental impact of the wastewater treatment plant is shown and analyzed using an environmental sustainability assessment. To do that, data were collected from a wastewater treatment plant provider located in UAE, meetings were taken to get the data and understand it from the engineer working there. Followed by analysis as explained in detail in the next sections.

The assessment modeling is done through OpenLCA software and Agribalyse database by using the well-known ReCiPe impact assessment midpoint approach. The environmental sustainability assessment is done through several steps as shown in Figure 18 1) goal and scope definition, 2) inventory analysis, and 3) impact assessment.

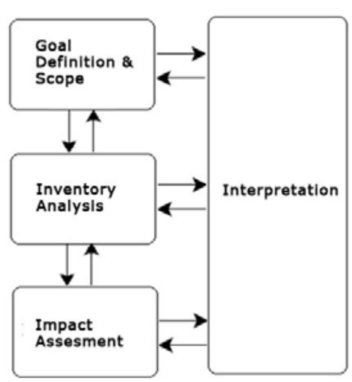

Figure 18: Assessment methodology (International Organization for Standardization [ISO], 2006)

2.1 Wastewater treatment processes

Several processes are proposed for the wastewater treatment which are aeration, settling, and tertiary treatment. The raw sewage is transferred to treatment facility using the sewage trucks commonly used in the UAE. Once in the treatment plant and in the equalization tank for primary storage, they go through the lifting station to the rest of the processes.
The treatment process of the wastewater goes as follow:

- Screening: remove large particle
- Bioreactor: biological treatment through active bacteria
- Settling: transfer through gravity to form flocs and settle
- Filtration: filtration through PVC trickling filters followed by multimedia sand filtration
- Disinfection: sodium hypochlorite dosage and contact tank

2.1.1 Functional unit

Data collected and used in the assessment all have different units and are measured compared to different parameters. A functional unit of 1m^3 of wastewater was chosen to unify all parameters and to be able to compile and compare their impact. For example, the wastewater treatment plant has a capacity 100m^3/day equivalent to 4.2m^3/h. electrical energy used is given in kWh, which will be divided by 4.2 to get how many kW were used to treat 1m^3 of wastewater. In addition to that, results were analyzed annually as shown in table 2 to provide a broader picture of the environmental impacts.

2.1.2 Assumptions

The data available in the literature and provided by the company were not enough to get all the inputs needed for the environmental sustainability assessment, thus some assumptions had to be made based on commonly used information and from literature review:

- Trucks:
  - Capacity: 20m^3
  - Number of trucks needed: 5
  - Fleet distance: 40km
  - Diesel consumption: 25liters/100km
- Lifespan:
  - PVC: 25 years
  - Anthracite: 1.5 years
  - Activated carbon regeneration: 6 months
  - Activated carbon replacement: 5 years

2.2 Life cycle inventory

Interviews with working employees at the company that designed and installed the plant were conducted to gather process-specific data. The data input gathered from the company regarding the energy consumption of the machinery in the treatment plant, the dosage of chemicals used, and the effluent characteristics are listed in Table 18. The energy input was then converted into CO_2 emissions based on data released by the UAE's ministry of environment and water which is 600g CO_2/kWh. For the lifting's station activated carbon filter, the data was collected from the literature review for both production and regeneration and are presented in Figure 19. The inventory for the anthracite production was extracted from the literature review as well and is divided into emissions to water Figure 20 and emissions to air Figure 21. For the rest of the inventory, the direct impact for the production of sodium hypochlorite and the production and maintenance of PVC pipes were found in the literature and added to the impact assessment section, the data is presented in Figure 22 and Figure 23 respectively.

Specific details of the wastewater treatment plant such as area, location, etc. can't be shown, as agreed when the data was taken from the responsible company since the project is governmental and confidential. So, information will not be publicly released; readers may contact the authors for more details.

Table 18: Data collected from the contractor's company

Input	Values
Lifting station pump	1.06 kW/h
Automatic screen	0.25 kW/h
Bioreactor air blower	7.5 kW/h
Chlorination dosing pump	0.075 kW/h
Sodium hypochlorite dose	10 mg/l
Multimedia filter pump	1.2 kW/h
BOD	< 10 mg/l
COD	< 10 mg/l
TSS	< 10 mg/l
NH_4	< 10 mg/l

Process	Amount	Units
Continuous dye treatment (10 kg dry weight GAC)		
Pumping	2.79	kWh
GAC production (1 kg GAC)		
Hard coal	1.00	kg
Hard coal combustion	60.8	MJ
Electricity, medium voltage, production UCTE	1.60	kWh
Deionised water	12.0	kg
Natural gas combustion	13.2	MJ
GAC regeneration (10 kg to regenerate, 9 kg produced)		
Electricity, medium voltage, production UCTE	0.30	kWh
Hard coal combustion	30.4	MJ
Steam	6.00	kg
Natural gas combustion	105	MJ

Figure 19: Activated carbon production and regeneration input (Gabarrell et al., 2012)

Waterborne emissions from coal production

No.	Parameter	Coal mine[a]	Coal cleaning[b]	Uncontaminated river[a]
1	pH	3.5	6.2	6.5
2	BOD_5 (g/m^3)	52.4	13.6	42.6
3	Total suspended solid (g/m^3)	103	68	4
4	Total solid (g/m^3)	278.47	NA	6.30
5	Arsenic (As) (g/m^3)	0.0056	0.0046	0.0021
6	Total Nitrogen (N) (g/m^3)	1.75	NA	1.12
7	Total Phosphorus (P) (g/m^3)	1.40	NA	0.26
8	Cadmium (Cd) (g/m^3)	0.11	0.012	0.03
9	Total Chromium (Cr) (g/m^3)	0.0046	0.0002	0.0029
10	Copper (Cu) (g/m^3)	0.34	0.012	0.05
11	Iron (Fe) (g/m^3)	234	2	0.6
12	Manganese (Mn) (g/m^3)	12.02	0.86	0.46
13	Mercury (Hg) (g/m^3)	0.0008	0.0005	0.0001
14	Lead (Pb) (g/m^3)	0.056	0.006	0.003
15	Nitrates (NO_3^-) (g/m^3)	6.85	1.64	0.67
16	Sulfates (SO_4^{2-}) (g/m^3)	745	351	32
17	Oils (g/m^3)	1.4	0.2	0.0

Figure 20: Anthracite production, emissions to water (Chinh et al., 2007)

Air emissions from anthracite production in Vietnam

Pollutant	Coal extraction	Coal preparation	Transport
PM10 (g/tonne)	88,194	532	189
SO_2 (g/tonne)	56	25	3
NO_x (g/tonne)	92	68	10
CO_2 (g/tonne)	48,995	21,854	999
CO (g/tonne)	978	96	2
N_2O (g/tonne)	0.73	0.48	0.04
CH_4 (g/tonne)	1760	28	0.60
NMVOC (g/tonne)	47	17	2
Metals (g/tonne)	0.48	0.28	0.01

Figure 21: Anthracite production, emissions to air (Chinh et al., 2007)

Chemical	Impact category	Process LCA	Input–output LCA			Hybrid LCA
			Zero order	Higher order	Total	
Sodium hypochlorite (13 % *w/w*)	GWP, kg CO_2-eq	3.58E+02	1.45E+02	1.96E+02	3.41E+02	4.09E+02
	PE, GJ	4.05E+00	1.60E+00	1.32E+00	2.92E+00	4.12E+00
	WU, ML	4.70E−02	5.15E−04	4.55E−04	9.71E−04	4.71E−02
	FETP, kg DCB-eq	1.46E−01	3.90E−03	3.44E−03	7.34E−03	1.47E−01
	METP, kg DCB-eq	1.10E+04	2.77E+02	2.14E+02	4.92E+02	1.10E+04
	TEP, kg DCB-eq	4.31E+00	4.40E−01	2.12E−01	6.52E−01	4.34E+00
	HTP kg DCB-eq	2.84E+00	5.51E−01	1.92E−01	7.43E−01	2.88E+00

Figure 22: Life cycle impact assessment of sodium hypochlorite production (Alvarez-Gaitan et al., 2013)

Categories	Unit	Primary PVC
		Value
Climate change	kg CO_2 eq	2.82×10^3
Ozone depletion	kg CFC-11 eq	9.30×10^{-5}
Terrestrial acidification	kg SO_2 eq	9.59
Freshwater eutrophication	kg P eq	0.03
Marine eutrophication	kg N eq	0.48
Human toxicity	kg 1,4-DB eq	428.42
Photochemical oxidant formation	kg NMVOC	12.29
Particulate matter formation	kg PM_{10} eq	3.58
Terrestrial ecotoxicity	kg 1,4-DB eq	14.99
Freshwater ecotoxicity	kg 1,4-DB eq	0.76
Marine ecotoxicity	kg 1,4-DB eq	6.29
Ionising radiation	kBq U235 eq	110.41
Agricultural land occupation	m^2a	10.34
Urban land occupation	m^2a	7.20
Natural land transformation	m^2	0.17
Water depletion	m^3	57.52
Metal depletion	kg Fe eq	48.48
Fossil depletion	kg oil eq	1.12×10^3

Figure 23: Life cycle impact assessment of PVC production (Ye et al., 2017)

2.3 Impact assessment

For every inventory input, a relation to an impact had to be defined. The database used for the impact assessment was ReCiPe Midpoint (H). If any of the parameters had no impact in this specific database then it was added, data was collected from different databases with common factors to similar impacts, this way a larger database was created for the project to consider all the inputs added.

The ReCiPe Midpoint (H) assess the following impacts: Fine particulate matter formation, Fossil resource scarcity, Freshwater ecotoxicity, Freshwater eutrophication, Global warming, Human carcinogenic toxicity, Human non-carcinogenic toxicity, Ionizing radiation, Land use, Marine ecotoxicity, Marine eutrophication, Mineral resource scarcity, Ozone formation, Human health, Terrestrial ecosystems, Stratospheric ozone depletion, Terrestrial acidification, Terrestrial ecotoxicity, Water consumption.

3. Results and discussions

After adding the inventory and linking them to the corresponding impacts, a software run was conducted, and the results for the functional unit of $1m^3$ of wastewater were analyzed. To get a more realistic view of the wastewater processes impact, the impact for 1 year of operation was calculated as well and added to the results shown in Table 2. Results show that the most significant impact is global warming, human non-carcinogenic toxicity, fine particulate matter formation, marine toxicity, marine eutrophication, and fossil resource scarcity.

The main contributors to the global warming are two processes: the wastewater transportation generating up to 1.3 kg CO_2 eq contributing to almost 43% of the total impact, the bioreactor air blowers generating up to 1.1 kg CO2 eq contributing to around 38% of the total global warming impact. On the other hand, for the fine particulate matter formation the main contributors are the transportation process (~1.8E-4 kg PM_{25} equivalent to 65% of total PM_{25} emitted) in addition to the filtration anthracite production (~8.7E-5 kg PM_{25} equivalent to 32% of total PM_{25} produced). Whereas for the fossil resource scarcity the operation and maintenance of the activated carbon holds the higher contribution by using up to 0.5 kg of oil per functional unit consisting of 93% of the total fossil resources usage. The results show that the main contributor to the environmental impact is the transportation of the wastewater, which suggest that different alternatives need to be considered to transport the wastewater, perhaps a renovation and building a connecting sewer system may be a good alternative on the long run. An environmental sustainability assessment of the alternatives needs to be done and compared to the current one to be able to choose the most sustainable option to move forward and start applying it.

Table 19: Life cycle impact assessment results

Impact category	Reference unit	Result (per m3)	Results (per year)
Fine particulate matter formation	kg $PM_{2.5}$ eq	0.000268113	9.79
Fossil resource scarcity	kg oil eq	0.53408355	19,494.05
Freshwater ecotoxicity	kg 1,4-DCB	2.9595E-06	0.11
Freshwater eutrophication	kg P eq	5.50036E-08	0.00
Global warming	kg CO_2 eq	2.81618897	102,790.90
Human carcinogenic toxicity	kg 1,4-DCB	2.86713E-05	1.05
Human non-carcinogenic toxicity	kg 1,4-DCB	0.100690559	3,675.21
Land use	m^2 crop eq	0.00153	55.85
Marine ecotoxicity	kg 1,4-DCB	0.110010305	4,015.38
Marine eutrophication	kg N eq	0.003440772	125.59
Metal depletion	kg Fe eq	7.41744E-05	2.71
Ozone formation, Human health	kg NOx eq	0.001600733	58.43
Stratospheric ozone depletion	kg CFC11 eq	1.4229E-10	0.00
Terrestrial acidification	kg SO_2 eq	0.000591263	21.58
Terrestrial ecotoxicity	kg 1,4-DCB	6.63347E-05	2.42
Water consumption	m^3	0.000282646	10.32

4. Conclusions

Water is a valuable resource, and with the scarcity that the world is facing, wastewater treatment is a necessity. Different wastewater processes are available and implemented worldwide, but although the processes will help reduce the environmental impact of the wastewater, they themselves contribute to the impact on the environment as well. This paper analyzes the environmental impact of the processes used in the operation of a wastewater treatment plant newly built in the UAE. An impact assessment was conducted to set a baseline for future project to be able to compare and chose the option that has the least impact on the environment. Results showed that the main contributor to the environmental impact is the transportation of the wastewater to the treatment plant using trucks, thus different alternatives need to be studied to compare their impact. In addition, the production of the materials used in the processes were found to have a significant impact on the environment as well, which opens the research for different alternatives and different processes to be studied for comparisons and improvements.

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The Impact of Project Context on Management Practices in the North Cyprus Construction Industry

Balkiz YAPICIOĞLU[1]

[1] Arkin University of Creative Arts and Design, North Cyprus, Kyrenia
balkiz.yapicioglu@arucad.edu.tr

Abstract

The environment in which projects take place has a major impact on how they are managed. This paper examines the context in which the North Cyprus construction industry operates. The North Cyprus economy experienced a construction boom in the aftermath of the UN Peace Plan for settling the Cyprus problem. However, the local construction industry is underdeveloped and unable to exploit any resulting commercial opportunities. Despite recognition of the need for improvement in project management practices, little has been done to address this. This paper examines the context of the North Cyprus construction industry considering political, economic, social and technical factors (PEST analysis). It is shown that uunresolved political conflict leads to a resistance to change in management practices in the local construction industry. This analysis of context can be useful in attempting to improve management practices in projects affected by political conflict.

Keywords

Construction, Cyprus, Islands, PEST analysis, Small economy

1. INTRODUCTION

The increasing demand for quality, productivity and performance in the construction industry is particularly challenging in states that face financial crisis, are small in size, or are experiencing conflict and trauma. The problems facing these states cannot be ignored, especially as the leading governments, UN agencies, NGOs and private companies have gained unprecedented access and influence over the internal affairs of these states (Duffield, 2001).

Even though substantial has identified the need to adapt and localize established project management principles and methodologies to support project management in construction, small economies because of their open economy lacks the attention by the scholars. Culture and the socio-political environment are formed over a long timescale, and changes in management practice may meet with resistance. Management is influenced by the policies and culture of the company and society and these must be understood before making changes. Marsden (1991, p. 36) asserts that "indigenous knowledge may be the basis for building more sustainable development strategies, because they begin from where the people are, rather than from where development experts would like them to be".

Variations in project context can make the application of appropriate project management techniques challenging and that a contextual analysis considering the external and internal environment and the interests and influences of major stakeholders can be helpful in deciding how a project is to be managed. PESTLE analysis as a useful approach to analysing the project context and is one of the most used models in evaluation of the external business environment that is highly dynamic (Perera, 2017). PESTLE is an acronym for 'political, economic, social, technical, legal and environmental', which are the major influencing factors in the project environment. This is often condensed to PEST analysis, with the legal aspects being considered part of the political environment and the environmental factors being considered under the 'social' heading. PEST analysis can help the organization to respond to its environment in order to improve its competitive position (Gillespie, 2007) and is concerned with the constraints put upon a company or an industry by the environment in which it operates. As such, it is highly relevant to project-based industries seeking to improve their performance.

This paper presents a general background to the construction industry in North Cyprus using a handful of research available in the field and authors' recent field research on the topic where data is collected via semi-structured interviews of the infrastructure construction companies and the local news on the subject matter. The results of the interviews, which were analysed using thematic analysis, and the findings from the literature and the media then followed by an analysis of the environment in which the industry operates, considering the different elements of the PEST technique. This analysis is then used to explain the current approach to construction project management in the industry. Although the construction industry accounted for 18% of GDP in North Cyprus only 10 years ago its economy recently experienced a serious downfall of -25% (TRNC SPO, 2021), research on the management problems challenging this sector is limited. Common problems affecting the sector in developing countries include: lack of management skills, shortage of skilled labour, low productivity and poor quality of supplies construction in these countries has largely failed to make progress and there has not been any breakthroughs in knowledge (Ofori, 2019). In addition, the sector in North Cyprus has issues including project overruns, poor quality of structures, inappropriate procurement systems, failure to cope with infrastructure needs resulting from the inability to adopt best practices (Yitmen, 2007), and resist to change (Yapicioglu and Lawlor-Wright, 2014). The following section examines the political, economic, social and technical challenges affecting the industry. The aim is to examine how these issues affect the ability of local construction companies to participate effectively in local infrastructure projects.

2. Pest Analysis of the Sector

2.1. Political Factors

The construction industry is one of the driving sectors of the economy in North Cyprus. Urgent demand in development and rehabilitation of the infrastructure of North Cyprus, followed by a boom in housing construction has initiated several infrastructure projects on the island. In addition, recently, more funding is being provided by international sources such as Turkish Republic, EU and UNDP. Therefore, there are more opportunities in the infrastructure construction industry with larger and more complex projects. Unfortunately, only a few local contractors are qualified to participate in these projects. The risk that these opportunities might be lost to international firms has led to protests by local industry (Sonay, 2011). For example, the Association of General Contractors claimed that public tender conditions put smaller firms and the local contractors at a disadvantage. With the majority of major contracts being awarded to international firms, the organization has warned the government that, in order to ensure the survival of the local construction industry, such tenders should not be open to foreign companies. However, these attempts have been unsuccessful. In September 2012, one of the most prestigious and expensive infrastructure projects (€ 350 m) for North Cyprus, the upgrading of the country's only airport, was awarded to a company from Turkey and all the highway construction projects are tendered in Turkey without the knowledge of the local industry (Kibris Postasi, 2021).

Local industry is heavily affected by the political status and lack of recognition of North Cyprus. Economic and political embargoes, placed on North Cyprus since 1974, severely affect its economy and governance. North Cyprus operates as a *de facto* state; it is unrecognized by the international community, but conforms to the description given by Pegg (1998, p. 26),

> "a secessionist entity that receives popular support and has achieved sufficient capacity to provide governmental services to a given population in a defined territorial area, over which it maintains effective control for an extended period of time".

In *de facto* states, financing the public sector is an immense challenge, and access to international aid is extremely limited under circumstances of non-recognition (Özyiğit and Eminer, 2021). Instead of economic imperatives, politics is the utmost factor that runs the state; therefore Lynch (2004) describes *de facto* states as "political animals".

Turkish Cypriot Competitiveness Report in 2012 identifies the most important barriers to the Turkish Cypriot economy's competitiveness as the 'small size of its market', 'limited financial market sophistication', 'deep-seated structural macroeconomic weakness and instability' and 'unsophisticated businesses and inefficient goods market'. 'Political instability', 'inconsistent government/coup d'état', 'corruption' and 'inadequate supply of infrastructure' are identified as the most influential factors on conducting business in North Cyprus in the report (Sertoglu et al., 2012). Furthermore, the last report (Süreç and Eminer, 2020) also adds flexibility and innovation as factors which lacks in the business environment.

The difficult economic situation and lack of international recognition mean that North Cyprus depends heavily on financial aid from Turkey. As a result, the politics and government policies of Turkey dominate the politics of North

Cyprus (Süreç and Eminer, 2020). In 2004, the Turkish community on the island accepted the proposed 'Annan Peace Plan' by popular vote for a solution to the chronic Cyprus Problem, however, it was simultaneously rejected by the Greek Cypriots. Both EU and UN declared their commitment to end the isolation of Turkish Cypriots and encourage economic development, but to this date no actions are taken in regards to these commitments and the business environment is trying to cope with these obstacles.

2.2. Economics Issues

2.2.1. Small island economy

The economy of the North Cyprus administered area is dominated by the services sector, including the public sector, trade, tourism, and education, with smaller agriculture and light manufacturing sectors. As such, although the economy is small, it is not as flexible or innovative (Süreç and Eminer, 2020). It operates on a free-market basis, although it is handicapped by the political isolation of North Cyprus, the lack of private and public investment, high freight costs, and shortages of skilled labour.

Islands, like Cyprus, are isolated and disconnected locations and, as Baldacchino (2005) states, not only on the "fringe of goings on, but also ill-equipped to be competitive because of defensive self-absorption" (p. 148). Market fragmentation, limited labour supply and skills, little technical advancement and investment capital are all reasons of increased volatility. Small island economies' inherent handicaps include: small populations, limited domestic market, openness, and limited resources which prevents these economies competing for opportunities offered by globalization. The result is often behaviour described as 'rent-seeking' (Svensson, 2000). This is "expenditure of resources in order to bring about an uncompensated transfer of goods or services from another person or persons to one's self as the result of a 'favourable' decision on some public policy" (Biller, 2003, p.125). This behaviour slows economic growth and innovation (Murphy et al., 1993) and limits industrialization. Over time, this results in a relatively large, bloated public sector, and a very small private sector which is mainly engaged in commercial, import-oriented wholesale and retail trade (Baldacchino and Milne, 2000).

Political arrangements and international political alliances of small island economies (both current and past) also have a great impact on their economic growth (Duffield, 2001; Tisdell, 2009). The economic borders of small island jurisdictions are very strictly tied to their politics with bigger nations. Furthermore, these kind of political and historical relationships with other nations, affect the small island economies' foreign financial aid, pattern of international trade, direction of their capital movements and the migration patterns and possibilities of their citizens. For example, North Cyprus relies mostly on financial aid from its patron state Turkey. This aid is controlled by the Turkish government, with recent high value Turkish Cypriot infrastructure project contracts being awarded to contractors from Turkey.

Imperfect competition is a chronic problem affecting island states and is the result of the small domestic market. Small economies seek foreign aid to enhance their economies, but introducing too many large-scale investors might harm small local business and small firms as they exist in most small economies cannot compete effectively in a global market (Mazzarol, 2004; Wang et al., 2007; Tisdell, 2009).

2.2.2. Small business

The importance of small and medium-sized enterprises (SMEs) to world economies is well documented (Birch 1989; Storey 1994; 2000; Ng and Kee, 2018). SMEs with 250 or less employees (EU Commission, 2003; 2005), make up the largest business sector in every world economy (Culkin and Smith, 2000). On small islands, SMEs are by far the primary source of private employment (Tanova, 2003). The global economic environment and the need for continuous innovation force companies to improve their competitiveness (Aragón-Sánchez and Sánchez-Marín, 2005). However, SMEs are heterogeneous and their traits heavily rely on each region's history and characteristics (Romani and Atienza, 2005).

SMEs are a vital component of the North Cyprus economy, 99% of all enterprises in North Cyprus are SMEs and are no large size or international Turkish Cypriot contractors in Northern Cyprus construction market (Egemen and Mohamed, 2007; TRNC SPO, 2021). The fact that North Cyprus is not recognized by the international community also means that construction companies are restricted to servicing the local market and lack international standards, performance levels and quality (Yapicioglu, 2015).

In every country, small contractors dominate the construction industry in terms of numbers. A major difference between large and small businesses (SMEs) is the social distance between owners and managers (Vos and Roulston, 2008). Unlike decision makers in many larger organizations, in small businesses, the owner and the manager are often the same person. The owner/manager is responsible for all decision making and the business is tied up with their life and identity (Culkin and Smith, 2000; Vos and Smith, 2003; Mazzarol, 2004; Moeuf et. al., 2018). Such firms are characterised by an informal management style, and a considerable number of family members employed in the firm.

Owner/managers tend to hire family members for the key positions to maintain tight control of the strategic decision-making process. To maintain the control of the family members, the owner/managers usually restrict the firm's growth (Bratkovic et al., 2009). However, it is found that the degree of owner involvement in small businesses and owner/manager's personal values has a direct impact/influence on the overall business performance (Kozan et al., 2006; Vos and Smith, 2003). Robinson and Pearce (1984) argue that the owner/manager's absence of formal business planning is attributed to such things as: i) lack of time to devote to such activities; ii) lack of knowledge about how to plan; iii) inadequate planning skills; and iv) an unwillingness to share strategies with others or commit ideas to paper. It has been argued that small business owner/managers do not plan because they lack the knowledge, confidence or skills to do so (Wang et al., 2007). Due to these shortcomings, many small enterprises fail to adjust in response to environmental changes. Their ability to formulate strategy and introduce new technology management is limited (Moeuf et. al., 2018).

Although a large number of small-construction firms is not necessarily undesirable, and it is a fact of life in island economies, many of them have little prospect of growth and development (Wang et al., 2007). Due to the informal and irregular manner in which operations are carried out by family businesses, the financial flows of the enterprise may not be separated from the economy of the family (Psaila, 2007) and traditional project management processes do not meet small business's needs (Turner et al., 2010).

2.3. Social Issues

2.3.1. History

After Cyprus became independent from the Britain in 1960, ethnic violence between the Greek and the Turkish on the island resulted in many casualties and the forced displacement of over 30,000 Turkish Cypriots to "ethnic enclaves", which only covered 3% of the island (Tocci, 2000). The living conditions in the enclaves were quite inhumane - in some enclaves the Turkish lived in caves, or tents, and it was common for more than one family to share a single house. Enclaves were economically embargoed by the government (Greek Cypriot) on strategic goods and services. No public expenditure was directed to the Turkish Cypriot community living in ethnic enclaves. Freedom of movement and employment of the Turkish Cypriots were denied for eleven years until the war on the island in 1974, after which the two communities were completely isolated from each other (Tamkoç, 1998; Lacher and Kaymak, 2005).

Turkish Cypriots, following the interference of Turkey, now controls of 37% of the island, and declared its independence in 1983 as Turkish Republic of Northern Cyprus (TRNC). However, the isolation of the Turkish Society continued, since the new state "North Cyprus" is denied recognition by the international community and declared a *de facto* state since 1974. Internationally, it is only recognized by the Republic of Turkey which has unprecedented control over the politics of TRNC.

The long-term effects of trauma on the Turkish Cypriot community and identity have been highlighted by Volkan (2008). In addition to individual and social psychological effects of past events, Turkish Cypriots still have to face the economic consequences of these traumatizing events which still impact on even basic business activities. This includes difficulties with importing and exporting, attracting foreign direct investment, facing embargoes, lack of direct flights and lack of state recognition. As Öksüzoglu (2010) puts it, emotional scars coupled with financial losses have an impact on individual and social behaviour, the perception of what is ethical and what is not, and on daily business practices in North Cyprus. Adžanela (2010) reports similar behaviour in post-war Bosnia and Herzegovina, with unethical use of personal connections, often accompanied by favouritism and nepotism. In the absence of the "rule of law" personal connections prove to be a much more effective mechanism to achieve one's rights, privileges and benefits than the official mechanisms. The statement that "The relatively long history of inter-communal violence, combined with larger Greco-Turkish enmities, has penetrated in the minds of the Cypriots to such an extent that each side, as a group, fears that it would become victim once again" (Yilmaz, 2005, p. 87) summarizes why this resistance to change may continue in North Cyprus.

2.3.2. Effects of Trauma

To understand the behaviour of the Turkish Cypriots towards business in construction, it is also important to understand the behaviour of large groups after a shared trauma. A traumatic event is one that causes horror, terror, or helplessness at the time it occurs, and can include community violence, acts of terrorism, war experiences, natural and human-made disasters (APA, 2008). Cultural trauma, on the hand refers to a "dramatic loss of identity and meaning, a tear in the social fabric, affecting a group of people that has achieved some degree of cohesion" (Eyerman, 2001, p. 2), which is caused by a traumatic event, where the memories of "a shared past are retained by the members of a group large or small, that experienced it" (Schuman and Scott, 1989, pp. 361-362). When massive trauma occurs where the large-group's identity is threatened, the group experiences regression, confusion and disorganisation (Volkan, 2006).

In the case of the Turkish Cypriots, threats result from the violent conflict prior to 1974 as well as on-going embargoes and lack of recognition from the international community. This results in a form of helplessness within the society of North Cyprus. As Volkan (2008, p. 97) comments,

> …the northern part of Cyprus is inhabited by people who do not have typical human rights, who do not have a large-group identity that is legally accepted by billions of others surrounding them (except Turks on the mainland) and who, in a sense, are second-class human beings. After living in actual enclaves for eleven years, the Cypriot Turks from 1974 to the present time have continued to live in an invisible enclave.

Volkan (2006) explains 'chosen trauma' as "the shared mental representation of an event in a large group's history in which the group suffered a catastrophic loss, humiliation, and helplessness at the hands of enemies". When members of a victim group are unable to mourn such losses and reverse their humiliation and helplessness, they pass on to their offspring the images of their injured selves and psychological tasks that need to be completed (Volkan, 2006; Bohleber, 2007). This process is defined by Volkan (2006) as "trans-generational transmission of trauma." All such images and tasks contain references to the same historical event, and as decades pass, the mental representation of such an event links all the individuals in the large group. Thus, the mental representation of the event emerges as a significant large-group identity marker. As Caruth (1995, p. 17) puts it: "it is not the experience itself that produces traumatic effect, but rather the remembrance of it".

Following Erikson's (1956, p. 57) description of a person's identity as "a sustained feeling of inner sameness within oneself .... [and] a persistent sharing of some kind of essential character with others", Volkan (1999, p. 32) defines large group-identity as "subjective experience of millions of people – most of whom will never meet one another in their lifetimes – who share a persistent sense of sameness (we-ness) while also sharing some characteristics with others in foreign groups". Volkan (1999) observed that large-group identity issues are crucial in understanding resistance to change and the process of attempting to resolve large-group antagonism.

2.3.3. Technical Issues

Few publications address technology and innovation within the construction industry in North Cyprus. The existing infrastructure of the government also limits access to reliable data and statistics of the construction sector in North Cyprus. Yitmen et al. (2011) argue that research is very challenging without reliable statistics. The majority of the research in this area relies on direct observation and data collection from industry itself.

It is widely accepted within the North Cyprus construction industry that innovation and adaptation to new technology is slow (Yitmen and Al Qadi, 2005; Egemen and Mohamed, 2007; Yitmen, 2007). Celikag and Nami (2011) suggest that even the design technology of the projects is limited; they also suggest that there is a serious need for training in this area, in design and in introducing new technologies. Egemen and Mohamed (2007) also refer to the limited technology and innovation in this sector. They show that 92.5% of the contractors in North Cyprus have never used any statistical or mathematical model to assist their bid/no bid or mark-up size decisions, and 97.5% of the contractors use intuition as their primary tool for decision-making process. Moreover, even though the IT infrastructure is available on the island, construction companies in North Cyprus consider investment in this as an unnecessary additional cost (Sertoglu et al., 2012).

3. Results and Discussion

In the past few decades, the internationalisation of firms and their ability to provide services across boundaries has changed the dynamics of business. Some states, however, face unique challenges because of a combination of geographical location, their small size, conflict and political challenges. This has meant that they are unable to compete in the global marketplace. Globalization has created the need for businesses to improve competitiveness. Increased demand in production and quality and customer satisfaction is a major factor that affects competition in a lot of industries, and is also valid for the construction sector globally.

Adaptation of new techniques in project management for the increased success of projects is a method suggested in the literature. However, challenges facing states and communities vary, and project management methods may not be directly transferrable from one state to another. Before trying to adopt changes in management in North Cyprus, the project context influences need to be addressed. Based on the PEST analysis of the construction industry in North Cyprus, this paper has explored the harsh political, economic, social and technical environment faced by the local industry. The construction industry in North Cyprus is affected by a unique combination of challenges in its environment. It is small in land area, on an island divided by political conflict and recent war. Being an isolated, *de facto* state, the lack of international recognition adds additional difficulties to daily business. In such an environment, the life cycle of a project might alter drastically with unexpected events. These include cultural clashes, unexpected changes in the law and government, unrest with the state, inflation and embargoes. Consequently, management in the local infrastructure construction companies are primarily concerned with managing external political stakeholders and reacting to the external environment. Over time, this has become an accepted part of the local life style where the public and the companies alike cannot predict the future and do not plan. This has led to the lack of focus on project planning and control and the lack of investment in supporting training and technology as was mentioned by (Yapicioglu and Lawlor-Wright, 2014).

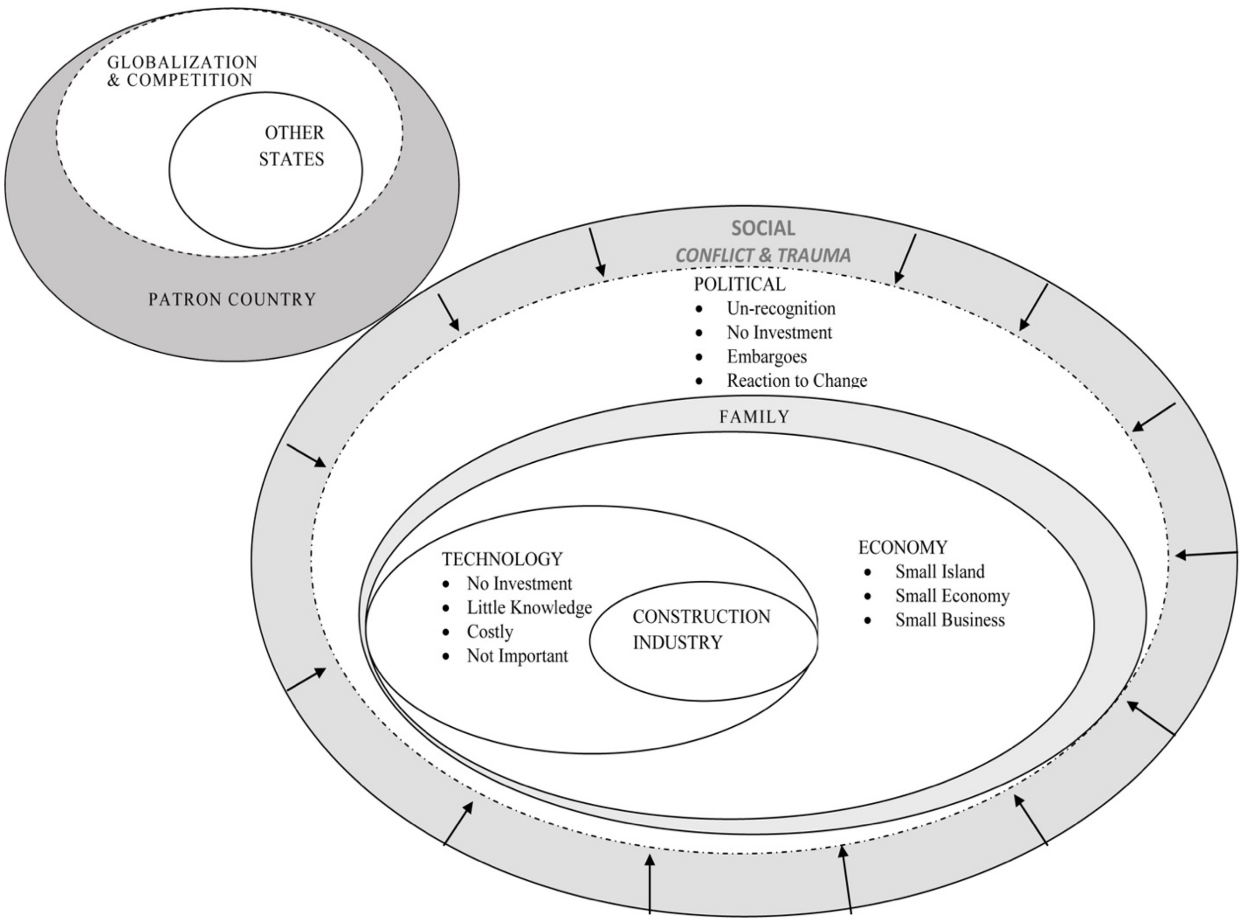

Fig. 1. The business environment framework to construction in North Cyprus (Yapicioglu, 2015).

A framework depicting the business environment in construction in North Cyprus is shown in Fig. 1, to illustrate why managing projects in construction is highly influenced by the influence of project stakeholders (Yapicioglu, 2015). As can be seen in Fig.1, the family owned construction businesses are tied to the politics of the *de facto* state which is 'enclaved' or separated from the international community. The business, political and economic environment is under the control of the patron country. This reinforces the collective memory of the owner/managers of the past which was dominated by the violent conflict. Growth of the industry in the past has been constantly interrupted (and prevented) by external factors beyond the control of the local industry. This lack of political resolution is not conducive to business growth or investment, and leads to a management approach where appeasement of powerful external stakeholders takes priority. In addition, it reinforces the tendency for the SMEs to remain as micro-enterprises keeping control of the business within a tight family circle. The ability of the businesses to expand and develop is therefore restricted by the knowledge and experience within the family as well as the limited opportunities within the state.

4. Conclusion

In North Cyprus, a combination of political, economic and social factors presents major challenges to the local industry and increases the tendency of SMEs to maintain the control of their organisations within a tight family circle. This restricts the future growth of the company and is not conducive to the adoption of new methods of management.

It is widely recognized that the project context has a great impact both on project success and the management approach used. The political environment of projects in conflict zones eventually leads to a situation where management of stakeholders and adapting to changes in the external environment take precedence over management of the project itself. The challenges of political conflict also play a significant role on the financial, material, information technology and human resource necessary to achieve the project aims.

However, being a small island economy driven mainly by small businesses, and being a *de facto* state results in a society which rejects change. The factors leading to resistance to change in North Cyprus are unique and more social-political than industry specific. The management of local construction companies claims a willingness to adopt project management methods and approaches, but does nothing to improve their practice. With limited international competition and the political influence over awards of project contracts, they have managed to survive due to the high effort expended on nurturing their local stakeholders.

The outcome of this study indicates that the political climate of North Cyprus has the potential to suppress the development of the construction industry. Advancement of technology and improving their project management methods is not their priority. Managing the constant changing political environment to ensure the award of future contracts is more important for their business survival. It is imperative that the local government provides support for the improvement of project management practices and use of supporting technology. Unless this is addressed, the potential risk for the local construction industry is that, by the time the conflict is resolved, local companies will be unable to compete. The next stage in this research is to conduct qualitative research with the local industry and the political stakeholders to identify the support needed and how this can be most effectively delivered.

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Improving Health and Safety (H&S) on South African Construction Projects with Industry 4.0

Nobukhosi Mazibuko[1] and John Smallwood[1]

[1]Nelson Mandela University, Port Elizabeth, PO Box 77000, 6031, South Africa

john.smallwood@mandela.ac.za

Abstract

The South African construction industry experiences a high level of accidents, injuries, and fatalities, despite efforts to reduce their occurrence. This study aims to investigate the potential of Industry 4.0 in terms of improving H&S on South African construction projects. A detailed survey was conducted among medium to large general contractor members of the East Cape Masters Builders Association (ECMBA), and candidates or professionally registered persons with the South African Council for the Project and Construction Management Professions (SACPCMP) who are based in the Eastern Cape such as H&S practitioners, construction project managers (CPMs), and construction managers (CMs). The salient findings include: monitoring H&S hazards onsite is difficult; design-originated and onsite hazards are often experienced onsite; fatalities, injuries, illnesses, and worker fatigue often occur; drone technology has the potential to improve H&S monitoring in construction; building information modelling (BIM) has the potential to reduce design-originated hazards, and virtual reality (VR) has the potential to improve H&S training. It is concluded that implementing Industry 4.0 technologies in construction will improve H&S. Recommendations include: construction H&S-related training and tertiary education should address Industry 4.0 technologies, and various industry stakeholders should promote Industry 4.0-related construction continuing professional development (CPD).

Keywords

Construction, Health and Safety, Industry 4.0.

1. Introduction

Many workers within the construction industry sustain injuries or are killed annually worldwide due to accidents. Despite H&S legislation and regulations having been evolved and implemented, there has been a limited reduction in accidents (Azmy and Zain, 2016). Furthermore, H&S-related challenges have persisted despite a range of H&S-related developments and interventions in addition to H&S legislation and regulations.

Research findings indicate that the advent of Industry 4.0, and a range of related technologies, if adopted, have the potential to provide a long-lasting solution to construction H&S-related issues. Many studies have focused on the implementation of VR, BIM, robotics, and sensors to improve H&S in construction by reducing the number of injuries and fatalities (Haupt, Akinlolu and Raliile, 2019). Investing in equipment to ensure H&S, better communication and training of workers, alongside adopting digital technology, will greatly assist in improving the H&S issues faced in construction (Haupt et al., 2019).

Given the continuing poor H&S performance recorded in the construction industry in South Africa (Construction Industry Development Board (cidb), 2009), the aim of the study was to evolve a framework of interventions to improve H&S in construction using Industry 4.0 technologies, the objectives of the study being to:

- Identify the number of injuries and fatalities in construction;
- Identify the occurrence of H&S phenomena on construction projects;
- Analyse Industry 4.0 technologies that can mitigate fatalities, injuries, and illness;
- Identify the potential of using VR in H&S training;
- Identify the potential of Industry 4.0 technologies and robots to reduce worker fatigue;

- Identify the potential of BIM to mitigate design-oriented hazards, and
- Identify the potential of drones in monitoring onsite H&S hazards.

2. Review of the literature

2.1 Drone technology for construction H&S monitoring

According to Gheisari and Esmaeili (2016) unmanned aerial systems (UASs) or drones can be used to monitor construction on site, collect real time information, and assist in terms of the identification of hazards, and improvements in H&S. Drone technology enables hazard identification at different stages of the construction project which assists in the creation of mitigation measures (Gheisari and Esmaeili, 2016). Drones have the potential to improve H&S as they can operate faster than supervisors conducting inspections in areas which are unsafe, or which are inaccessible to humans. The study proposed that drones or UASs can ideally act as an H&S inspection assistant, enabling the provision of real-time access to images or videos from various areas on the construction site and voice interactions with the construction workers onsite (Esmaeili, Gheisari, Kosecka, and Rashidi, 2019).

2.2 BIM

A study was conducted, which determined that BIM and 4D models can identify and prevent construction hazards such as falls onsite from occurring. BIM enables risk identification to take place prior to a construction project which enables the reduction of design-originated hazards (Turner, Oyekan, Lampros and Griffin, 2020). Design-originated hazard mitigation methods and solutions can be tested or practiced through BIM, the solutions are assessed and compared against other possible measures allowing for H&S risks to be mitigated during the design state. A virtual site can be created where the potential hazards can be explored without the need to put construction workers in danger or expose them to these hazards (Health and Safety Executive, 2018). The system can also be used to assess the viability of the equipment and the structures available to designers. design-originated hazards can be mitigated through BIM as possible clashes using the 3D models can be detected. BIM models are utilised for virtual prototyping of more complex structures and construction procurement processes to assess possible H&S risks, enabling the analysis of different construction methods which can result in the identification, removal, and reduction of site hazards (HSE, 2018).

2.3 VR

A study conducted by Sacks, Perlman and Barak (2013) determined that VR based training was more efficient and effective than traditional H&S training, which occurred in classrooms and from presentations using slides. Virtual reality provides simulated environments for the user, using software, computers, and hardware which is peripheral. The environment may be simulated to be more real or may be imaginary. This form of training enables the worker to analyse, and assess the situations which are presented virtually, decide regarding the action to be taken, implement that action, and observe the results instantly. 3D Game based VR, uses 3D gaming technology to enable the worker or user to interact within an environment. Tasks which are included in the real construction process are designed and included in VR training enabling users to collaborate and interact during the training process (Wang, Wu, Chi, 2018).

2.4 Robots and automation

Robotics are often used to survey construction sites and collect data used to generate 3D models of buildings. These robots can reduce fatigue associated with heavy lifting, as they assist workers in carrying heavy materials and tool kits. Just-in time manufacturing of buildings' components and 3D printing technology allow for less manual labour to take place, as additive methods can build 3D structures through block laying robots or welding arms (Turner et al., 2020). Wearable robotics can provide support to workers by supporting their backs, this is done by sensing the workers motion and a signal is then sent to motors which rotate the gears. Supporting their upper body reduces lower back stress of the worker by 15 kilograms (Li and Ng, 2018). This technology enables workers to carry heavy loads such as construction tools more easily, with less stress on the body as its configuration transfers the loads through the skeleton to the ground when the construction worker is kneeling or standing (Haupt et al., 2019). Robotic arms are ergonomic tools for arms, designed to operate or use heavy tools weightlessly, the Esko Bionics Zero G arms can hold up to 19 kilograms and balance this weight. Robots enable the worker to maneuver the load safely and more accurately in all directions without injury or fatigue. The possible application of robotic arms in construction was investigated and it was found that they can be used to improve workers comfort and H&S through stabilising, bracing, and reducing the effort necessary to carry out repetitive construction activities (Haupt et al., 2019).

2.5 Sensors

Applying sensors in H&S is essential for real time monitoring of construction activities to ensure that structures are safe. Sensory technologies have been implemented to prevent accidents from occurring and workers from being injured due to collisions, through monitoring of the entire construction site. Sensors can be categorised as location based, vision based and wireless sensor networks as the numerous types of sensory based technologies are implemented to ensure H&S management in construction. Wireless sensor networks have been found to improve and facilitate the flow of information within the design team on construction sites (Haupt et al., 2019).

3. Research

3.1 Research Method and Sample Stratum

The quantitative research study entailed an online questionnaire survey. The sample included 70 potential respondents in the form of general contractor members of the East Cape Master Builders Association (ECMBA), and H&S practitioners, CMs, and CPMs in the Eastern Cape registered as candidate and professionals with the SACPCMP. The questionnaire consisted of eighteen questions – seventeen closed-ended, and one open-ended. Ten of the close-ended questions were Likert scale type questions, and seven were demographic related questions. 31 Responses were included in the data analysis, which entailed the computation of frequencies, and a measure of central tendency in the form of a mean score (MS), which equates to a response rate of 44.3%.

3.2 Results

Table 1 indicates the frequency at which H&S phenomena occurred on the respondents' construction projects in terms of percentage responses to a range of never to constantly, and a MS with a minimum value of 1.00 and a maximum value of 5.00. MSs > 3.00 indicate that in general, respondents can be deemed to perceive that the frequency at which the H&S phenomena occur on their construction projects is frequent as opposed to infrequent, as in the case of MSs ≤ 3.00. It is notable that 2 / 8 (25.0%) of the MSs are > 3.00. 7 / 8 (87.5%) Phenomena have MSs > 2.60 to < 3.40, which indicates that the respondents can be deemed to perceive their frequency of occurrence to be between rarely to sometimes / sometimes – workers experience fatigue followed by onsite hazards, injuries, design-originated hazards encountered onsite, illnesses, ineffective training, and difficulty in monitoring H&S onsite. The MS of fatalities is ≥ 1.00 to ≤ 1.80, which indicates that they occur between never to rarely.

Table 20. Frequency of H&S phenomena occurring on construction projects

Phenomenon	Response (%)						MS	Rank
	Unsure	Never	Rarely	Sometimes	Often	Constantly		
Workers experience fatigue	3.2	0.0	12.9	48.4	29.0	6.5	3.30	1
Onsite hazards	0.0	3.2	9.7	51.6	25.8	9.7	3.29	2
Injuries	0.0	3.2	22.6	48.4	25.8	0.0	2.97	3
Design-originated hazards are encountered onsite	0.0	0.0	25.8	51.6	22.6	0.0	2.97	4
Illnesses	3.2	3.2	19.4	64.5	9.7	0.0	2.83	5
Ineffective H&S training	6.5	6.5	22.6	48.4	12.9	3.2	2.83	6
Difficulty in monitoring H&S onsite	6.5	6.5	32.3	45.2	9.7	0.0	2.62	7
Fatalities	3.2	51.6	38.7	3.2	3.2	0.0	1.57	8

Table 2 indicates the extent to which H&S-related processes need improvement in construction in terms of percentage responses to a range of 1 (minor) to 5 (major), and a MS with a minimum value of 1.00 and a maximum value of 5.00. It is notable that all the MSs > 3.00, which indicates that in general, respondents can be deemed to perceive that the extent to which the H&S-related processes need improvement in construction is major as opposed to minor, as in the case of MSs ≤ 3.00. 6 / 9 (66.7%) Processes have MSs > 3.40 to ≤ 4.20, which indicates that the respondents can be deemed to perceive the need for improvement of the H&S-related processes to be between some extent to a near major extent / near major extent - mitigation of injuries followed by reduction of design-originated hazards, mitigation of fatalities, automation of onsite activities, and monitoring H&S hazards. The MS of mitigation of illnesses, reduction of construction-originated hazards and H&S training is > 2.60 to ≤ 3.40, which indicates that respondents perceive that they need improvement in construction between a near minor extent to some extent / extent.

Table 2. Extent to which H&S related processes need improvement in construction

Process	Response (%)						MS	Rank
	Un-sure	Minor……………………..Major						
		1	2	3	4	5		
Mitigation of injuries	0.0	0.0	9.7	35.5	35.5	19.4	3.65	1
Reduction of design-originated hazards	0.0	0.0	9.7	41.9	32.3	16.1	3.55	2
Mitigation of fatalities	0.0	6.5	9.7	35.5	25.8	22.6	3.48	3
Automation of onsite activities	6.5	3.2	9.7	29.0	41.9	9.7	3.48	4
Monitoring H&S hazards onsite	0.0	0.0	9.7	45.2	38.7	6.5	3.42	5
Mitigation of illnesses	3.2	3.2	6.5	45.2	32.3	9.7	3.40	6
Reduction of workers' fatigue	6.5	3.2	3.2	32.3	41.9	12.9	3.39	7
Reduction of construction-originated hazards	3.2	0.0	12.9	41.9	35.5	6.5	3.37	8
H&S training	0.0	3.2	12.9	45.2	25.8	12.9	3.32	9

Table 3 indicates the potential of Industry 4.0 technologies to improve the H&S-related processes in construction in terms of percentage responses to a range of 1 (minor) to 5 (major), and a MS with a minimum value of 1.00, and a maximum value of 5.00. It is notable that all the MSs are > 3.00, which indicates that in general, respondents can be deemed to perceive that Industry 4.0 technologies have the potential to improve the H&S-related processes in construction to a major as opposed to a minor extent, as in the case of MSs ≤ 3.00. 4 / 9 (44.4%) Processes have MSs > 3.40 to ≤ 4.20, which indicates that the respondents can be deemed to perceive that the Industry 4.0 technologies have between some potential to near major potential / near major potential to improve H&S-related processes in construction - automation of onsite activities followed by H&S training, reduction of design-originated hazards, and monitoring H&S hazards onsite. 5 / 9 (55.6%) Processes have MSs > 2.60 to ≤ 3.40, which indicates that the respondents can be deemed to perceive that Industry 4.0 technologies have between near minor potential to some potential / some potential to improve the H&S-related processes in construction – fatigue experienced by workers followed by reduction of construction-originated hazards, and mitigation of fatalities, injuries, and illnesses.

Table 3. Potential of Industry 4.0 technologies to improve the H&S-related processes in construction

Process	Response (%)						MS	Rank
	Un-sure	Minor……………………..Major						
		1	2	3	4	5		
Automation of onsite activities	6.5	0.0	12.9	19.4	48.4	12.9	3.66	1
H&S training	3.2	0.0	6.5	45.2	35.5	9.7	3.50	2
Reduction of design-originated hazards	3.2	0.0	6.5	35.5	38.7	16.1	3.48	3
Monitoring H&S hazards onsite	0.0	0.0	9.7	48.4	25.8	16.1	3.48	4
Fatigue experienced by workers	6.5	3.2	12.9	32.3	41.9	3.2	3.31	5
Reduction of construction-originated hazards	9.7	0.0	16.1	54.8	6.5	12.9	3.18	6
Mitigation of fatalities	16.1	3.2	12.9	45.2	16.1	6.5	3.12	7
Mitigation of injuries	0.0	3.2	12.9	61.3	16.1	6.5	3.10	8
Mitigation of illnesses	3.2	9.7	9.7	54.8	16.1	6.5	3.00	9

Table 4 indicates the level of awareness or knowledge the respondents have of Industry 4.0 technologies in terms of percentage responses to a range of 1 (limited) to 5 (extensive), and a MS with a minimum value of 1.00 and maximum value of 5.00. MSs > 3.00 indicate that in general, the respondents can be deemed to perceive that their level of knowledge or awareness of Industry 4.0 technologies is extensive as opposed to limited, as in the case of MSs ≤ 3.00. It is notable that 3 / 6 (50.0%) of the MSs are > 3.00. The MS of BIM technology is > 3.40 to ≤ 4.20, which indicates that the respondents can be deemed to perceive that their level of awareness or knowledge of BIM is between average to above average / above average. 5 / 6 (83.3%) Industry 4.0 technologies have MSs > 2.60 to ≤ 3.40, which indicates that the respondents can be deemed to perceive their level of awareness or knowledge of Industry 4.0 technologies to be between below average to average / average – automation followed by drones, VR, wearable technology / sensors, and robotics.

Table 4. Respondents' level of awareness or knowledge of Industry 4.0 technologies

Technology	Response (%)						MS	Rank
	Un-sure	Limited…………………Extensive						
		1	2	3	4	5		
BIM	6.5	3.2	6.5	35.5	41.9	6.5	3.45	1
Automation	6.5	9.7	3.2	41.9	32.3	6.5	3.24	2
Drones	0.0	6.5	3.2	54.8	32.3	3.2	3.23	3
Virtual reality	6.5	6.5	16.1	51.6	12.9	6.5	2.97	4
Wearable technology / sensors	0.0	9.7	29.0	38.7	12.9	9.7	2.84	5
Robotics	6.5	16.1	22.6	48.4	6.5	0.0	2.48	6

Respondents were requested to indicate the potential impact Industry 4.0 will have in terms of improving H&S in construction in terms of percentage responses to a range of 1 (minor) to 5 (major). Given that the resultant MS of 3.41 is > 3.40 to ≤ 4.20, the respondents can be deemed to perceive that Industry 4.0 has between some potential to near major potential / near major potential to improve H&S in construction.

Table 5 indicates the potential of drones in terms of improving H&S-related processes in terms of percentage responses to a range of 1 (minor) to 5 (major), and a MS with a minimum value of 1.00 and a maximum value of 5.00. MSs > 3.00 indicate that in general, respondents can be deemed to perceive that the potential of drones to improve the H&S-related processes is major as opposed to minor, as in the case of MSs ≤ 3.00. It is notable that 2 / 3 (66.7%) of the MSs are > 3.00. The MS of identifying H&S hazards is > 3.40 to ≤ 4.20, which indicates that drones have between some potential to near major potential / near major potential to identify H&S hazards. The other 2 / 3 (66.7%) processes have MSs > 2.60 to ≤ 3.40, which indicates that the respondents can be deemed to perceive that drones have between near minor potential to some potential / some potential to improve H&S related processes – monitoring H&S hazards in construction, followed by reducing H&S design-originated hazards.

Table 5. Potential of drones to improve H&S-related processes

Process	Response (%)						MS	Rank
	Un-sure	Minor……………………..Major						
		1	2	3	4	5		
Identifying H&S hazards	6.5	3.2	0.0	35.5	35.5	19.4	3.72	1
Monitoring H&S hazards in construction	9.7	6.5	12.9	41.9	12.9	16.1	3.21	2
Reducing H&S design-originated hazards	3.2	12.9	22.6	45.2	12.9	3.2	2.70	3

Table 7 indicates the potential of BIM to improve aspects of H&S in terms of percentage responses to a range of 1 (minor) to 5 (major), and a MS with a minimum value of 1.00 and maximum value of 5.00. MSs > 3.00 indicate that in general, respondents can be deemed to perceive that the potential of BIM to improve the aspects of H&S is major as opposed to minor, as in the case of MSs ≤ 3.00. It is notable that all the MSs are > 3.00. 2 / 3 (66.7%) Aspects have MSs > 3.40 to ≤ 4.20, which indicates that the respondents can be deemed to perceive that BIM has between some potential to near major potential / near major potential to improve H&S – reducing H&S design-originated hazards followed by identifying H&S hazards. The MS of reduction of construction originated hazards is > 2.60 to ≤ 3.40, which indicates that BIM has between near minor potential to some potential / some potential to reduce construction originated hazards.

Table 6. Potential of BIM to improve aspects of H&S

Aspect	Response (%)						MS	Rank
	Un-sure	Minor……………………..Major						
		1	2	3	4	5		

Reducing H&S design-originated hazards	12.9	3.2	0.0	32.3	35.5	16.1	3.70	1
Identifying H&S hazards	9.7	3.2	6.5	45.2	19.4	16.1	3.43	2
Reduction of construction originated hazards	16.1	6.5	19.4	38.7	3.2	16.1	3.04	3

Respondents were requested to indicate the potential of VR to improve aspects of H&S training in terms of percentage responses to a range of 1 (minor) to 5 (major). The resultant MS of 3.63 is > 3.40 to ≤ 4.20, which indicates that the respondents can be deemed to perceive that VR has between some potential to near major potential / near major potential to improve aspects of H&S.

Table 7 indicates the potential of wearables and sensors to mitigate fatalities, injuries, and illnesses in terms of percentage responses to a range of 1 (minor) to 5 (major), and a MS with a minimum value of 1.00 and the maximum value of 5.00. MSs > 3.00 indicate that respondents can be deemed to perceive that the potential is major as opposed to minor, as in the case of MSs ≤ 3.00. It is notable that 2 / 3 (66.7%) of the MSs are > 3.00. All the impacts have MSs > 2.60 to ≤ 3.40, which indicates that the respondents can be deemed to perceive that wearables and sensors have between near minor potential to some potential / some potential mitigate fatalities, injuries, and illnesses.

Table 7. Potential of wearables and sensors to mitigate fatalities, injuries, and illnesses

Impact	Response (%)						MS	Rank
	Un-sure	Minor……………………..Major						
		1	2	3	4	5		
Mitigate fatalities	22.6	0.0	12.9	32.3	22.6	9.7	3.38	1
Mitigate injuries	6.5	3.2	16.1	45.2	25.8	3.2	3.10	2
Mitigate illnesses	9.7	3.2	19.4	48.4	19.4	0.0	2.93	3

Respondents were required to indicate the potential of robots and automation to reduce worker fatigue in terms of percentage responses to a range of 1 (minor) to 5 (major). Given that the MS of 3.83 is > 3.40 to ≤ 4.20, the respondents can be deemed to perceive that robots and automation have between some potential to near major / near major potential to reduce worker fatigue.

4. Discussion

The findings indicate that eight H&S-related phenomena are experienced on projects, and in the case of 25.0%, frequently as opposed to infrequently - workers experience fatigue, and onsite hazards predominate. The former is an issue frequently cited in the literature due to the physically demanding nature of the industry, long working hours, and weekend work. Robots and automation constitute interventions to mitigate the physically demanding nature of construction. Onsite hazards are a challenge as they introduce risk, and are the gateway for injuries, fatalities, and illness. Constant monitoring of the workplace in terms of identifying hazards and risk is challenging, however, drones can facilitate such monitoring, including accessing areas that are physically difficult to reach. Injuries, and design-originated hazards are encountered onsite follow, both of which have MSs of 2.97. The mitigation of injuries, fatalities, and illnesses are largely dependent upon the mitigation of hazards. The reduction of design-originated hazards is dependent upon 'designing for H&S' interventions, however, it can be facilitated using BIM. Ineffective H&S training can be remedied through the use of VR due to the trainees experiencing immersion, and involvement. The difficulty in monitoring H&S onsite can be remedied by the deployment of drones.

The extent to which nine H&S-related processes need improvement in construction is major as opposed to minor. As stated above, the mitigation of injuries, fatalities, and illnesses are largely dependent upon the mitigation of hazards. The reduction of design-originated hazards has been discussed above. The reduction of construction-originated hazards is dependent upon a range of interventions, however, it can be facilitated by the use of drones for monitoring. Automation of onsite activities has a role to play in the reduction of construction-originated hazards, and along with the deployment of robots, the reduction of workers' fatigue. The role of VR in enhancing the delivery of H&S training is addressed above.

The automation of onsite activities, H&S training, reduction of design-originated hazards, and monitoring H&S hazards onsite, predominate in terms of the potential of nine Industry 4.0 technologies to improve the H&S-related processes in construction, followed by fatigue experienced by workers, reduction of construction-originated hazards, and the mitigation of fatalities, injuries, and illnesses. These findings reinforce the potential of Industry 4.0 technologies to mitigate the occurrence of eight H&S-related phenomena on projects, and to contribute to improving nine H&S-related processes.

The respondents' level of awareness or knowledge is above average relative to three, and below average relative to a further three Industry 4.0 technologies is notable. Despite this, respondents identified the potential impact Industry 4.0 will have in terms of improving H&S, the potential of drones to improve H&S-related processes, the potential of BIM to improve aspects of H&S, the potential of VR to improve aspects of H&S training, the potential of wearables and sensors to mitigate fatalities, injuries, and illnesses, and the potential of robots and automation to reduce worker fatigue. However, the level of awareness or knowledge is notable due to the origination of Industry 4.0 in German manufacturing in 2011, and the coining of the term in 2016 by Klaus Schwab, founder, and executive chairman of the World Economic Forum (WEF).

Although the findings are not novel, and underscore the international findings reported on in the literature, they do provide a snapshot of the status quo in a province in South Africa.

5. Conclusions

Given the frequency at which H&S phenomena occurred on respondents' construction projects, it can be concluded that the respondents' experience the majority of these phenomena on their construction projects. In conclusion improvement is required, and there is a need for Industry 4.0 implementation. Given the extent of the need for improvement of H&S processes in construction, it can be concluded that the perceptions of the respondents reflect the general experience in construction in South Africa, which amplifies the need to implement Industry 4.0 technologies.

Given the respondents' level of awareness or knowledge of Industry 4.0 technologies it can be concluded that there is a need for an increase in the level of awareness through education by tertiary education programmes, and to integrate these technologies into construction training. Given the potential of Industry 4.0 technologies to improve H&S processes in construction it can be concluded that there is a need for the implementation of Industry 4.0 in construction.

Given the potential of drones to improve H&S processes, it can be concluded that the implementation of drone technology has the potential to improve several H&S processes in terms of identifying H&S hazards, monitoring H&S hazards in construction, and reducing H&S design-originated hazards. Given the potential of BIM to improve aspects of H&S in terms of reducing H&S in terms of reducing H&S design-originated hazards, identifying H&S hazards and reducing of construction originated hazards, it can be concluded that there is a need for the implementation of Industry 4.0 related technologies.

Given that VR can improve aspects of H&S training, the potential of wearables / sensors to improve H&S-related processes in terms of mitigating fatalities, injuries, and illnesses, and that robots and automation can reduce worker fatigue, it can be concluded that there is a need for the implementation of Industry 4.0 related technologies.

Given the size of the sample, and the geographical location of the study, the findings cannot be deemed to be representative, but indicative.

6. Recommendations

Recommendations include: the cidb should compile 'Industry 4.0 in Construction' guidelines; construction H&S-related training and tertiary education should address Industry 4.0 technologies, and various industry stakeholders should promote, and preferably deliver Industry 4.0-related construction H&S continuing professional development (CPD).

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Factors Influencing Selection of a Project Manager for Energy Retrofit Projects in Ghana

John Dadzie[1], Brookman Asare-Dadzie[2], Susan Djokoto[3]

[1&3] Department of Building Technology, Kumasi Technical University, Kumasi, Ghana
[2]Managing Director, AMS And Sons Ltd, Kumasi, Ghana

eeedadzie@gmail.com

Abstract
Project management is a complex process that requires commitment, strong will and teamwork to ensure success in terms of cost, time, quality, safety and client satisfaction. The concept of green renovation is new as actions to reduce CO_2 continue to capture the attention of the world. The main aim of the study is to align the concept of green renovation to the selection of competent project managers/consultants. A survey of selected district assemblies in Ghana was undertaken. The nature of green renovation influenced the selection of the district as those with no records of such renovations were not included. District assemblies are motivated to select project managers with adequate working experience and knowledge of sustainable technologies. The results indicate ability to work effectively in a team, evidence of adequate training and green renovation projects managed also influence selection of a project manager. The theory underpinning project management reinforces the results identified as challenges that hinder effective project delivery are addressed. The findings inform government decision to engage project managers for green renovation projects and provides literature for teaching and learning.

Keywords
Project Management, Project Manager, Green Renovation, Experience, sustainable technology, policy

1. Introduction
Green renovation is the process of using sustainable strategies and technologies to improve existing buildings and systems to deliver energy and CO_2 savings. Green renovation or sustainable upgrade generally applies to existing buildings, equipment or systems that present poor environmental outlook. The form of upgrade depends on cost of renovation, availability of technologies and technical skills to undertake renovations. The role of a project manager (PM) is critical to the delivery or execution of green renovations. Thus, a project managers' understanding of energy retrofit project contributes to improved project performance. Often, urgency of a project at hand, project duration, variations, political influence from higher authority, untimely decisions on the part of the consulting team and a lack of experience of the design team affect the performance of consultants (Dadzie et al., 2012).

Attitude and general personal characteristics of a project manager and success were linked by Ha and Tran (2018) and the role of project managers by Jazebi and Rashidi (2013). Sharma and Kumar (2018) highlighted enthusiasm, high self-esteem, political sensitivity, ability to delegate and evidence of capacity to mobilise as factors influencing selection of project managers. A successful project manager should be able to delegate, that is, allow subordinates to participate in decision making which is in tandem with effective project delivery. A project manager should be flexible, patient and persistent, with good communication skills, be a good planner with credible capabilities (Horvath, 2019). These factors in one way or the other ensure successful project delivery as the PM provides leadership (Sharma & Kumar, 2018). Kondalkar (2020) discussed the concept of organisational behaviour and relates that to the functions of a project manager. A client expects a project management team to deliver on time and within budget by supporting the functions of a builder. Technical understanding of all forms of construction including green renovation is therefore relevant to the success of a project manager. Clients are always looking for a consultant capable of meeting project timelines at a reasonable cost. To be successful as a project consultant requires strong commitment, capacity to work with different people and the ability to work effectively in a team (Sankaran et al., 2020).

A methodology for selecting project managers is studied and extensively reported in the literature. Jazebi and Rashidi (2013) developed an automated procedure for selecting project managers in construction firms. The model used 15 field data and fuzzy rules to develop a predictive model. Moradi et al. (2020) presented a competency model for the selection and performance improvement of project managers in collaborative construction projects using behavioural characteristics. Chaghooshi (2016) proposes the joint use of the Fuzzy DEMATEL (FDEMATEL) and Fuzzy VIKOR methods of a decision-making process for selecting the most suitable managers. The FDEMATEL method is used to prioritise the importance of various criteria and the FVIKOR is used to rank the alternatives in a preferred order to select the best project manager from several alternatives. Similarly, Çelikbilek (2018) proposes a Grey Analytic Hierarchy Process (G-AHP) for engineering and managerial problems with grey systems to make objective decisions. The results of the case study concluded with the effectiveness and applicability of the proposed G-AHP method for science, engineering and management. These methods are for the selection of a project manager, not providing detailed information of factors that influence selection, particularly for green renovation. The main aim of the study is to investigate factors influencing the selection of a project manager for green renovation projects. To date, the extent to which project managers are assessed with green related parameters to motivate selection is lacking. Many studies are aligned to the conventional construction approaches as the concept of green renovation is often not addressed. Identifying and investigating these factors, the concept of green renovation is reinforced and tied to reductions in CO_2 emissions.

2. Settings and Methods

2.1 Theoretical framework

PMBOK® defines a project as a temporary endeavor to create a unique product, service, or result. Levy (2018) defines project management as "application of knowledge, skills, tools and techniques to meet project requirements". Project management is accomplished through the application and integration of concepts such as project initiation, planning, executing, monitoring and controlling and closing. It is the process of planning, directing and controlling resources to ensure high level of project performance which is normally expressed in terms of time, cost, quality and stakeholder satisfaction (Meredith, 2020).

Factors that influence selection of a project manager

The role of a project manager is distinct from that of a functional manager or operations manager. Typically, a functional manager focuses on providing management oversight for a function or business unit. Operations managers are responsible for ensuring that business operations are efficient. A project manager is a person assigned to lead a team that is responsible for achieving a set of project objectives. The selection of project managers is linked to basic requirements, experience, education, communication, computer and management skills and time management. Other factors include cost, resource, quality and project management skills, planning, interpersonal skills, decision making and team development (Afshari, 2017). A project manager must manage costs, time and resources and be able to plan and develop skills of a project team (Sadatrasool et al., 2016). Also, knowledge, legal skills, communication skills, social awareness, action management, financial management, and ability to identify risk affect decisions to select project managers (Sadatrasool et al., 2016). The authors added that effective human resource management, procurement skills, time management, quality design and control and technical impact selection of a project manager. Sharma and Kumar (2018) discussed factors that influence selection of a project manager to include enthusiasm, high self-esteem and political sensitivity. Although Sharma and Kumar (2018) sought to reinforce findings of earlier studies, ability to delegate, team management good communication skills were identified and included. The position of Sharma and Kumar (2018) is in line with that investigated by Sadatrasool et al. (2016). By proposing the joint use of the Fuzzy DEMATEL (FDEMATEL) and Fuzzy VIKOR methods, Chaghooshi et al. (2016) investigated many variables including site management capacity, technical level, level of leadership and personal qualities. Management capacity include project, program and portfolio orientation, health, security, safety and environment. Earlier studies by Dodangeh et al. (2014) and Sadeghi et al. (2014) applied various selection criterion in developing selection tools and models. They are basic requirement, project management skills, management and interpersonal skills. Sadeghi et al. (2014) relied on the competencies for project managers, records of past performance and behavioural parameters.

Wen et al. (2021) developed a new method that focuses on fuzzy multiple decision-making methods in civil engineering. The outcome of the study addresses the issue of high error in decision making, which is a very common phenomenon in the construction industry. The models were examined using a case study in a project-based organization for selecting the most suitable project construction manager. Education, planning, controlling, communication skills, experience etc., were used for the second round of a Delphi approach. The third round involves basic requirements, management skills, interpersonal skills and project management skills. Manaan et al. (2014) demonstrated a fuzzy-based method for assessing the performance level of a project manager (PM) at the construction phase of Mass Housing Building Projects (MHBPs). Seven competencies including knowledge of appropriate site layout techniques for repetitive construction works, dedication and knowledge of appropriate technology transfer were applied (Manaan et al. 2014).

Afshari (2018) showed that in small projects, a PM with strong communication skills is needed to maximize performance, whereas negotiation skills in medium projects and project management knowledge in large projects are the most critical. Gharouni and Noorzai (2021) propose a framework to determine the most appropriate project manager (PM) to enhance the performance of occupational groups (POGs) in large, medium and small road construction projects in warm regions. The occupational groups (OGs) in road projects were divided into three categories: workers, technicians, and engineers. Using the Pareto principle, 14 critical project manager competencies (PMCs) were extracted from a 70-item list developed by performing a comprehensive literature review. Two indexes were ranked in each size of road project using the analytic hierarchy process (AHP) technique.

Similarly, leaderships, technical skills, performance level and certification level for each project manager is a critical selection criterion (Keren et al., 2014). Other factors include computer knowledge, experience, age, education depth of the expertise, extent of comprehensive knowledge and management knowledge (Afshari & Kowal, 2017). Leadership, communication, staffing, decision making, character, psychology, physiology influence project manager selection (Afshari & Kowal, 2017). Luţaş et al. (2020) identified the profile of an ideal project manager by presenting an overview of studies regarding the profile of a good project manager. In that regard, the authors analysed the perceptions of organisations' managers and HR specialists. The empirical research provides evidence that persons involved in project managers' selection perceive the value of education, certification, experience or soft skills differently, based on their professional role. Secondly, it shows that project management certifications are relevant for project managers' selection and are much appreciated around the world. Although each project requires specific skills and competencies of a project manager, the research ascertains a preferred profile based on the perception of over one hundred respondents, involved in the selection process. Mohammadi et al. (2014) developed an approach in the form of a hybrid Quality Function Deployment (QFD) and Cybernetic Analytic Network Process (CANP) model for project manager selection. This involves the use of QFD to translate the owner's project management expectations into selection criteria and the CANP to examine the expectations and selection criteria. The research involves the development of 18 selection features in response to the owner's three main expectations of time, cost and quality. Other factors include experience, academic achievement, communication skills, Microsoft Project Software experience and planning skills were the selection criteria adopted and applied to develop the model. The survey of literature shows that planning, project initiation skills, implementation and closeout are important in the selection of a project consultant (Moradi et al, 2021). Sang et al. (2018) studied the effects of project manager competency on green construction performance in China. The study identified the position of a project manager as an important factor determining the success of a project that is complex in nature. The authors argued that with the deterioration of the environment, green buildings present better environmental outlook compared to conventional buildings. Green buildings encounter more complex problems during the construction process thus project managers are faced with greater challenges. A survey questionnaire was used to investigate the understanding of the importance of project manager skills. Structural equation modelling was applied and the results demonstrate leadership skills and emotional intelligence of project managers are important factors that affect green construction performance.

2.2 Research methodology

In line with the research questions, a quantitative approach is adopted to explore and discuss factors that influence selection of project managers for green renovation. The study is focused on projects that align to sustainable upgrade of existing buildings. District assemblies and regional coordinating professionals in Ghana are the main respondents. A five-point Likert scale was used to understand factors that affect selection of PMs for sustainable upgrade projects. The respondents were asked to rate the items in relation to the degree of agreement or importance as 1=strongly disagree; 2=disagree; 3=neutral;4=agree;5=strongly agree. A pilot survey of experts to test the variables for suitability as the concept of green renovation is new to many professionals. A total of 15 professionals were engaged online during the pilot stage of the study. Specific modifications to the variables were proposed that helped to restructure the survey for distribution. Thereafter, potential respondents were identified through personal contacts or referrals from staff of the district assemblies. The survey was sent to 182 professionals at the district and regional assembly level with adequate knowledge and understanding of green renovation. Those with no clear insight of the concept of sustainability and related impact of green renovation on the environment were excluded. Also, poorly answered survey questionnaires were rejected. The survey covered a period of 3 months as attempts to improve the initial response contributed to extension of the survey. The last month served as a mop-up to encourage professionals to participate. Within the first month, 25 professionals had responded, this was improved in the subsequent months. Overall, 55 professionals responded, providing a response rate of 30.2%. The mean and standard deviation as applied in this study are consistent with similar studies related to environment and energy efficiency.

$$Mean = \frac{\sum_{i-1}^{5} W_i . X_i}{\sum_{i-1}^{5} X_i}$$

where: i – responses category of a Likert scale – 1,2, 3, 4, 5. W_i – is the weight assigned to i^th^ response – (5 is Strongly agree, 4 for agree, 3 for neutral, 2 is disagree, 1 for strongly disagree); and X_i – frequency of the i^th^ response. The Chi-squared test for the study is given by:

$X^2 = \sum \frac{(O_i - E_i)^2}{E_i}$, Where X^2= Chi-squared, O_i = observed value, E_i =expected value

3. Results

Calculated means provide the descriptive analysis of the study for detailed and further analysis, based on the maximum and minimum values. The standard deviation estimates become relevant as that forms basis for ranking of similar means.

3. 1 Factors influencing selection of project managers for green renovation

Table 1 presents the overall results of the study on the factors that influence selection of PMs for energy retrofit projects. The Table presents the factors, mean, standard deviation, variance, rank, p-value and the hypothesis.

Table 21. Factors influencing selection of project managers for green renovation

S/N	Factors	Mean	SD	variance	Rank	p-value	Decision
1	Academic Qualification	4.88	0.853	0.7276	1	0.002	Reject
2	Working experience	4.44	0.769	0.5914	4	0.001	Reject
3	Relationship with clients	3.94	0.667	0.4449	13	0.000	Reject
4	Human relations	3.52	0.718	0.5155	21	0.000	Reject
5	Conflict management skills	3.72	0.832	0.6922	17	0.000	Reject
6	Work effectively in a team	4.24	0.891	0.7939	8	0.000	Reject
7	History of delays	4.18	0.946	0.8949	10	0.000	Reject
8	History of payment	3.85	0.862	0.743	14	0.063	Accept
9	Records of cost overrun	3.45	0.684	0.4679	22	0.000	Reject
10	Availability of funds	3.36	0.734	0.5388	23	0.000	Reject
11	Safety records	4.01	0.647	0.4186	12	0.144	Accept
12	Green renovation projects managed	4.75	0.854	0.7293	2	0.000	Reject

13	Green certified/NABERS	3.56	0.733	0.5373	20	0.000	Reject
14	Interest in continuous green training	3.65	0.688	0.4733	19	0.000	Reject
15	Energy and Co2 emission savings	3.70	0.721	0.5198	18	0.000	Reject
16	Cleaner construction records	4.23	0.869	0.7552	9	0.070	Accept
17	Size of green renovation project	4.56	0.987	0.9742	3	0.000	Reject
18	Understanding of green renovation	4.36	0.88	0.7744	6	0.000	Reject
19	Experience of workers	3.02	0.897	0.8046	24	0.000	Reject
20	Type of technologies involved	3.74	0.875	0.7656	16	0.000	Reject
21	Quantity of technologies involved	3.81	0.779	0.6068	15	0.311	Accept
22	Location of project	4.25	0.722	0.5213	7	0.000	Reject
23	Cost of project	4.09	0.86	0.7396	11	0.000	Reject
24	Project duration	4.41	0.786	0.6178	5	0.000	Reject

In all 24 factors were affirmed after the initial pilot study that identified over 30 variables. The pilot study reinforced the initial data by contributing to the rejection and modification of variables. Table 1 presents the factors that influence the selection of project managers or consultants. Academic qualification (mean = 4.88), green renovation projects managed (mean = 4.75), size of new green renovation project (mean = 4.56), working experience (mean = 4.44), project duration (mean = 4.41), understanding of green renovation (mean = 4.36), project location (mean = 4.25), work effectively in a team (mean = 4.24), cleaner construction records (mean = 4.23) and history of delays (mean = 4.18) ranked from 1st to 10th in that order. Least ranked factors include quantity of technologies involved (mean = 3.81), type of technologies (mean = 3.74), green certification (mean = 3.56), availability of funds (mean = 3.36) and experience of workers (mean = 3.02). Chi-square test results confirm the rejection of the null hypotheses that the factors do not affect selection of project managers for green renovation projects. Table 1 shows that for each of the independent variables $X^2est>X^2\beta$ at $p<0.05$. This implies that the factors do affect selection of project managers hence rejection of the null hypothesis. There is a strong statistical relationship between the variables and selection of project managers.

4. Discussion

The academic qualification provides detailed information about the level or expertise of project managers. According to the results the Ministry of Local Government is interested in the training and academic background of experts. To be successful at the expression of interest stage of a tender process, a consultant or project manager should present required and expected qualifications. Project managers without the appropriate qualification tend to perform poorly thereby negatively impacting the project in terms of cost, quality and safety. Critical verification of training and other forms of training in line with construction management ensure that delays and project failures are avoided (Alvarenga et al., 2019). The concept of green renovation makes the issue of academic qualification important as it is a unique area, new and relates closely with CO_2 emissions. The results agree with Creasy and Anantatmula (2016) in a study that indicates personal traits have a relationship with project success. The uniqueness of green renovation makes it necessary to have evidence of past projects managed and the level of success achieved. Having the qualification does not guarantee selection, however being able to present details of green renovation managed in the past presents a positive outlook. Clients are interested in the number of green renovation projects managed and the success rate. The local government officers consider a project manager or consultant qualified by looking at the nature of energy retrofit projects undertaken, records of systems adopted and the energy savings obtained. Given the technologies adopted and the volume of works executed, clients are presented with the necessary data to aid decision making processes. The results indicate the size of green renovation as a factor that motivates selection of project managers. Identifying size of projects handled provide basis to connect experience gained to a new project. New projects are complex particularly energy conservation renovation projects, thus the size also relates to experiences and selection decisions (Hadad et al., 2013). For example, a project manager with no experience of pumps, motors, cooling systems, cooling tower systems retrofit may not be able to handle similar projects.

5. Conclusions

Past studies on project manager selection are focused on conventional buildings, with little knowledge on the concept of green renovation. Indeed, the literature presents little information on the factors that influence selection of project managers for green renovation. The main aim of the study is to investigate factors influencing selection of project managers for energy conservation refurbishments. The literature review provided secondary data of various factors although there is little information on energy retrofit and selection of project managers. A survey design in the structure of a questionnaire ensured factors that influence selection of consultants are identified and investigated. As presented in Table 1, the main factors include academic qualification, green renovation projects managed, size of green renovation project, working experience, project duration, understanding of green renovation and project location. The study is limited to a developing economy thus future studies can focus on expanding the variables. The findings fill the gap in the literature and provide data for the selection of project managers. Policy makers are provided with a tool to follow in relation to appointment of project managers or consultants for green renovation projects.

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An Assessment of Trade Unions in the South African Architecture, Engineering and Construction Industry

Olusegun Aanuoluwapo Oguntona[1], Clinton Aigbavboa[2], and Mogale Mpotwane[2]

[1] Department of Built Environment, Walter Sisulu University, Butterworth, South Africa
[2] cidb Centre of Excellence, University of Johannesburg, South Africa
architectoguntona12@gmail.com ooguntona@wsu.ac.za

Abstract

The Architecture, Engineering and Construction (AEC) industry is known to be one of the largest employers of labour globally. The diverse and multi-faceted characteristics of the industry ensure it caters for the employment of both skilled and unskilled workers. However, the unfavourable working environment and conditions, exploitation of labour, and poor welfare of the workers are a few of the ills associated with the AEC industry. Hence, the establishment and proliferation of trade unions for mitigating the numerous challenges facing construction workers. This paper aims to assess the state of trade unions in the AEC sector using South Africa as a case study. A questionnaire survey was used to obtain the required data for this research study. The respondents were quantity surveyors, site engineers, foremen, safety officers, and quality control officers who are actively affiliated with a trade union in South Africa. A quantitative approach to data analysis was employed. The results revealed the major factors responsible for the establishment of trade unions in the South African AEC industry. Poor impact on project performance, intimidation of striking workers, disturbance of project process, organizational conflict and drag in negotiations are identified in the study as the major adverse impacts of trade unions in the AEC industry. The results revealed securing better wages, improved fringe benefits, improved workplace safety measures, prompt management responsiveness to employees, and improved health and safety of employees are the major benefits of trade unions in the AEC industry. It is believed that the presence of a versatile and effective trade union will optimize productivity and create a safe workplace culture in the built environment.

Keywords

Built Environment, Construction Industry, Construction Workers, Health and Safety, Labour Unions, South Africa, Sustainability.

1. Introduction

Globally, the Architecture, Engineering and Construction (AEC) industry is significantly relied upon to enhance the quality of human life. According to Roodman and Lensen (1994), one-tenth of the world economy is concentrated on the preparation, construction, operation and maintenance of buildings and structures. In South Africa, the AEC industry aids employment generation and grows the economy (Oyewobi et al., 2015). It plays a major role in the implementation of small to mega commercial, residential, hospitality, leisure, industrial, energy, transportation, and water infrastructural projects (Adamu et al., 2015). In developed and developing countries, the AEC sector has become one of the important sectors for optimizing economic, social and environmental development. Despite the numerous opportunities that the AEC industry presents, there is an equal proportion of challenges manifested in different forms by the sector. The capability to meet these challenges, therefore, remain paramount to ensuring a safe, conducive and productive work environment in the AEC industry.

A major challenge hindering the growth and sustainable development of the AEC industry relates to the safety and welfare of construction employees (skilled and unskilled). Despite the government's increased investments in the AEC industry, the growth had not been complemented by a fair upscale in compensation, remuneration and welfare of workers (Mabugu & Mohamed, 2008). The industry is still faced with challenges of poor remuneration and compensation, growing inequality, unfairness to workers, substandard workers' welfare, injuries and death. The resultant effect of these challenges is largely responsible for the underperformance and negative impacts of the sector.

Mohamed and Motinga (2002) observed that the increased preference for subcontracting systems in the execution of construction projects has resulted in numerous firms that minimize costs, lower work standards and disregard workers' welfare, health and safety. Most contractors often weaken labour rights in their business operations, especially in a competitive sector like the AEC industry where the focus is usually concentrated on profit (Mayhew et al., 1997). Delays in salaries and poor remunerations, lengthy working hours, and poor welfare of workers are a few factors that characterized the operations of these contracting firms as employees are afraid to complain due to the fear of job loss. According to Okafor (2007), construction firms engages workers on casual and short-term contracts to remain competitive and maximize profit. Multinationals and local construction firms are known to exploit their employees in their bid to maximize profit. For example, thousands of migrant workers engaged in construction sites in Qatar have died since the nation got awarded the right to host the world cup (Erfani, 2015). Hence, the justification for the establishment of trade unions to promote and protect the rights and privileges of skilled and unskilled workers in the different sectors of the economy. To this end, this study is aimed at assessing the state of trade unions in the AEC industry using South Africa as a case study. The first part of this paper introduces the paper, followed by a literature review on the overview and concept of trade unions. The research methodological framework of the study is discussed, followed by the presentation of results and discussions and lastly drawing conclusions and recommendations for the study.

2. Overview and Concepts of Trade Unions

According to Bendix (2010), the labour relations system that is operational in a particular society is a direct product and structure of that society. This means that a system, organization, region or nation where inequality, injustice and discrimination are endemic will explicitly reflect the same in its labour relations. In South Africa, the issue of massive social, economic and political inequality that characterized the apartheid system is also identified in the present labour market. The study of Venter and Levy (2014) posited that the many ills of the apartheid system of governance in South Africa manifested for the greater part of the twentieth century. Therefore, the history and development of employment relations in every nation are unique (Nel et al., 2005), and inherent to their history and system of government. The manifestation of systemic racial divisions, inequalities, unfair salaries and remunerations, unprotected and precarious employment conditions, cheap labour and exploitation, coercion, and repression amongst others, in the labour market, necessitated the emergence of trade unions.

Trade unions are described as an organization of workers who collectively seek to promote and protect their mutual interests through the tool of collective bargaining (Gupta, 2013). As explained by Bendix (2010), trade unions are a continuous alliance of wage earners for the objective of improving or maintaining their working conditions. Trade unions represent the interest of their members (employees) while their prescribed membership dues or affiliation fees are payable to help in running, supporting and promoting the roles and objectives of the union (Crounch, 2017). Since its inception, the roles of trade unions have become broad to fulfil their mandate. These are regulatory, service, capacity development, social welfare, and political roles.

Trade unions have spearheaded the clamour for the social welfare of the underrepresented members of society such as the elderly and disabled persons (Black, 2018). According to Wood and Glaister (2008), trade unions deploy their resources and manpower to influence political decisions in their favour. Due to their roles in enhancing members' potential, trade unions create platforms for their members' capacity development and growth by offering leadership opportunities, training, and relevant information dissemination (Bagilhole, 1997; Bezuidenhout, 2000). Trade unions are also providing services to their members and the public through their banks, insurance, pension and housing schemes, provision of soft loans, cooperative and thrift organizations, and other non-traditional outlets (Webster & Buhlungu, 2004; Bhorat et al., 2014). As Freeman (2005) indicated, trade unions influence the establishment, regulation, and implementation of workplace norms. As part of a completed research study that evaluates the impact of trade unions in the South African AEC industry, this paper presents the quantitative aspect of the study.

3. Research Methodological Framework

This study employed the quantitative research approach to evaluate the factors responsible for the establishment, pros and cons of trade unions in the South African AEC industry. Primary (structured questionnaire survey) and secondary (literature review) data were utilized to achieve the objectives of this study. The respondents for the study are purposively selected, active and duly registered workers who are affiliated with a trade union in the South African AEC industry. They are site engineers, foremen, safety officers, quantity surveyors and quality control officers. One hundred and sixty (160) structured questionnaires consisting of close-ended questions are administered (physically and using google forms) to the identified respondents with One hundred and one (101) responses received, representing a 63% response rate.

The development of the questionnaire was informed by the factors deduced from the literature review. The first part (Section A) of the questionnaire survey dealt with the demographic background of the respondents. The second part (Section B) contained questions on the respondent's level of agreement on the factors responsible for the establishment of trade unions in the South African AEC industry. The third part (Section C) contained questions on the respondent's perception of the adverse impacts of trade unions in the South African AEC industry. The last part (Section D) of the questionnaire sought to identify the potential benefits of trade unions in the South African AEC industry. The questions in sections B, C and D were based on a five-point Likert scale (strongly agree= 5, agree= 4, neutral= 3, Disagree= 2, strongly disagree= 1). The Statistical Package for Social Sciences (SPSS) version 22 software was used to analyze the retrieved data using the descriptive statistical tools. The mean and standard deviation values of the variables identified were then tabulated and presented for comparison and discussion. A Cronbach's alpha reliability test of the data collection instrument was done, and the result showed that the factors responsible for the establishment, negative impacts, and benefits of trade unions in the South African AEC industry have 0.960, 0.948 and 0.953 values respectively. These high values (above the reliability coefficient of 0.7 considered acceptable) showed that the items have relatively high internal consistency (Ursachi et al., 2015).

4. Results and Discussions

4.1 The demographic background of Respondents

For the educational qualification of the respondents, the findings revealed that 33% had matric (senior secondary school) certificates, 39% had diplomas, 13% had bachelor's degrees, 12% had honours degrees and only 3% had master's degrees. The majority of the respondents are male (68%) while 32% were females. This result aligns with the general knowledge that the AEC industry remains a male-dominated sector of the economy. The results further showed that quantity surveyors constituted 30%, foremen constituted 28%, quality control officers constituted 17%, safety officers constituted 13% and site engineers constituted 12%. The respondents with 1-5 years of work experience were 34%, those with 6-10 years were also 34% and those with 11 years and above were 32%.

4.2 Factors Responsible for the Establishment of Trade Unions in the Architecture, Engineering and Construction Industry

Table 1 presents the mean value of the nineteen (19) identified factors responsible for the establishment of trade unions in the South African AEC industry. The result showed that all the 19 factors evaluated by the respondents possess mean scores higher than 2.5 making the factors significant to the study according to Field (2013). The result established that the identified factors are deemed significant based on the respondent's level of agreement. From the Table, 'lack of representation on grievances', 'unfair treatment, 'lack of platform for self-expression', 'lack of counsel in disciplinary hearing', and 'discrimination' are the major factors identified as responsible for the establishment of trade unions in the South African AEC industry. Other identified factors by the respondents are 'poor job security', 'lack of fringe benefits', and 'poor participation of workers'. The findings from this study aligned with the position of Freeman and Rogers (1996), and Ratna and Kaur (2012) that lack of representation in dispute resolutions, employer reprisals, lack of worker's representative, poor welfare of workers amongst others necessitated the establishment of trade unions.

Table 1. Ranking of Factors Responsible for the Establishment of Trade Unions in the AEC Industry.

Factors	Mean ($\bar{x}$)	Standard Deviation (σX)	Rank (R)
Lack of representation on grievances	3.80	1.053	1
Unfair treatment	3.75	1.158	2
Lack of platform for self-expression	3.67	1.111	3
Lack of counsel in a disciplinary hearing	3.67	1.189	4
Discrimination	3.67	1.285	4

Poor job security	3.63	1.116	6
Lack of fringe benefits	3.59	1.129	7
Poor participation of workers	3.57	1.058	8
Fragmented forms of employment	3.56	1.247	9
Diminishing employer prerogative	3.56	1.104	9
Poor access to learning and skills acquisition	3.53	1.175	11
Poor employer-employee relationship	3.51	1.158	12
Low salaries	3.48	1.272	13
Lack of staff retention	3.47	1.149	14
Poor opportunities for advancement	3.40	1.261	15
Lack of pension plans	3.37	1.185	16
Poor input in job negotiation	3.34	1.147	17
Workplace health and safety concerns	3.30	1,326	18
Non -compliance with labour codes	3.15	1.345	19

3.2 Adverse Impacts of Trade Unions in the Architecture, Engineering and Construction Industry

Table 2 presents the mean value of the sixteen (16) identified variables on the negative impacts of trade unions in the South African AEC industry. The result showed that all the 16 negative impacts assessed by the respondents have mean values greater than 2.5. According to Field (2013), a mean score of 2.5 and more is an indication that a factor is significant to a study. Therefore, it can be established that the respondents agree that all the 16 identified factors are the negative impacts of trade unions in the South African AEC industry. The results further showed that the respondents considered 'poor impact on project performance', 'intimidation of striking workers', 'disturbance of project process', 'organizational conflict', and 'drag in negotiations' as the top five adverse impacts of trade unions in the South African AEC industry. Other major adverse impacts identified by the respondents are 'poor employer-employee relationship', 'loss of salary for striking employees', 'low standard of work', 'poor corporate image for construction firms', and 'vandalism and theft' amongst others. The results are in tandem with the position of other researchers on the negative impacts of trade unions (Memon et al., 2011; Murwirapachena & Sibanda, 2014; Bhorat et al., 2017).

Table 2. Ranking of Adverse Impacts of Trade Unions in the AEC Industry.

Adverse Impacts	Mean ($\bar{x}$)	Standard Deviation (σX)	Rank (R)
Poor impact on project performance	3.55	1.174	1
Intimidation of striking workers	3.55	1.287	1
Disturbance of project process	3.52	1.257	3
Organizational conflict	3.51	1.141	4
Drag in negotiations	3.43	1.309	5
Poor employer-employee relationship	3.41	1.254	6
Loss of salary for striking employees	3.33	1.237	7
Low standard of work	3.29	1.240	8
Poor corporate image for construction firms	3.18	1.315	9
Vandalism and theft	3.19	1.240	9
Possible loss of life	3.18	1.254	11
Accident and injuries	3.15	1.254	12
Employee dismissal	3.13	1.384	13
Loss of organizational investment	3.11	1.281	14
Retrenchment	3.08	1.340	15

Possible increase in crime rate	3.07	1.307	16

3.3 Benefits of Trade Unions in the Architecture, Engineering and Construction Industry

Table 3 presents the tabulated mean value ranking of each of the identified beneficial factors to reveal the respondent's level of agreement. The result indicated that all the 18 beneficial factors assessed by the respondents have mean values higher than 2.5 making the factors significant to the study according to Field (2013). The result established that the respondents agree that all the 18 identified factors are beneficial factors of trade unions in the South African AEC industry. Based on the results from the descriptive analysis and Table 3, the respondents considered 'secure better wages for employees', 'improved fringe benefits for employees', 'improved workplace safety measures', 'improved management responsiveness to employees', and 'improved health and safety of employees' are the five major benefits of trade unions in the South African AEC industry. Other beneficial factors that align with the respondent's agreement level are 'promote employee welfare condition', 'ensure equality', 'increase learning and skills acquisition', 'expand opportunities for promotion', and 'reduce discrimination' amongst others. The results are on par with the position of other researchers on the benefits of trade unions (Freeman & Medoff, 1984; Doucouliagos & Laroche, 2003; Hirsch, 2004).

Table 3. Ranking of Beneficial Factors of Trade Unions in the AEC Industry.

Benefits	Mean ($\bar{x}$)	Standard Deviation (σX)	Rank (R)
Secure better wages for employees	3.97	1.019	1
Improved fringe benefits for employees	3.90	0.990	2
Improved workplace safety measures	3.85	1.038	3
Improved management responsiveness to employees	3.84	1.012	4
Improved health and safety of employees	3.80	1.063	5
Promote employee welfare condition	3.79	1.018	6
Ensure equality	3.77	1.062	7
Increase learning and skills acquisition	3.75	1.029	8
Expand opportunities for promotion	3.72	1.102	9
Reduce discrimination	3.71	1.148	10
Improve transparent of management responsibilities	3.70	1.106	11
Provide job security	3.69	1.043	12
Provide legal advice and representation	3.64	1.088	13
Increase employee discipline	3.59	1.155	14
Improve employer-employee relationship	3.57	1.139	15
Increase economic development	3.56	1.255	16
Increase staff retention	3.48	1.158	17
Support poverty reduction	3.44	1.148	18

5. Conclusion and Recommendations

This research paper is aimed at assessing the state of trade unions in the South African AEC industry. To achieve the aim, factors responsible for the establishment of trade unions were examined. The pros and cons of trade unions were further assessed to understand their impacts. Based on the findings, it can be deduced that inequality, discrimination and repression remain inherent in the South African labour system. The majority of construction firms in the country are more focused on maximizing their profits at the expense of workers' welfare, work environment, health, and safety. It can be concluded that the attributes of the apartheid era still manifesting in the present post-apartheid regime coupled with the delicate nature of the AEC industry made it imperative for the establishment of trade unions. Without the presence of trade unions and their competitiveness, the fate of workers would have been sealed in the hands of their paymasters. Also, the presence of active trade unions in the South African AEC industry and other sectors of the economy has led to construction project delays, time and cost overruns, poor standard of work, conflicts, and a sour employer-employee relationship which are a few of the adverse impacts on the sector. However, the study revealed the beneficial dimension of trade unions in the South African AEC industry. These benefits can be categorized as workers-related, employer-related, government-related and people-related. The findings are further corroborated by research scholars. With better wages, fringe benefits, and proper workplace safety measures as the top benefits of trade unions, the resultant effect on the South African AEC industry will likewise be beneficial. Project delays, time and cost overruns, and poor quality of work due to workers downing tools and shutting down activities on construction sites will be minimized.

It is therefore recommended that the Department of Labour and other related agencies of government ensure the rights and welfare of workers are safeguarded. These agencies of government in collaboration with other stakeholders should ensure effective and efficient frameworks, policies and laws are enacted, adopted and implemented from time to time and as demanded. Anonymous avenues for reporting persons and organizations disregarding the labour laws should be put in place. Professional bodies, higher education institutions (HEIs), technical and vocational education and training (TVET) colleges and other relevant outlets are recommended to incorporate work and labour ethics into the training programmes of skilled and unskilled workers. This will ensure the workers are fully aware of the expectations of their prospective employers thereby reducing conflicts in the process of discharging their duties. A fair and unbiased avenue for dialogue and mediation which is acceptable and trusted by all stakeholders in the industry should be established to effectively address cases of disagreements and protests. It is believed that with the cooperation of all relevant stakeholders, especially the trade unions, the South African AEC industry will sail towards a truly sustainable path.

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Research Methods in Construction Robotics and Human-Robot Teams: - A Scientometric and Systematic Review

Adetayo Onososen[1], Innocent Musonda[2] and Molusiwa Ramabodu[3]

[1, 2] Center of Applied Research and Innovation in the Built Environment (CARINBE)
Department of Quantity Surveying and Construction Management
Faculty of Engineering and the Built Environment
[3] Department of Quantity Surveying and Construction Management
Faculty of Engineering and the Built Environment
Onososen@outlook.com

Abstract

In the emerging studies on construction robotics, discussions on methodological approaches are lacking. Despite the potential of robotics adoption in construction to enhance productivity and improve safety, debates regarding research methods have been identified as an underlying factor in limited output in the area. With limited studies and publication in the domain, a methodology review is needed to further develop knowledge in this area. Using a two-phased literature review adopting scientometric review and systematic literature review, the study reviews 112 Journal articles on the Construction robotics research domain and identified insights from the analysed publications. An overview of publications between 1987 and 2021 is presented, examining the topics and approaches researchers adopt most in construction robotics and human-robot teams. The findings offer insight into the popular methods and the need to adopt comprehensive methods specific to the nature of the research problem. The study's findings are vital to guiding subsequent studies in construction robotics on available methods, those frequently used and emerging approaches.

Keywords

Collaborative robots, Construction Robotics, Human-Robot teams, Research Methods, Scientiometric, Systematic Review

1. Introduction

Rate of fatalities and incidents occurring on Construction sites, inhibited productivity in the face of increasing infrastructure demands, ageing population of workers and shortage of skilled workers are challenges advancing the need to adopt innovative technologies in the built environment. Primary amongst these emerging technologies is the potential in the use of robotics and collaborative human-robot teams to improve dangerous aspects of construction in high-risk areas, enhance productivity, avail prompt and sustainable infrastructure delivery even during shock events such as pandemics and improve overall construction resilience, responsiveness, health and safety (Huang and Mao, 2021; Atkinson and Clark, 2014). This is further reiterated by Cai et al. (2020), stating that research and techniques in construction automation and robots have emerged to cut costs while also improving productivity, quality, and safety. Therefore, the argument for their favourable adoption is inevitable because traditional building methods have reached their limits in serving the construction industry's rising needs. A future technology disruption of construction automation and robotics' ubiquity has been projected (Bock 2015). Ergo, the use of robots has been promoted as one of the most promising methods for industry change (Pan et al., 2020a)

However, despite the gains of widely adopting these technologies, the advancement of research and development in construction robotics and the human-robot teams' domain is constrained by varying factors (Edwards et al., 2021). Among these factors is the dearth of studies on research methods in construction robotics and human-robot teams able to provide pathways and clarity on the approaches researchers adopt in solving construction robotics challenges. According to Agyekum-Mensah et al. (2020), there has been a current debate about the inappropriateness and dominance of quantitative data collection, regardless of the type and form of knowledge research, with academics disputing that the sampling procedure and mechanism is frequently inappropriate. This is further exacerbated with restriction of construction robotics research to selected approaches identified as resulting from lack of knowledge on the methods available and experimented by previous robotics researchers in the field of construction robotics and human-robot teams in the Architectural Engineering and Construction (AEC) sector. With construction research central to improving the effectiveness and efficiency necessary for practice, construction robotics research must be relevant and beneficial. A failure to adequately highlight research methods to advance research in informing development that resonates with workplace practices is unbeneficial to the built sector. Ergo, this study presents a review of research methods in construction robotics and human-robot teams vital to furthering research studies in this area through the integration of a Scientometric analysis and a systematic literature review

2. Methods

The current paper was developed using a four-research method, with the first stage involving the scientific search for publications, the second stage adopted the definition and application of exclusion criteria, the third stage integrated the development of a Scientometric analysis, and the fourth stage is the execution of a systematic literature review. The Scopus database was used as it is the largest database for scientific articles containing comprehensive publications (Abdullahi B. Saka & Chan, 2019). The keywords "Robotics" AND "Construction" were used to gather the most relevant publications associated with Construction Robotics. The document types were limited to Journal articles as they are considered more comprehensive, and all documents published in English only were selected(Cardoso et al., 2020). The initial query revealed 9971 documents which were further refined to 2082 documents related to the Construction domain. With the exclusion of other document types and refining of abstracts to remove redundant outputs, 112 publications were reviewed for this study as presented in Fig 1. The Scientometric analysis was limited to analytical queries related to the overarching objectives of the research. Thus, only the document citation and keyword co-occurrence network were highlighted from the study (Zabidin et al., 2020). The metric data was transferred from CSV to VOSViewer, which allows you to create bibliometric networks and execute analyses like this. The final and fourth phases involved identifying the primary themes and categories of information and dividing them into key subject categories, thus allowing the data to be presented systematically.

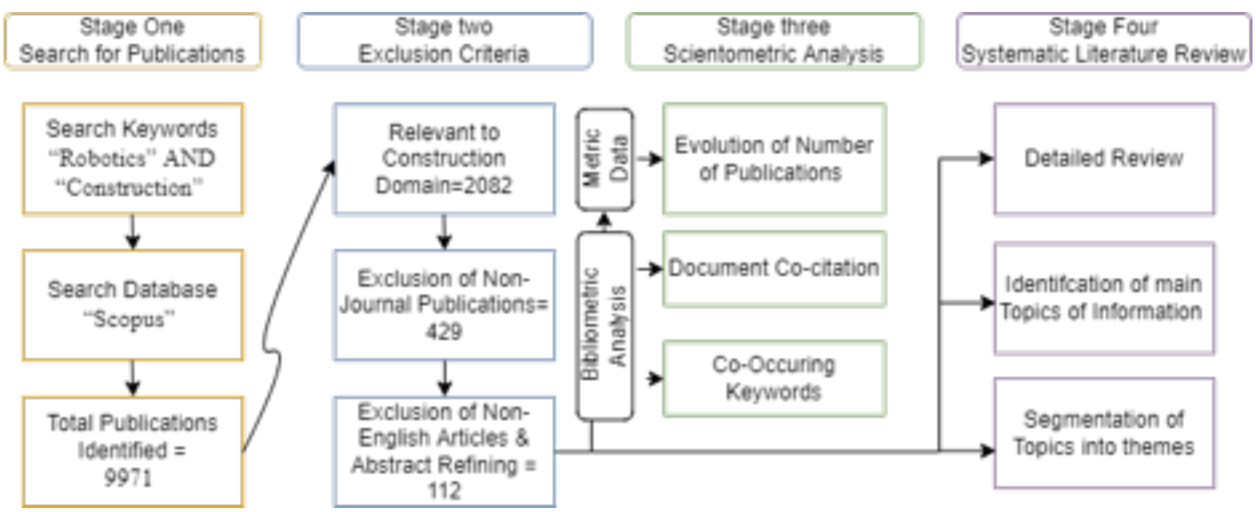

Fig 1. Research Method incorporating Scientometric Analysis and Systematic Literature Review

3. Results

3. 1 Evolution of Publications

The evolution of the number of publications on construction robotics was examined in the timeframe between the year 1987 and the year 2021 to comprehensively have a visual timeline of the inception of research in construction robotics till the present. The result reveals a steady increase in publications between 2016 and 2021, while the trend between 1987 and 2015 had been unsteady with intermittent highs and lows. The maximum number of publications was identified in 2021 with 43 publications. This corroborates the existing hypothesis that interest in construction robotics and collaborative robots is increasing. The high number of publications rising sharply between 2020 and 2021 could, amongst other factors, be due to shock events such as the COVID-19 pandemic necessitating alternative means of construction requiring minimal human interaction for sustainable infrastructure delivery in future shock events that might need humans to be off-site.

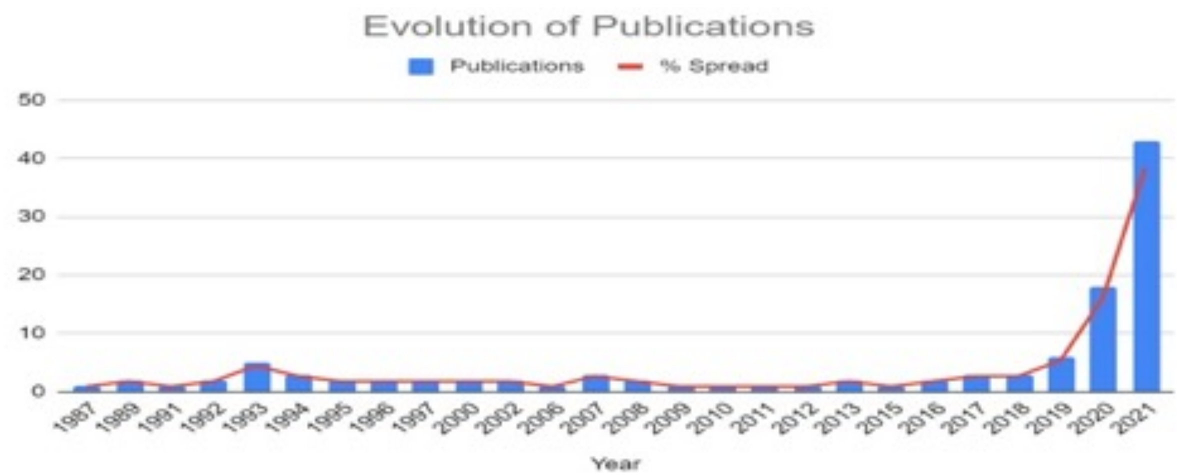

Fig 2. Evolution of Publications

3.2 Publication Outlets & Sources

The Publication sources revealed that Automation in Construction has the highest outcome in publishing articles on Construction robotics with 50 out of the 112 articles reviewed. Followed is the Journal of Construction Engineering and Management with 6 articles, the Journal of Building Engineering with 4 articles.

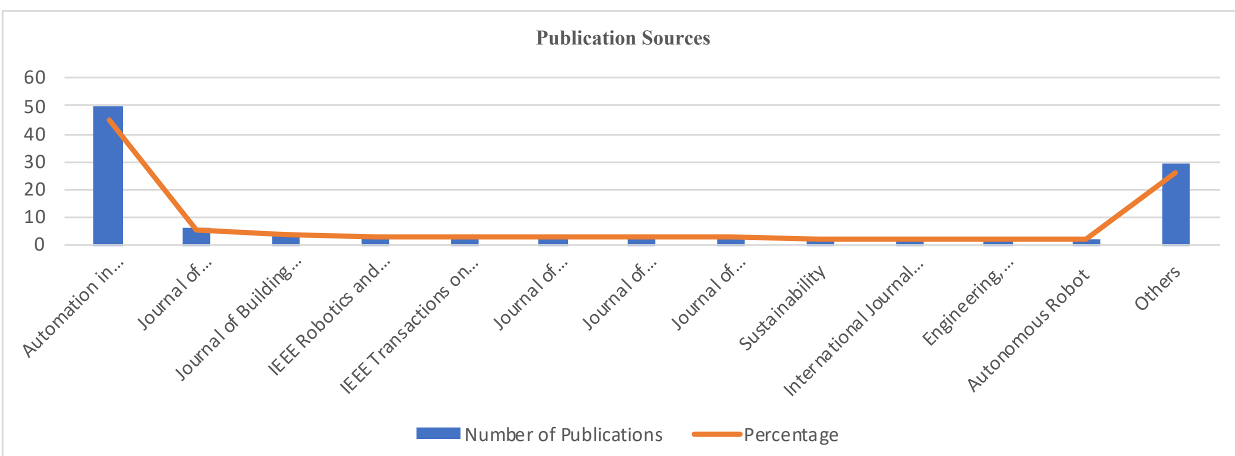

Fig 3. Publications Sources

The low amount of publications in all other Journals could be attributed to low turnout of Special Issues on Construction Robotics and Human-Robot Teams compared to more trendy topics such as "Building Information modelling" and "Sustainable development" The Journal with 3 articles were; Journal of Architectural Engineering, Journal of Information Technology in Construction, Journal of Management in Engineering, IEEE Robotics and Automation Letters, IEEE Transactions on Automation Science and Engineering. The Journals classified as others were those with single articles.

3.3 Most Cited Publications

The number of citations was also analysed and presented in Fig 4 below, Bock (2015) is the most cited publication, followed by Pan et al. (2020), Bogue, (2018) and Manuel et al. (2019), amongst other publications. Knowledge of the methods adopted by the most cited publications is essential to measuring the impact of the different approaches. While the most cited document, Bock (2015) adopted a review approach, an analysis of other most cited publications indicated the prominence of experimental and case study approaches. This is further validated by (Aghimien et al., 2020)

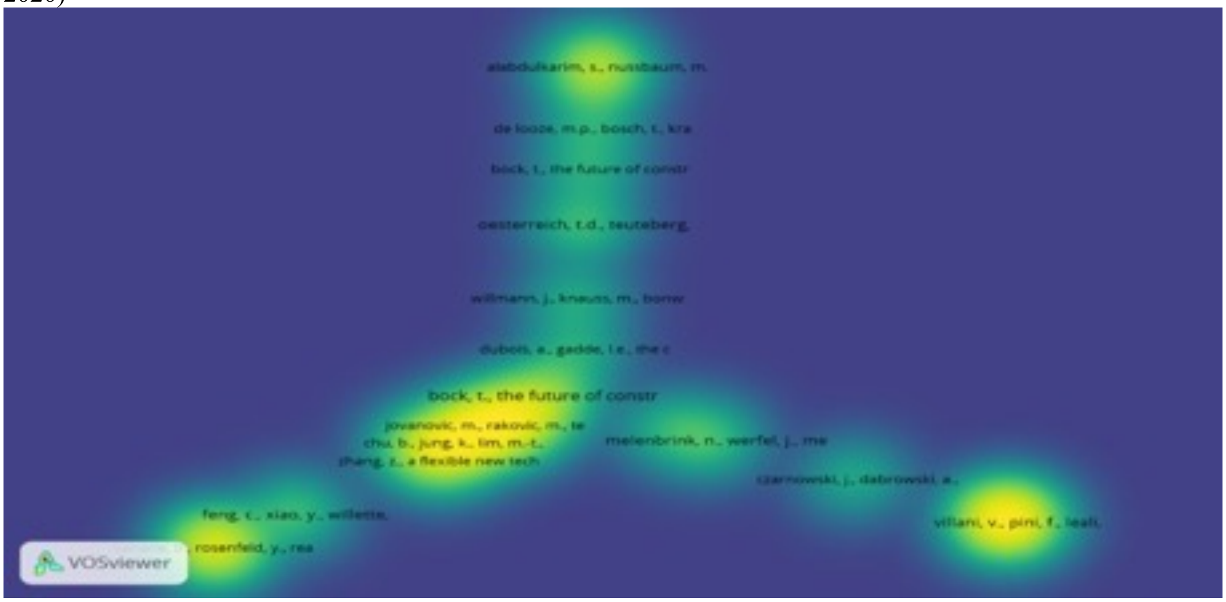

Fig 4. Most Cited publications

3.4 Co-Occurring Keywords

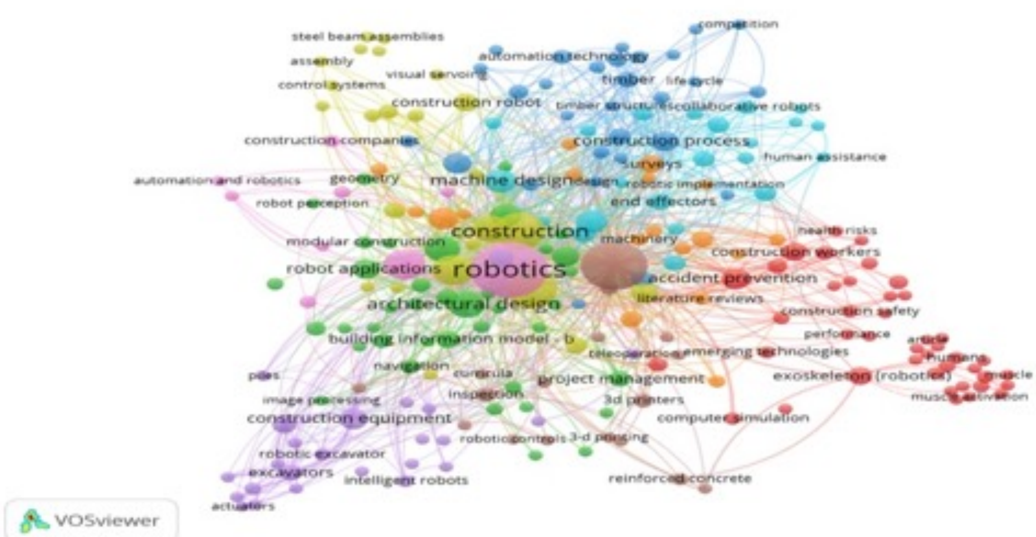

Fig 5. Co-occurring keywords

The map illustrates those keywords that occur frequently in the publications reviewed. The word robotics is the most commonly used author keyword in journals. The other keywords shown are; architectural design, accident and prevention, construction workers, collaborative robotics, intelligent robots, construction equipment, automation, computer simulation, etc. The appearance of construction workers, human assistance, collaborative robots reveals emerging discussion on the need to consider human factors research imperative to robotics adoptions in the AEC sector.

3.5 Comparison of Research Methods and No of Publications

In this section, key research methods were cross-tabulated with publications to identify the trends. The analysis reveals that quantitative methods were the most used research data approach in Construction robotics. Furthermore, most Journal publications also published articles with quantitative research methods. This is followed by review-based studies using systematic and Scientometric techniques to answer research questions and occurs more than the use of qualitative methods in the construction robotics research domain. The least considered research methods involve the use of mixed methods.

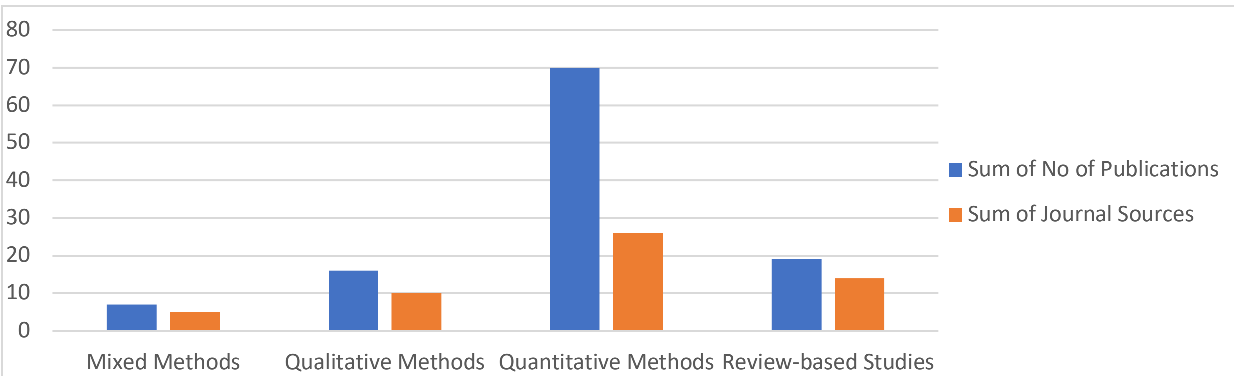

Fig 6. Pivot Chart cross tabulating research methods and number of publications.

3.6 Research Methods Adopted and Sub-Categories

This section brings together the methods associated with Construction robotics in the literature reviewed. While analysing this section, the key research approaches were grouped together and further discussed. The research methods were classified into four categories based on previous studies recommendations. The four categories were quantitative, qualitative, mixed, and review-based studies. The Quantitative methods had 63% of total publications with Surveys taking 4%, Experimental approaches taking 46%, Analytical techniques taking 13%, while qualitative methods took 14% of the total publications reviewed with Case studies having 8%, Interviews having 3%, Delphi Survey with 6%, focus group, and observations also with 6%. These were followed by Mixed Methods research taking 6% of total articles reviewed, while the review-based studies accounted for 17% of the 112 articles adopted for the two-phase reviews.

Table 22. Research Methods Adopted and Sub-Categories

Quantitative Methods	No of Publications	Percentage		Qualitative Methods	No of Publications	Percentage		Mixed Methods	No of Publications	Percentage		Review-based Studies	No of Publications	Percentage	
		α	β			α	β			α	β			α	β
Survey	4	6%	4%	Case Studies	10	63%	8%	Mixed Methods	7	100%	6%	Systematic /Scientometric	19	100%	17%
Experimental	52	74%	46%	Interviews	3	19%	3%								

Analytical	14	20%	13%	Delphi Survey	1	6%	1%								
				Focus Group	1	6%	1%								
				Observations	1	6%	1%								
Total	70	100%	63%		16	100%	14%		7	100%	6%		19	100%	17%

Note: **α represents the percentage spread of sub-groups under each research method. β represents the percentage spread of sub-groups to overall publication reviews**

4. Discussion

The study reviewed the research methods adopted in construction robotics using a two-phase literature review approach. The findings reveal the increasing interest in robotics research and its development, as highlighted in Fig 2. This is consistent with studies by (Bademosi & Issa, 2021; Aghimien et al., 2019; Bock, 2015). Also, as showcased in the study, automation in construction has the highest number of publications which was also revealed in (Aghimien et al., 2019). The decrease in publication across the other Journals has been attributed to a low commitment to advancing thematic research on robotics in the built environment. Bock (2015) is identified as the most cited researcher as also identified in Aghimien et al. (2019) while the keywords indicating most researched topics which also discusses the nature of the problem being examined are; architectural design, accident and prevention, construction workers, collaborative robotics, intelligent robots, construction equipment, automation, computer simulation etc

Categorising research methods was based on previous classifications validated by (Dainty, 2007) and (Agyekum-mensah et al., 2018) as Quantitative, Qualitative, Inductive and deductive research methodologies combined in mixed methods research and Review – based studies (literature reviews/Systematic/Bibliometric/Scientometric).

In comparing research methods and the number of publications, the study revealed that quantitative methods were the most used research data approach and most published by Journals, followed by the use of systematic and Scientometric ways to address research questions taking larger proportions than the use of qualitative methods in the construction robotics research domain. Mixed methods research is one of the least adopted research approaches.

Many domains have established techniques, especially pure sciences), but construction research draws from both natural and social sciences; therefore, many diverse paradigms struggle for methodological dominance, as stated by (Agyekum-mensah et al., 2018). The qualitative and quantitative techniques to data collection are the two basic extremes, though both can be used simultaneously. By examining the knowledge claims, tactics, and methods, researchers can determine whether they use a qualitative, quantitative, or mixed methodologies approach (Creswell, 2014). To advance practical and industry applicable solutions to robotics challenges, construction robotics researchers must begin to diversify their approach by not employing a single methodology to derive solutions but rather by replicating numerous research approaches based on the nature of the problem being examined. As revealed by the study, Quantitative methods had 63% of total publications, with Surveys taking 4%, experimental approaches taking 46%, and analytical approaches taking 13%, which validates the studies of Agyekum-mensah et al. (2020) and Dainty (2007) that quantitative approach was the most frequently used method. Virtual immersive environments are also increasingly helpful in human-robotics research as they can evoke psychological responses typical of case studies using robotics in practical usage on the construction site (Atkinson & Clark, 2014). As stated by Bernold & Lee (2010), the most effective way for examining the impact of any intervention on human performance is through group experiments. Experiments involving representative survey participants are necessary to provide generalisable conclusions. Furthermore, there are many advantages to testing in a controlled setting with large standardised equipment, but their relevance to reality in construction is lacking most of the time. (Bernold & Lee, 2010).

The use of VR and AR in built environment robotics research is valuable. It offers characteristics in which physical robot features and behaviour of interest interaction between robot and humans can be simulated to measure participants perception, disposition and attitudinal measures to the usage and adoption of robotics. A challenge to this method is inherent in skills and competencies to simulate and model the scenarios and the cost of procuring AR and VR systems for learning institutions, especially in developing economies. Also, qualitative methods took 14% of the total publications reviewed, with Case studies having 8%. Case studies are the driving force for robotics research in the built environment. They provide appropriate test cases to demonstrate the viability and feasibility of adopting robotics and ensure safety before interaction with humans on site. Atkinson & Clark (2014) stated that real-life scenarios of dangerous work tasks are imperative to providing a safe and effective performance of robots collaboration with humans, especially in unstructured environments such as construction sites. Furthermore, real-life scenarios offer an excellent opportunity to evaluate engineered robot capability and the possibility to provide needed aid during construction (Atkinson & Clark, 2014).

Interviews had 3% usage from the study, Delphi Survey with 6%, focus group, and observations also with 6%. User experience in the design of Human-Robot Interaction, as conducted by Prati et al. (2021), adopted user observation, focus groups, and interviews which are qualitative approaches and were demonstrated as the most common UX methodologies used to understand users perception. Because it allows users to be observed in their natural environment without impacting their usual behaviour and performance, user observations are frequently used for context analysis and preliminary user analysis. Focus groups and interviews, for example, allow users to participate more actively in gathering qualitative data about their needs, expectations, and fears in a variety of ways. Despite the low usage of Mixed Methods research taking 6% of total articles reviewed, mixed research methods are effective instruments for investigating complicated processes and systems in various fields. This technique can be beneficial to construction robotics research since qualitative results can help to support and guide the collection and analysis of quantitative data (Johnson & Onwuegbuzie 2004; Abowitz & Toole 2010). Brosque et al. (2020) is the first solution that uses physically correct simulations and real task data to allow robots to interact with construction site elements. This method was used to investigate the use of haptic interfaces for construction jobs and contribute to developing human-robot collaboration robots that can relieve workers of difficult and repetitive manual labour.

The review-based studies accounted for 17% of the 112 articles adopted for the two-phase review. Aghimien et al. (2019) adopted the bibliometric approach to map out the research focus of robotics in the built sector using the Scopus database, which has been identified as one of the major academic databases that cover scientific fields is frequently adopted by researchers. Tools adapted for bibliometric studies are VOS Viewers Gephi Survey (Golizadeh et al., 2019); while using other tools such as BibExcel, CiteSpace, CoPalRed, Sci2, VantagePoint is rare but has usage potentials for future studies depending on the objectives of the studies. VOS viewer has a high adoption rate in built environment research due to its strength in being freely sourced, ease of use, easily comprehensible results, while Gephi is also open source and Java-based has lesser usage compared to VOSviewer (Zabidin et al., 2020; Golizadeh et al., 2019; Abdullahi Babatunde Saka & Chan, 2019;)

In the built environment, research naturally attracts diverse disciplinary and methodological perspectives to solve problems. As Knight and Ruddock (2008) explain, this variety can at times necessitate the adoption of methods from the arts, sciences, and other disciplines to solve problems. Similarly, other studies have urged the use of different approaches; for example, Hallowell and Gambatese (2010) advocated for the use of Delphi, while Azhar et al. (2010) addresses 'action research,' both of which have not been widely used in construction robotics research. For bridging the gap between research and practice in construction safety, Zou et al. (2014) advocated for a mixed methodologies study design, while AlSehaimi et al. (2012) identified the 'need for different research approaches in construction management. Ergo, for Construction robotics research and collaborative teams, some scholars are beginning to consider the use of photos and videos elicitation for surveys, which shifts the locus of meaning away from empirically objective representations of objects or interactions, gaining significance from the way that participants engage the questions in the surveys. Therefore, studies on research methods are important in utilising a bridge between methodological perspectives and research. This is imperative in guiding further studies on approaches available for Construction robotics research which is essential in advancing research in construction robotics and human-robot teams

5. Conclusions

The study was conducted due to a lack of a two-phased review to deeply examine research methods in construction robotics as an emerging field in the AEC sector. It reveals the evolutions of publications, the components of research methods adopted, and the prominent approaches vital to construction robotics research. The findings offer insights into the adopted trendy approaches, the need to balance methods with the nature of problems addressed, and the novelty in adopting research methods from allied fields. Future research should be directed towards studying the limitations of these approaches, considering novel options to improve human-robot teams' research, and improving challenging areas to enhance robotics usage and collaboration in the built environment.

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ID 48

Evaluation of Atmospheric Exposure Test on Structural Steel and Hot-dip Galvanized Steel in the East of Thailand

Ugen Tashi Lhamo[1], Bunya Chea[2], and Taweep Chaisomphob[3]

[1] Graduate Student, School of Civil Engineering and Technology, Sirindhorn International Institute of Technology, Thammasat University, Thailand.
[2] Graduate Student, School of Civil Engineering and Technology, Sirindhorn International Institute of Technology, Thammasat University, Thailand
[3] Associate Professor, School of Civil Engineering and Technology, Sirindhorn International Institute of Technology, Thammasat University, Thailand
utlhamo455@gmail.com

Abstract

In today's civil engineering industry steel is one of the commonly used materials due to its versatility, high strength, and durability. However, it is highly susceptible to corrosion. Corrosion is the deterioration of steel and its critical properties due to the chemical reactions between the steel and the surrounding environment. Corrosion is unavoidable but it can be minimized by galvanizing and painting. The rate of corrosion depends on the coating and environmental conditions. This research aims to study the corrosion rate of two types of structural steel SS400 and SM490 for bare steel and Hot-dip galvanized steel, which is exposed at three locations at Chachoengsao, Rayong, and Chonburi in the Eastern part of Thailand. To determine the corrosion rate, and atmospheric exposure test is conducted. Following the ASTM G50, a test site is selected at each location and the specimens are exposed to the real environment for three months and six months, and so on. Weathering station at the test site collects and monitors environmental parameters. The exposed specimens are collected, cleaned and the data are gathered. The weight loss of the steel specimen's data is analyzed based on the ASTM standards. This analysis result shows the corrosion rate of both the bare steel and hot-dip galvanized steel, the changing appearance of steel specimen after three months and six months, and the importance of galvanizing. The result can be used for material selection and could contribute to the development of the steel corrosion manual of Thailand

Keywords

Steel corrosion, Atmospheric Corrosion Test, Structural Steel, Hot-dip Galvanized Steel, Corrosion Rate.

1. Introduction

Steel is one of the most used construction materials in the civil engineering industry. It is famous for its various properties such as strength, sustainability, and flexibility. It is also one of the most cost-effective materials and has high durability. However, steel's main shortcoming is, it is prone to corrosion. Corrosion is a natural process in which degradation of metal occurs due to the conversion of the metal to a more stable form. Corrosion of steel with or without corrosion protection is highly influenced by environmental factors. The environment has many factors which affect the rate of corrosion such as temperature, relative humidity, rainfall, presence of impurities, and presence of a suspended particle. The environment in different places differs from each other so the factors we consider for our research are different from others as well. As we know corrosion of steel cannot be avoided so the best thing, we can do to prevent corrosion is by minimizing the rate of corrosion by painting and galvanizing to improve the service life of the steel. Depending on the coating and environmental conditions, the corrosion rate varies as well. The rate of corrosion can be determined by conducting an atmospheric exposure test. The atmospheric exposure test is the test of exposing steel specimens to the environment in the desired location.

The environmental conditions in Thailand differ from those in other nations, therefore the environmental parameters we consider when determining corrosion rates vary as well. There are a variety of environmental variables that influence corrosion that we might investigate. As Thailand has a tropical climate, it's hot and humid, with heavy rainfall. In tropical climates, the influence of high temperatures combined with high precipitation and humidity are observed, because the moisture over time is very high (Mikhailov et al., 2007). The temperature plays an important role in accelerating the corrosion rate of metals (Prawoto et al,2009). Therefore, the temperature can be considered as one of the environmental parameters. Under humid conditions, metal will corrode at a much greater rate than under dry conditions (Francis, 2002). For corrosion to occur they need moisture so that the reaction could occur if there is no moisture the corrosion ceases. Rainfall and Humidity can be taken as one of the environmental parameters for Thailand as well. The prediction of the rate of corrosion of steel plays a significant role in the steel industry of Thailand because Thailand has a very corrosive environment which tends to reduce the service life rapidly if proper maintenance is not followed. Galvanizing and painting help protect the steel service life and minimize the rate of corrosion. There is no sufficient data on atmospheric corrosion to model or predict steel corrosion to design service life of steel structures in Thailand (Permsuwan et al,2011). Therefore, this paper aims to gather more information on hot-dip galvanized steel, compare between bare steel and hot-dip galvanized steel, how the environmental parameters affect both types of steel. This could also contribute to creating a corrosion map to predict corrosion in Thailand in the future.

2. Methods and Materials

2.1 Specimen Preparation

We focus on two types of structural steel in this study: are SS400 and SM490, which are commonly utilized in Thailand. In addition, for this exposure test, we focus on two types of coating: bare steel (no coating) and hot-dip galvanized steel. The dimensions for the test specimen are 100 x 150 x 4.5 mm which follows the ASTM G92 standard.

Specimen coating	Coating material	Total coating thickness	Standard
Bare Steel (No coating)	-	0	-
Hot-dip Galvanized Steel	Zn	75μm	ASTM A123

Table 1: Details of the two types of the coating system

Steel types	Chemical Composition (% by wt)													
	C	Mn	Si	P	S	Al	Ni	Cr	Mo	V	Cu	B	Cr+Mo	Cu+Ni +Cr+Mo
SS400	0.117	0.430	0.014	0.012	0.009	0.050	0.011	0.020	0.003	0.000	0.017	0.000	0.023	0.051
SM490	0.199	1.220	0.010	0.014	0.010	0.042	0.013	0.030	0.007	0.002	0.008	0.000	0.41	0.26

Table 2: Chemical composition of bare steel

Following the specification given in the ASTM G1 and ASTM G31, the test specimen needs to be prepared. We mark the specimens with a unique appropriate specimen code with an electric engraving which allows us to identify the specimens. After we finish marking, we measure the dimensions of the specimen using the digital caliper. After measuring, we follow up with the cleaning process in deionized water and acetone. We measure the weight after the specimens have been dried by an air dryer and then store it in the desiccator.

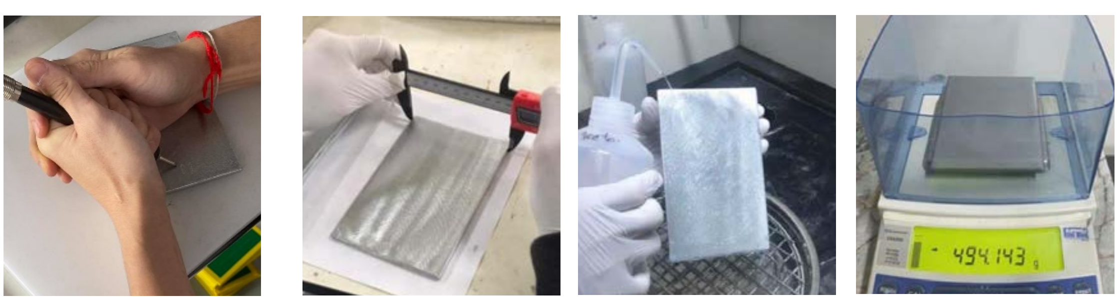


Figure 1 from left to right: Marking, measuring dimension, cleaning, and weighing

2.2 Exposure Test

Depending on the location and the environmental condition, the atmospheric corrosion rate varies significantly. The exposure sites are in three provinces: Chachoengsao, Rayong, and Chonburi in the eastern part of Thailand as shown in Fig.3. The atmospheric exposure test racks need to be installed so that we can place the prepared specimen and expose it to the real environment. The test racks are prefabricated structures made from hot-dip galvanized steel. Following the ASTM G50 standard, the test racks are installed at an angle of 30 degrees from the horizontal, facing to the south or ocean. The period of exposure for the steel specimens is 3 months, 6 months, and so on. Since environmental conditions affect corrosion, we collect the environmental data through weathering station. Based on IS0 9225, the weathering station is installed at a height higher than 1 meter so that the capture device can collect the environmental parameters such as relative humidity, temperature, and rainfall. The data are collected daily.

Station ID	Location	Province	No. of Racks and W. S
13	Union Galvanizer Company	Chachoengsao	2 racks, 1 w. s
14	Sangchareon Eastern Galvanize Co., Ltd	Chonburi	2 racks, 1 w. s
1	COTCO Metal Works Limited	Chonburi	1 rack, 0 w. s

Notes: W. S = Weathering Station

Table 3: Details of the Exposure Sites.

Union Galvanizer Company

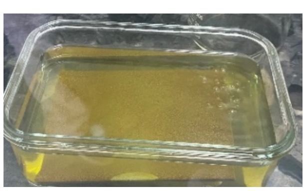
Sangchareon Eastern Galvanize

COTCO Metal Works Limited

Figure 2: Specimens at Eastern part of Thailand

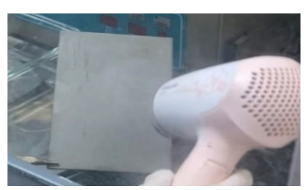
2.3 Calculation of Thickness Loss

After three months and six months of exposure to the real world, the specimens were analyzed. For each type of exposure, we gather two bare steel specimens and three hot-dip galvanized steel specimens. The thickness loss due to corrosion increases with time. To determine the thickness loss, we measure the weight of the exposed specimens before and after removing the corrosion products. We use ASTM G1 C 3.5 to remove corrosion products from bare steel, and ASTM G1 C 9.3 to remove corrosion products from hot-dip galvanized steel. The specimens are cleaned with deionized water and acetone after following the procedure for removing the corrosion product. Then we dry it and weigh it. This process is repeated several times to completely remove the rust. The data collected after cleaning the specimens are used to calculate the thickness loss.

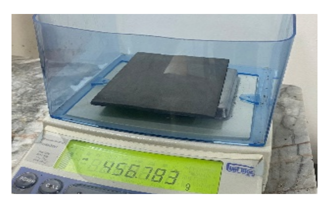


Dip the specimen in the solution (HCl+ H_2O) for 10 minutes

Cleaning with Acetone



Dry it with dryer



Weighing

Fig 3: Process of removal of rust from bare steel

Following the ASTM G1 standards, we plot the graph and use the following equation used to calculate the thickness loss.

$$C = \frac{W}{\rho * A} * 10^4 \text{ (micron)} \qquad \text{Equation (1)}$$

Where C = Thickness loss (micron)

A = Exposed Area (cm^2)
W= Mass loss (g)
ρ = Density of bare steel = 7.86 g/cm^3 or ρ = Density of HDG steel = 7.13 g/cm^3

3. Results and Discussions

3. 1 Appearance of Steel Specimen

The table is given below shows the changing appearance of the bare steel specimens for the two types at the three stations.

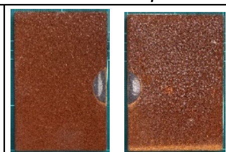
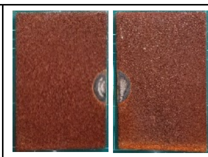
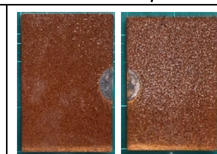
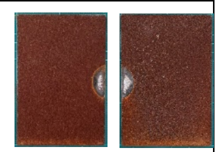
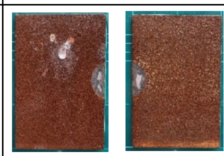
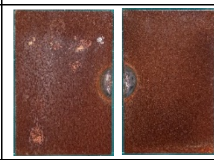
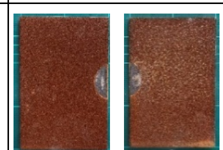
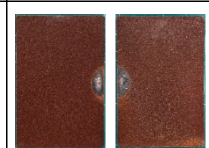
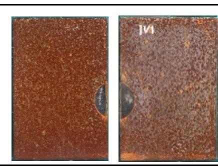
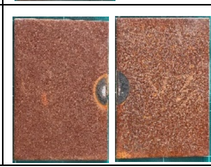
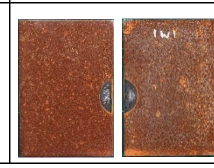
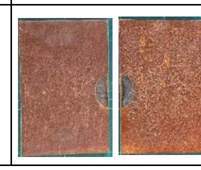
Station Name	Unexposed	Exposed for 3 months	Exposed for 6 months	Unexposed	Exposed for 3 months	Exposed for 6 months
	SS400 Specimen			*SM490 Specimen*		
Union Galvanizer Company						
Sangchareon Eastern Galvanize Co., Ltd						
COTCO Metal Works Limited						

Table 4: the changing appearance of the bare steel specimens (front and back)

The table is given below shows the changing appearance of the hot-dip galvanized specimens for the two types at the three stations.

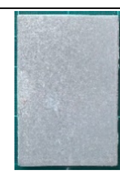
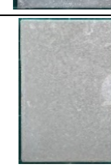
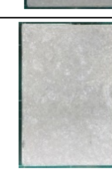
Station Name	Unexposed	Exposed for 3 months		Exposed for 6 months	
Types of Steel		SS400	SM490	SS400	SM490
Union Galvanizer Company					
Sangchareon Eastern Galvanize Co., Ltd					
COTCO Metal Works Limited					

Table 5: the changing appearance of the HDG specimens (front view)

In table 3, Both SS400 and SM490 bare steel specimens have corroded. From the images, we can see that Station 1 (COTCO Metal Works Limited) has lesser corrosion compared to the other two stations. The specimens that were collected after three months have a uniform red-orange rust color while the ones collected after six months have a more uniform brownish-orange rust color. From table 4, Both SS400 and SM490 hot-dip galvanized steel did not have any corrosion product. Though the color from the unexposed changed to gray, there was no corrosion taking place on the hot-dip galvanized specimen. The specimen collected after 6 months has a little bit of white rust on the specimens. From the comparison of the two tables, Hot-dip galvanized steel can withstand corrosion and uncoated steel is easily corroded within a few months. This shows how important galvanizing steel can be.

3.2 Thickness Loss

The corrosion rate is calculated in terms of thickness loss generally and the equation used to calculate the thickness loss is shown in equation (1)

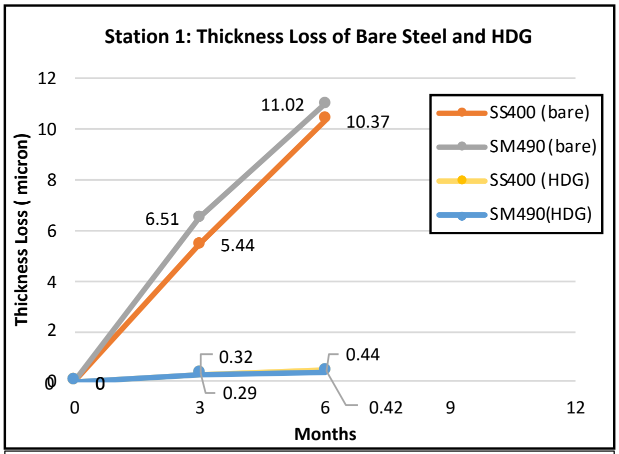


Fig 4: Thickness loss of specimen versus exposure time (Station 1)

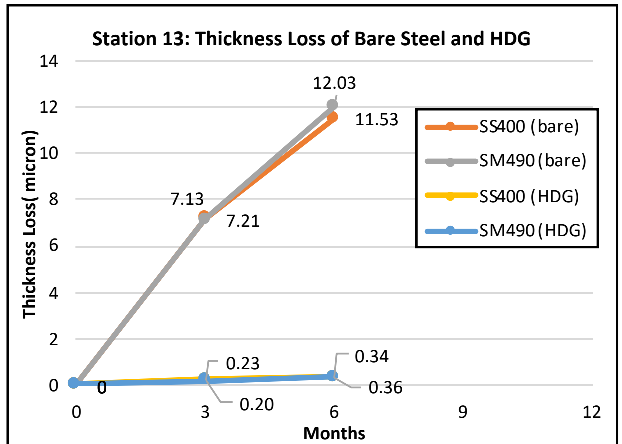


Fig 5: Thickness loss of specimen versus exposure time (Station 13)

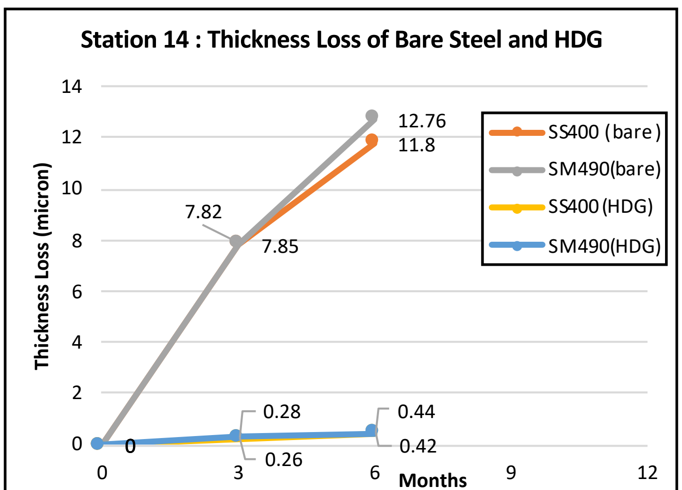


Fig 6: Thickness loss of specimen versus exposure time (Station 14)

From Figures 4,5 and 6, we can see the thickness loss of the bare steel and hot-dip galvanized steel at the three stations over 3 months and 6 months. While comparing the two types of bare steel SS400 and SM490, we discover that SM490 has a little higher thickness loss compared to SS400. This is due to the chemical composition of steel as shown in table 2, the percentage of carbon (C) for SM490 is higher but the percentage of Copper (Cu) is lower than SS400. Higher carbon also reduces air corrosion resistance, which causes rusting. (Dalton et al., 2020). Copper, on the other hand, boosts the steel's corrosion resistance and protects it from corrosion. Station 1 has the lowest thickness loss for bare steel, ranging from 10 microns to 11 microns when compared to the other stations. Even though stations 1 and 14 are in close proximity in terms of location, station 14 has a somewhat higher thickness loss due to the difference in specimen exposure duration. Stations 14 and 1 were exposed in March and June, respectively. As a result of the diverse environmental conditions that the specimens were exposed to, the thickness loss is also different. The thickness loss of bare steel is lower for station 13 compared to 14 because of the distance of the station to the sea. Thus, we can see that the corrosion rate is affected by location and environmental conditions. When we compare the corrosion rate of bare steel from 3 months to 6 months, the rate of corrosion of 6 months is less compared to 3 months. The formation of protective rust layers reduces the rate of corrosion in the long term (Permsuwan et al,2011). Therefore, the rust layer formed acts as a barrier layer and prevents the transport of moisture, oxygen, and other impurities.

When compared to bare steel, the thickness loss of hot-dip galvanized steel is very low. Just like bare steel, Station 13 has a lower thickness loss of HDG compared to stations 1 and 14. It is consistent with the behavior that the rate of corrosion is affected by location and environmental conditions. The thickness loss between the two types of grades is minimal since the exposed layer is zinc, so the bare steel is protected. This proves how effectively galvanized steel can prevent corrosion of steel. The rate of corrosion of hot dip galvanized is very less compared to the rate of corrosion of bare steel.

3.3 Environmental Data

From the weathering stations, we collected the environmental parameters such as temperature, rainfall, and relative humidity. Figures 7,8 and 9 are the data collected from the weathering station. Station 13 and Station 14 were exposed in March 2021, while station 1 was exposed only in June 2021, due to the different exposure of timing the best comparative result can be found between stations 13 and 14. The average temperature from March to September in station 13 (Chachoengsao) was not consistent, as indicated in figure 7, the relative humidity was around 76 percent, and the rainfall was 174 mm. The temperature was constant at station 14, which is in Chonburi, and the humidity was more than 85%, however, the rainfall was around 137 mm. Climatic conditions interact to cause corrosion, an environment with a consistently high temperature, high relative humidity, and little rainfall becomes a more suitable corrosive environment. Therefore, Station 14 has a little higher thickness loss.

Station 1 thickness loss was lesser compared to the other two stations because the temperature was low compared to other stations, the relative humidity was not consistent, and rainfall was not so heavy as well. Corrosion is affected directly by temperature and humidity, therefore station 1 has less thickness loss compared to the other two stations.

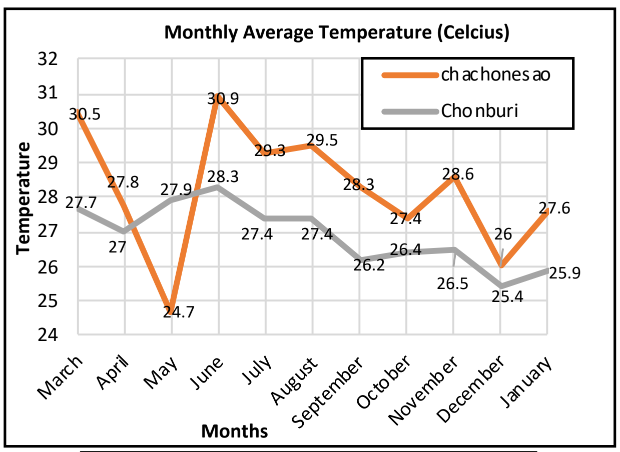


Fig 7: Monthly average temperature

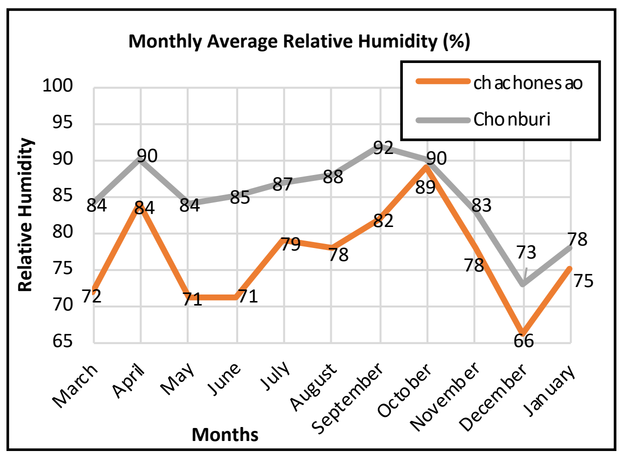
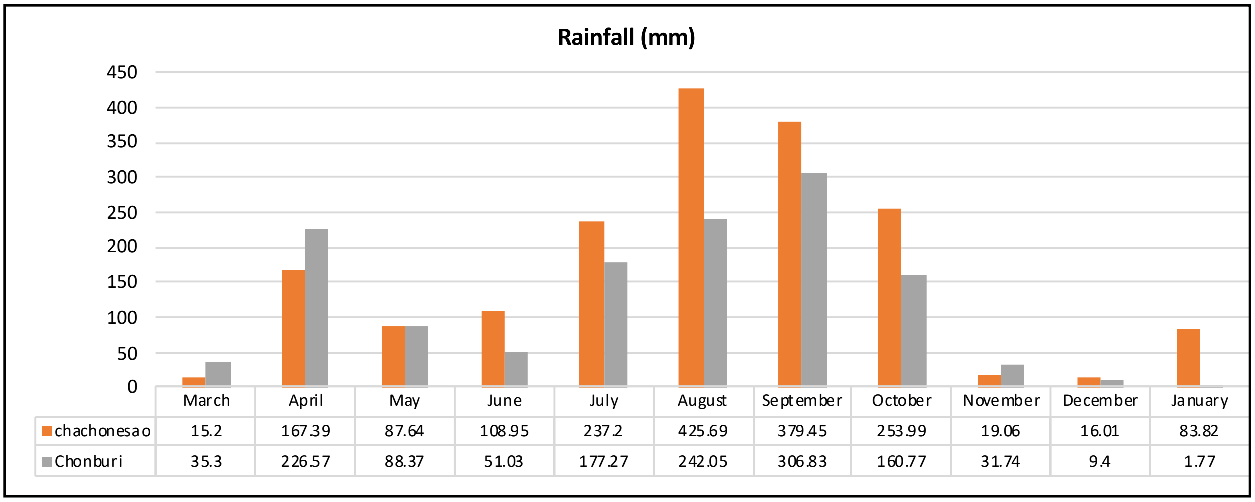


Fig 8: Monthly average relative humidity



4. Conclusions

Steel corrosion is heavily influenced by environmental factors as well as the distance from the sea. Galvanizing can be highly effective in extending the service lif

Fig 9: Monthly Rainfall

atic condition. All the three stations were in the eastern part of Thailand, the small difference in the environmental factors between the locations have caused changes in the corrosion rate as well. After 6 months of exposure in the eastern part of Thailand, thickness loss of bare steel ranges between 10 to 13 microns, and the thickness loss of hot-dip galvanized steel ranges between 0.3 to 0.4 microns which shows that the rate of corrosion can be lowered around 30 times. Therefore, the service life of the steel is now increased around 30 times. For a climatic condition like Thailand, the best option to reduce steel corrosion is by galvanizing. The thickness loss from the HDG specimens let us know that corrosion is unavoidable, and the only way is to reduce the rate of corrosion. Uncoated steel specimens are easily corroded by the atmospheric factors and though the rate of corrosion is reduced by the formation of rust layer, the rate of corrosion reduction is very less compared to the rate of corrosion reduced by galvanizing. The changes of the uncoated steel show how the rust formation color changes within months. The changes in galvanized steel show us how galvanizing can reduce the rate of corrosion and no corrosion product is being formed on the galvanized steel. From this research, we can understand the importance of galvanizing steel and how the environment affected steel corrosion. The limitation of this paper is that we have not considered the chloride and Sulphur dioxide present in the environmental factors as the eastern part of Thailand is close to the marine area and the stations selected are in the industrialized area as well so these two parameters could have affected the rate of corrosion as well.

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ID 49

Construction Site Top-view Generation Using Drone Imagery: The Automatic Stitching Algorithm Design and Application

Sisi Han[1], Yuhan Jiang[2]

[1] Marquette University, Milwaukee WI 53233, USA
[2] South Dakota State University, Brookings SD 57007, USA
yuhan.jiang@sdstate.edu

Abstract
This paper proposed an automatic stitching algorithm to process drone-captured top-view images (ortho-images) to generate a single frame high-resolution unified top-view image for construction site documentation. The initial step of the proposed algorithm is resizing adjacent ortho-images to the same scale. The next step is to find a common straight edge for merging the resized ortho-images. A vertical edge that closes to the right end of the left-image in left-right mode or a horizontal edge that closes to the bottom end of the upper-image in up-down mode is recommended. Then, merging adjacent ortho-images at the common edge. Stitching and aligning the corresponding elevation-maps at the common edge, if any. An automatic stitching tool was developed with comprehensive functions of automatic, semiautomatic, and manual stitching based on the stitching algorithm. Application results are presented and discussed in this paper, including grid stitching mode for large building sites and linear stitching mode for infrastructure projects. With the stitched ortho-image and elevation-map, the point cloud can be generated for 3D monitoring construction progress.

Keywords
Drone, Image stitching, Construction site, Documentation.

1. Introduction

Recent breakthroughs in micro quadrotor drones (or unmanned aerial vehicles, UAVs) have enabled dreams of drone photography and photogrammetry to get closer and closer to the reality of construction practices for construction site surveying (Shang & Shen, 2018; Siebert & Teizer, 2014), earthwork planning and monitoring (Haur et al., 2018; Nassar & Jung, 2012), and construction progress monitoring (Jacob-Loyola et al., 2021). Specifically, for construction site three-dimensional (3D) mapping, using drones with high-definition cameras for structure-from-motion (SfM) photogrammetry is the state-of-the-art approach for large construction site (Nassar & Jung, 2012; Vargo, 2020; Westoby et al., 2012). The commercial photogrammetry software packages, such as Autodesk ReCap Photo, can generate a two-dimensional (2D) orthophoto and a 3D point cloud for the scanned construction site (Jiang & Bai, 2021). However, it takes approximately one hour to process one hundred drone images in the SfM photogrammetry processing. As a result, “one processing day” is required for drone SfM photogrammetry-based soil measurement (Haur et al., 2018). When the contractor is only using drone imagery to document the construction project progress, using drone-captured 2D top-views of the construction site is enough. Then, with a series of top-views, project progress can be well monitored in building and infrastructure projects.

2. Data Acquisition

For architecture, engineering, and construction (AEC) applications and practices, "*DJI Phantom*" (Moon et al., 2019; Yang et al., 2018), "*DJI Inspire*" (Aguilar et al., 2019; Li & Lu, 2018), and "*DJI Mavic*" (Park et al., 2019) are the most popular ready-to-fly imaging drones. **Fig. 1** shows the components of a *DJI Phantom 4 Pro V2.0*, which is an easily controlled and portable quadcopter drone. It has a downward vision system and GPS for stable hovering at a planned position; the digital camera is mounted on a 3-axis (pitch, roll, yaw) gimbal to enhance the camera's stabilization (DJI, 2020). In this paper, ortho-imaging is defined as setting the gimbal's pitch-axis at –90° to make the camera lens face down to the construction site. Then, the drone captured images are top-views of the construction site with an approximate scale of ground sampling distance (*GSD*). Typically, *GSD* has the unit of cm/pixel, which means a pixel's length stands for a physical length of ground in centimeters.

As shown in **Fig. 2**, the *GSD* has an inverse relationship to drone flight height (altitude). To obtain high-resolution ortho-images, a low altitude is necessary. Then, for scanning the entire construction site, multiply stations are required for either a linear project or a larger area project; see the examples shown in **Fig. 3**. Next, stitching the overlapped ortho-images is required to generate a single frame high-resolution unified top-view of the construction site.

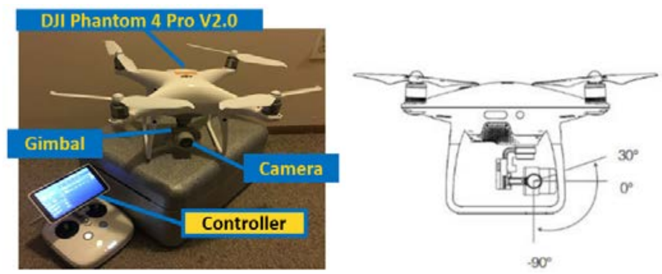

Fig. 1. Drone system, gimbal, and camera.

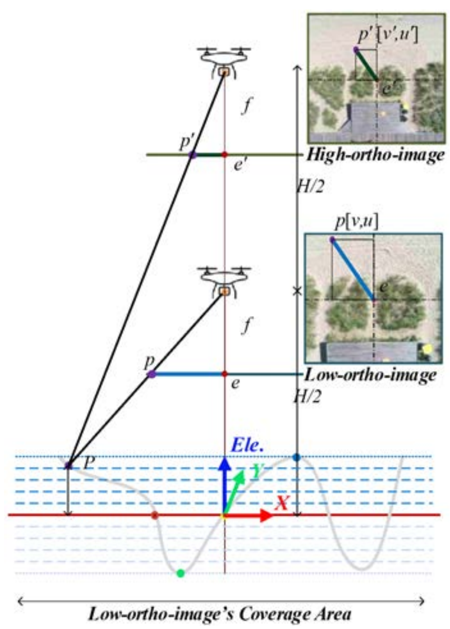

Fig. 2. Sketch of drone ortho-imaging in low-high altitudes**.**

Previous research (Jiang, 2020; Jiang & Bai, 2021) proposed an up-forward-down drone flight path to capture low-high image pairs (example shown in **Fig. 2**) on a construction site, where "forward" means the drone flight direction between two sequence stations; and "up" and "down" stand for the drone flight direction at each station, which is either moving up or down. When the construction site is prepared for a linear infrastructural project like **Fig. 3**(a), where stations are set from the start point to the endpoint, then the left-right stitching mode is required to merge the adjacent results along the drone flight direction. When the construction site is prepared for a large building project like **Fig. 3**(b), where stations are planned in a grid style, the left-right mode is used in each row first, and then, the up-down mode is required for merging the stitched rows' results of images to cover the entire construction site.

Furthermore, the previously developed *PGMED* algorithm (Jiang, 2020; Jiang & Bai, 2021, 2020), *Fast-PGMED* algorithm (Han, 2020; Han et al., 2022) can quickly process low-high image pairs for construction site dense 3D reconstruction and elevation determination of each station covered area. The generated elevation-map has the same pixel coordinates as the low-image (dropped edges in four sides) at each station. Therefore, it would be great if a single frame high-resolution unified elevation-map could be created along with the ortho-image stitching.

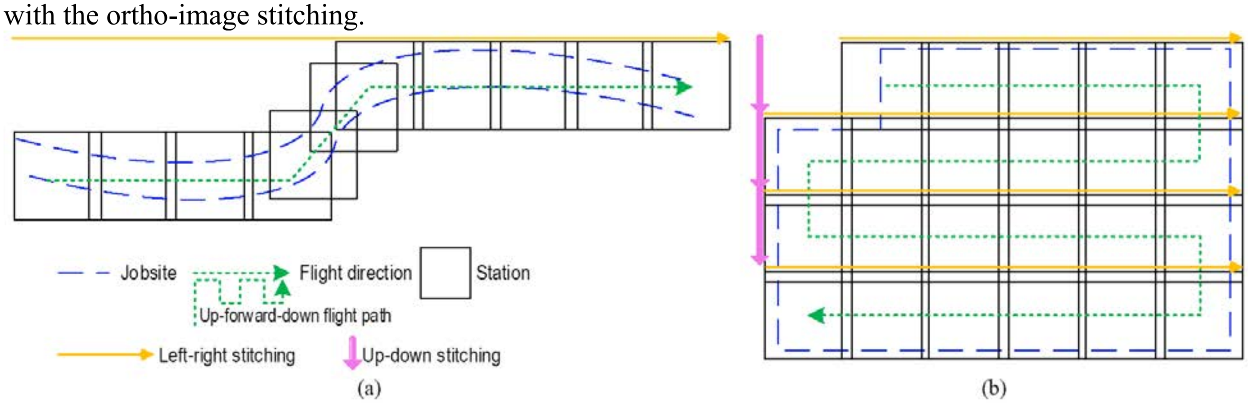

Fig. 3. Stitching modes: (a) linear infrastructure, (b) building.

3. Stitching Algorithm Design

This research aimed to optimized both stitching modes shown in **Fig. 3** to automatic level and also supported the ortho-images with different *GSDs*, which means ortho-images can be captured at different altitudes. **Fig. 4** demonstrates the processes of both left-right and up-down modes, where the matched keypoints are annotated as "×" with indication numbers in overlaps. The used keypoint is Scale-invariant Feature Transform (SIFT) keypoints, which is suitable for matching two images with different scales and orientations (D.G. Lowe, 1999; David G. Lowe, 2004).

The initial process is resizing adjacent ortho-images to have equal *GSD*. The linear scaling ratio can be calculated from the selected two pairs of matched SIFT keypoints like **Fig. 4**(a), where the largest distance is desired to guarantee the accuracy; it can also be automatically performed by selecting one keypoint at the beginning row and another at the ending row of the matched keypoint *DataFrame* (a type of data format in *pandas*) (Pandas, 2020), in which keypoints are sorted by u-axis (along the horizontal direction of the ortho-image) for left-right mode and v-axis (along the vertical direction of the ortho-image) for up-down mode in increasing order like **Fig. 4** (a and c), respectively.

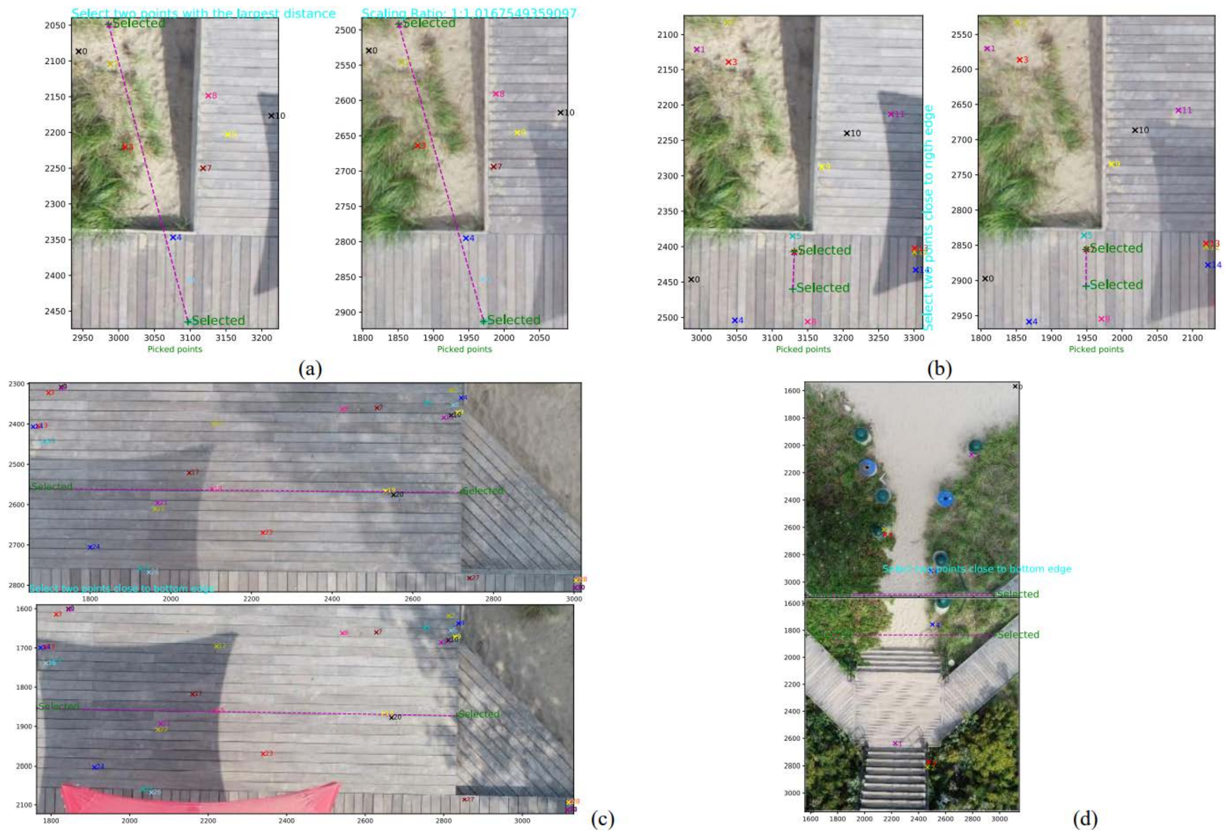

Fig. 4. Stitching processes: (a) scaling ratio, (b) left-right edge, (c) up-down edge, and (d) few SIFT keypoints**.**

The second process is determining a common straight edge for merging the resized ortho-images, preferably a vertical edge that closes to the right end of the left-image in left-right mode or a horizontal edge that closes to the bottom end of the upper-image in up-down mode. A suitable common edge can be determined via the proposed ***findCommonEdge***() algorithm shown in **Fig. 5**. For the left-right stitching in **Fig. 4**(b), the ***findCommonEdge***() algorithm uses the newly matched and sorted keypoint *DataFrame* of the resized ortho-images as the input. Moreover, when the number of matched SIFT keypoints is less than 30 to activate ***findCommonEdge***() or occurs with unsatisfied conditions, the selections of identical pixels can be manually performed like in **Fig. 4** (c and d).

```
findCommonEdge(pointDataFrame, leftrightBool): # pointDataFrame [u0, v0, u1, v1], matched keypoints; u0 and v0 refer the left or upper image
  for condition1 in range(1,50,1): # travel begins at the smallest value to guarantee the common edge in vertical or horizontal as much as possible
    for i in range(N − 1,0, −1):     # travel begins at the largest value in u-axis (left-right mode) or v-axis (up-down mode); N, number of keypoints
      for j in range(i − 1,0, −1): # travel keypoints in order of u-axis (left-right mode) or v-axis (up-down mode)
        index0, index = j, i         # index0, the first keypoint; index, the second keypoint; and then, two points determine a straight line
        u_diff = pointDataFrame['u0'][index0] − pointDataFrame['u0'][index] # difference between the current selected keypoints in u-axis
        v_diff = pointDataFrame['v0'][index0] − pointDataFrame['v0'][index] # difference between the current selected keypoints in v-axis
        condition0 = −50 × condition1   #adjustable condition0, guarantees the selected keypoints are not close to each other
        if abs(u_diff) < condition1 and v_diff < condition0 and leftrightBool == True: # u_diff closer to zero, the line is more vertical
          return index0, index             # negative v_diff guarantees first keypoint above the second keypoint
          break
        elif abs(v_diff) < condition1 and u_diff < condition0 and leftrightBool == False: # v_diff closer to zero, the line is more horizontal
          return index0, index             # guarantees first keypoint at the left of second selected keypoint; False, in case the up-down mode
          break
```

Fig. 5. Pseudocode of *findCommonEdge*() algorithm.

The additional processes to perform the ***stichingLeft&Right***() and ***stichingUp&Down***() algorithms include:

(1) Rotating both resized ortho-images to make the selected common edge vertical in left-right mode or horizontal in up-down mode, where both rotation centers are set at the first keypoints.
(2) Discarding the left-image's right part and the right-image's left part in left-right mode or discarding the up-image's bottom part and the down-image's upper part in up-down mode.
(3) Translating the right-image in v-axis to align with the left-image at the first keypoint in left-right mode or translating the bottom-image in u-axis to align with the upper-image at the first keypoint in up-down mode.
(4) Concatenating the left-right images or up-down images at the common edge.
Moreover, both ortho-images are padded in the above operations of rotation, translation, and concatenation to retain all ortho-images' information. The corresponding elevation-maps are automatically scaled and rotated along with ortho-images via the same keypoints and common edge. In addition, elevation-maps (8-bit grayscale image) are aligned to the same grayscale values at the common edge before concatenating them.
Furthermore, to automatically conduct stitching with multi-station, the ***stitchingLinear***() algorithm (see **Fig. 6**) is proposed to process a singular command list with the format of [0, '**40Z**', '**40Y**'], in which the "0" is used for activating ***stichingUp&Down*** () and "1" for ***stichingLeft&Right*** ( ), which returns the stitched results as '**40Z_NEXT_Y**'("40" in the file name indicate it is a 20-40-m ortho-image pair).

```
stitchingLinear(commandList = [0, '40Z', '40Y']):
  if len(commandList) == 2:
    return commandList[1]
  if commandList[0] == 0:
    baseName = commandList[1]
    nextNameList = commandList[2:]
    for i in nextNameList:
      stichingUP&Down(baseName, i)
      baseName = baseName + "_NEXT_" + i
  elif commandList[0] == 1:
    baseName = commandList[1]
    nextNameList = commandList[2:]
    for i in nextNameList:
      stichingLeft&Right(baseName, i)
      baseName = baseName + "_NEXT_" + i[2:]
  return baseName
```

Fig. 6. Pseudocode of *stitchingLinear*() algorithm.

4. Application Results and Discussion

This research used the *PGMED* algorithm with low-high ortho-image pairs to determine construction sites' elevations. **Table 1** lists the properties of *PGMED*'s outputs of ortho-images and elevation-maps for each input of a pair of low-high ortho-images captured by a *DJI Phantom 4 Pro V2.0* over a target station at the low altitude $H/2$ and high altitude H. The scanned station X is referenced as 10-20 X or **20X**, in which 10 refers to the designated low altitude $H/2$=10m, 20 is the designated high altitude H=20m.

Table 1. Ortho-image and elevation-map at a station.

Properties	*10-20 ortho-image*	*20-40 ortho-image*
Drone captured image size	3648×4864-pixel	3648×4864-pixel
Assembled low-high ortho-image size	1824×1824-pixel	1824×1824-pixel
Generated ortho-image size	1568×1568-pixel	1632×1632-pixel
Generated elevation-map size	1568×1568-pixel	1632×1632-pixel
Approximate *GSD*	0.54 cm/pixel	1.08 cm/pixel
Covered construction site area	8.5×8.5 m^2	17.6×17.6 m^2

Measurable elevations	[-5 m,5 m]	[-10m, 10m]
Elevation-map value	[0,255]	[0,255]
Elevation-map interval	0.0392-m	0.0784-m
Elevation-map system error	0.0196-m	0.0392-m

Note: see the detailed definitions and values of the listed properties in (Jiang & Bai, 2021)

Since the captured ortho-images have GPS coordinates, their related directions can be easily determined. The four ortho-images, shown in **Fig. 7**(a), have an approximate 2×2 grid relationship. Then, the stitching command list can be written as [[1, '40Z', '40Y'], [1, '40S', '40V']] for the ***stitchingGrid***() algorithm shown in **Fig. 8**, where each singular command list is a row of **Fig. 7**(a). At the end of the process, the ***stitchingGrid***() algorithm creates a command list [0, '40Z_NEXT_Y', '40S_NEXT_V'] for applying the up-down stitching of the two stitched rows by ***stitchingLinear***() and returns the 2×2 stitched 40Z_NEXT_Y_NEXT_S_NEXT_V, as shown in **Fig. 7**(d).

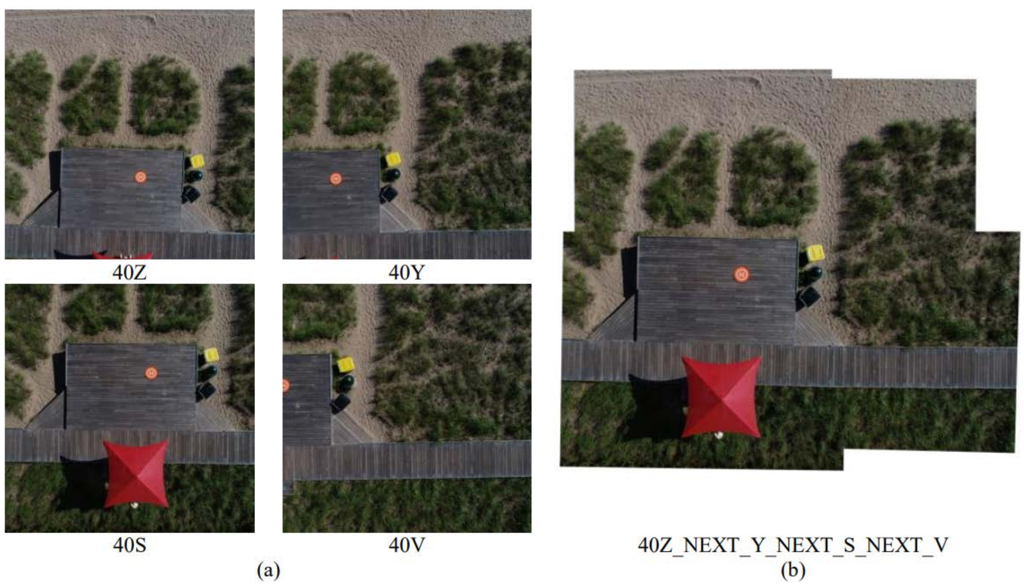

Fig. 7. Stitching modes: (a) 2×2 grid, and (b) stitched ortho-image.

```
stitchingGrid(commandList = [[1, '40Z', '40Y'], [1, '40S', '40V']]):
  colNameList = [0]
  for rowlist in commandList:
    colNameList.append(stitchingLinear(rowlist))
  stitchingLinear(colNameList)
```

Fig. 8. Pseudocode of *stitchingGrid*() algorithm.

Three pairs of ortho-images and elevation-maps of 40CA, 40CH, and 40CI ("40" indicates they are 20-40-m ortho-image pairs) with the image size of 1632×1632-pixel were collected from (Jiang & Bai, 2021); an ortho-image and elevation-map pair of 40CJ with size of 1568×1568-pixels was collected from (Han, 2020). These four pairs of ortho-images and elevation-maps were automatically stitched with ***stitchingGridColThenRow***() algorithm (shown in **Fig. 9**) via the command [[0, '40CJ', '40CI'], [0, '40CH'], [0, '40CA']], which called ***stitchingUp&Down***() to merge 40CJ and 40CI first. Then, the merged results of 40CJ_NEXT_CI were stitched with 40CH and 40CA in sequence via ***stitchingLeft&Right***().

```
stitchingGridColThenRow(commandList = [[0, '40CJ', '40CI'], [0, '40CH'], [0, '40CA']]):
  rowNameList = [1]
  for collist in commandList:
    rowNameList.append(stitchingLinear(collist))
  stitchingLinear(rowNameList)
```

Fig. 9. Pseudocode of *stitchingGridColThenRow*() algorithm.

Additionally, the developed automatic stitching tool has comprehensive functions and graphic user interfaces (GUIs) for automatic, semiautomatic, and manual stitching. In process command [[0,'40CJ','40CI'],[0,'40CH'],[0,'40CA']], the automated stitching was activated in the up-down stitching of 40CJ and 40CI, while semiautomatic stitching and manual stitching were used in the remaining two left-right stitching because the matched SIFT keypoints were less than the thresholds (10 for determining scaling ratio and 30 for determining common straight edge) to activate automated stitching. In **Fig. 10**(a), common keypoints of 19 and 18 were picked to determine the common edge via typing them into the command line. In **Fig. 10**(b), the common keypoints of 6 and 7 were discarded because the determined straight line occurred on the edge of the wooden platform and would produce errors in elevation alignment. Thus, the keypoint 0 was set as the starting point, and the ending points were picked along the direction of the chink between two boards via cursor in the final. The final stitched results of ortho-image and elevation-map are shown in **Fig. 11**, where a wooden path links two stairs and a platform.

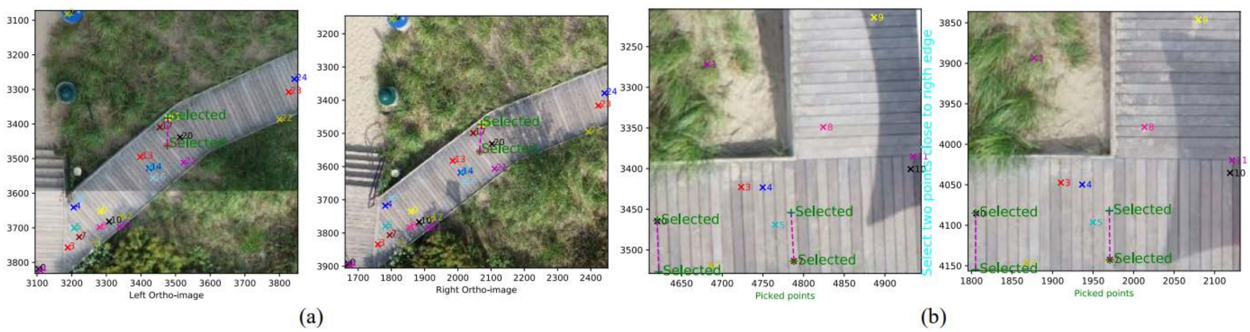

Fig. 10. Stitching examples: (a) semiautomatic left-right stitching and (b) manual left-right stitching.

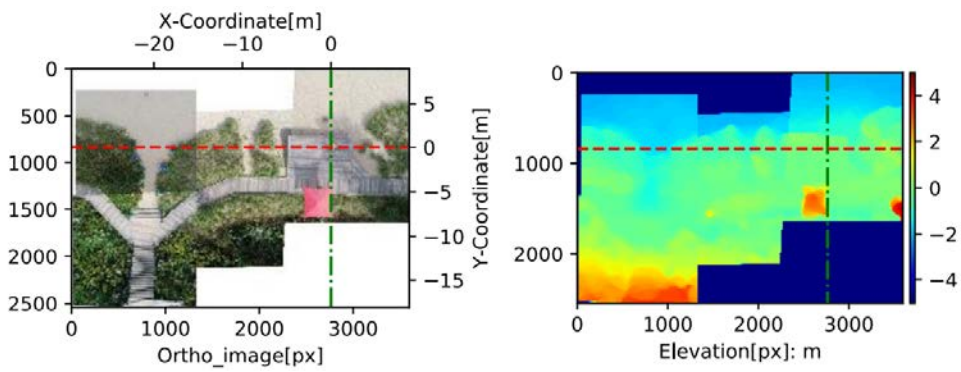

Fig. 11. Stitched ortho-image, elevation-map.

Furthermore, the *GSD* of 1.04 cm/pixel was determined for the stitched ortho-image and elevation-map via detecting the placed drone landing pad, same as the examples shown in (Han et al., 2022; Jiang & Bai, 2021). The determined *GSD* is close to the approximate value listed in **Table 1**, which means the drone's altitudes were not at 20-40m to the ground. Thus, *GSD* adjustment is necessary for the 3D point cloud generation, and the stitched ortho-image and elevation-map converted 3D point cloud is shown in **Fig. 12**.

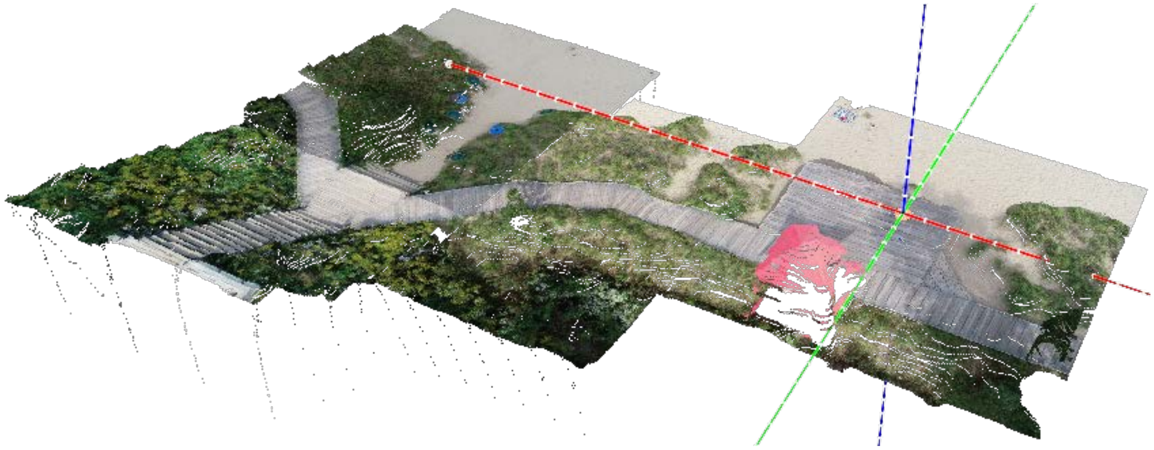

Fig. 12. 3D point cloud.

5. Conclusion

This paper proposed an automatic stitching algorithm to process drone captured top-view images (ortho-images) to generate a single frame high-resolution unified top-view image for construction site documentation with the following steps:
(1) The initial step of the proposed stitching algorithm is resizing adjacent ortho-images to have equal scale.
(2) Next, a common straight edge for merging the resized ortho-images is determined. A vertical edge closes to the right end of the left-image in left-right mode, or a horizontal edge that closes to the bottom end of the upper-image in up-down mode is recommended.
(3) Then, adjacent ortho-images are merged at the common edge.
The automatic stitching tool was developed with comprehensive functions and graphic user interfaces (GUIs) for automatic, semiautomatic, and manual stitching based on the proposed algorithm. Applications of 2×2 grid stitching and the mixed stitching were tested. The corresponding elevation-maps were aligned and stitched along with the ortho-image stitching.
The proposed drone imaging approach can be applied to document construction sites during the preconstruction, construction, and constructed phases. The coverage can be extended via automated image stitching, and the coordinate conversion and orientation alignment can be completed via setting a single landing pad as the ground control point. With the *PGMED*/*Fast-PGMED* algorithm, the elevation-map and point cloud could be created. Moreover, with deep learning-based segmentation approaches (Jiang et al., 2020, 2022), construction site objects could be easily extracted for as-constructed modeling.

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ID 50

Remote Sensing and Neural Network-Driven Pavement Evaluation: A Review

Yuhan Jiang [1]

[1] South Dakota State University, Brookings SD 57007, USA
yuhan.jiang@sdstate.edu

Abstract
This review paper aims to evaluate the remote sensing and neural network-driven pavement evaluation (RSNNPE) techniques. The collected studies were published in recent years and mainly relate to pavement distresses detection, classification, and quantification. The data collections were conducted by remote sensing and non-destructive techniques, including photography, hyperspectral imagery, satellite imagery, photogrammetry, laser scanning, ground penetrating radar, and laminography. The data analysis was conducted by neural network (NN) modeling, image filtering, threshold segmentation, template matching, SVM, and random forest. The NN architectures include MLP, RNN for structured data; CNN, Faster R-CNN, NIN for 2D/3D imagery patch-wise or object-orientated pavement distresses detection; and FCN, U-net, SegNet, PSPNet, DeepLabv3+, Mask-RCNN, DeepCrack, CrackSeg, FPHBN, CrackGAN for 2D/3D imagery pixelwise segmentation. Moreover, this paper discusses drone photogrammetry-based data acquisition, data preparation, and NN architecture selection for pavement evaluation. Based on the results of the review, future research recommendations are proposed.

Keywords
Pavement Distress Detection, Remote Sensing, Neural Network Modeling, Photogrammetry, Literature review.

1. Introduction

Using destructive testing techniques to evaluate pavement conditions is still necessary for some specific objectives, such as inspecting the source of the problematic layer or layers and to acquire materials for further laboratory testing, however the engineering, construction and operation community (ECO) has adopted and developed several remote sensing and neural network-driven pavement evaluation (RSNNPE) approaches to conduct pavement evaluation in non-contact and non-destructive ways with advantages of cost-effectiveness, staying up-to-date, and limited traffic regulation requirements. Previous reviews summarized well the flexible pavement cracking detection, classification and quantification (Zakeri et al., 2017), pavement distress classification and detection (Ragnoli et al., 2018), and pavement asset management systems (Peraka & Biligiri, 2020). In this review, the reviewed studies include 1 technical report, 1 Ph.D. dissertation, 1 preprinted article, 28 peer-reviewed journal articles and 5 peer-reviewed conference papers. The majority of journal articles are from ECO's research publications, such as *Automation in Construction*, *Journal of Computing in Civil Engineering*, and *Construction and Building Materials*. Moreover, the computer science and electronic engineering, remote sensing and geoscience, and biomedical engineering communities are continually improving and developing image processing algorithms and neural network (NN) models for crack detection in surfaces of buildings, structures, and pavements.

2. Objectives for Pavement Evaluation

The reviewed studies have 156 author keywords. Fig. 1 shows a 20-category clustering results of the author keywords, based on the character lengths of the 1st, 2nd, 3rd , and 4th words. In the reviewed studies, "crack detection" occurred 12 times and is the most common keyword of the research objective, which is not only specific to pavement cracks, but also contains a wide variety of concrete surfaces, such as bridge structures, building walls, and sidewalks. After combining "convolutional neural network" (Dung & Anh, 2019; Ji et al., 2020; Kearney et al., 2020; Zou et al., 2019), "CNN" (Augustaukas & Lipnickas, 2019), "convolutional neural network (CNN)" (Ali et al., 2019),"convolutional neural networks" (Protopapadakis et al., 2019), "deep convolution neural network" (Q. Yang et al., 2020), and "deep convolutional neural network" (Huyan et al., 2019; Zhou & Song, 2020a), the "convolutional neural network" is the second most common keyword, occurring 10 times, and is the most common keyword of the data analysis method, but some of them did not exactly fit with the utilized or developed NN model in these studies. Other common keywords include: "deep learning"-7 times, "pavement crack detection" and "UAV" (unmanned aerial vehicle, or drone)-4 times, " fully convolutional network," "machine learning," "photogrammetry" (or structure from motion, SfM)-3 times, "3d mesh model," "computer vision," "image processing," "laser-scanned range image," "non-destructive testing," "pavement crack," "pavement distress," "remote sensing," "terrestrial laser scanning (TLS)," "U-net"-2 times.

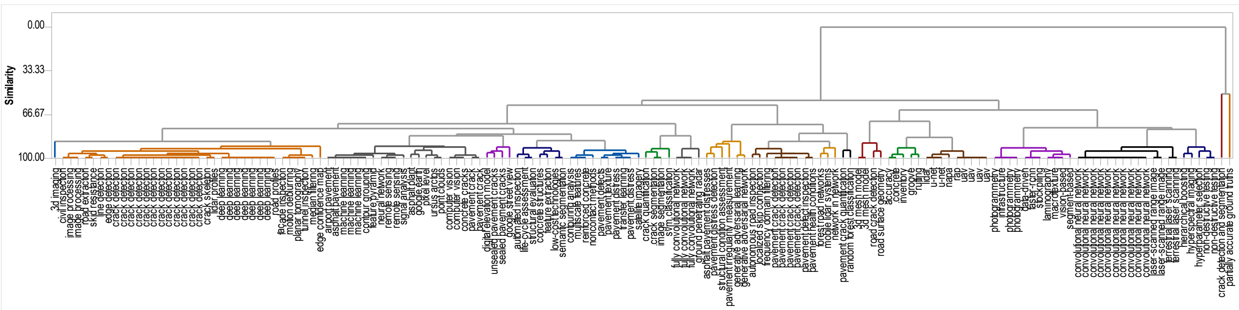

Fig. 1. Keywords relation.

Based on those keywords of research objectives, data collection and analysis methodology, it is safe to conclude that the RSNNPE research objectives are still focused on 2D imagery based pavement distress inspection, while starting to move to pavement performance evaluation (Puppala & Congress, 2019) and pavement irregularity measurement (Barbarella et al., 2019) with 3D models. The pavement distresses detection is still focused on cracking detection, while starting to move to crack segmentation (Alipour et al., 2019; Dung & Anh, 2019; Ji et al., 2020; Kalfarisi et al., 2020) and cracking quantification (Ji et al., 2020; Kalfarisi et al., 2020; Weng et al., 2019). The 3D data collection methods were not limited to terrestrial laser scanning and SfM, which also includes non-destructive techniques, such as ground penetrating radar (GPR) (Sukhobok et al., 2019; Tong et al., 2020) and planar tomography (Moosavi et al., 2020). The use of Google Street View (Maniat, 2019) and satellite imagery (Ashtiani et al., 2019; Kearney et al., 2020) started to develop cost-effective pavement evaluation tools. Furthermore, the detailed relationships between pavement evaluation objectives and data sources are summarized in ***Section 3***, and data analysis methods are summarized in ***Section 4***.

3. Remote Sensing Data Acquisition Techniques for Pavement Evaluation

The reviewed studies have achieved various pavement evaluation objectives with the remote sensing and non-destructive testing techniques in pavement surface properties evaluation, pavement geometrical properties evaluation, and other related objectives. There were different types of data sources used in different pavement evaluation objectives, while the most common two types are: a) 2D imagery that was captured by digital cameras (smart phones) that were carried by operators, mounted on vehicles, and carried by drones (Ali et al., 2019; Dadrasjavan et al., 2019; Dorafshan et al., 2019; Y. Liu et al., 2020); b) 3D imagery that was directly generated from laser line profile sensors (Edmondson et al., 2019; A. Zhang et al., 2019; Zhou & Song, 2020a, 2020b), and converted from point clouds by 3D laser scanner (Edmondson et al., 2019) and SfM photogrammetry (Edmondson et al., 2019; Roberts et al., 2020).

3. 1 Digital Camera and Photogrammetry

Digital Camera. Digital Camera is the most common technique in pavement cracking detection in the reviewed studies. 2D images contain crack and non-crack backgrounds that can be captured by a hand-held or vehicle mounted digital camera with its movement over the target area of a roadway, such as the data sets of pavement crack images collected from the campuses of Harbin Institute of Technology (Ji et al., 2020), Huazhong University of Science (Z. Liu et al., 2019), and Temple University (F. Yang et al., 2020). Another approach is capturing 2D images through a drone mounted digital camera (Ali et al., 2019; Dadrasjavan et al., 2019; Dorafshan et al., 2019; Y. Liu et al., 2020), which can minimize manual operation in most conditions, but is not a safe choice for surveying a roadway with a high traffic volume. Moreover, when the timeliness does not matter, according to studies (Maniat, 2019; Mohammed, 2017), extracting roadway images from Google Street View (images are captured by vehicle mounted 360° digital cameras) could get the accurate pavement cracking detection results without traffic regulation. 2D imagery typically has Red/Green/Blue (RGB) 3 channels and can be converted to 1-channel grayscale images. In a crack image, crack regions have higher pixel intensity standard deviation values and lower mean intensity values than the non-crack regions (Oliveira & Correia, 2013).

SfM Photogrammetry. 2D images can be used to create a 3D point cloud with the SfM method, such as using a commercial photogrammetry software, Agisoft PhotoScan (Edmondson et al., 2019; Roberts et al., 2020). The photogrammetric point cloud would be converted to digital elevation model (DEM) (Puppala & Congress, 2019) (for roadway and ground surface) and 3D mesh model (Kalfarisi et al., 2020; Roberts et al., 2020) (for other objects), and be translated to 3D imagery that is named as surface height plot (Edmondson et al., 2019), depth map (Roberts et al., 2020). The pixel value of a 3D image represents the elevation information instead of the intensity value of a 2D image. Then, pavement geometrical information, such as the longitudinal slope and transverse slope of a roadway, would be determined (Puppala & Congress, 2019), the detailed surface shape and profiles of the pavement would be reconstructed (Edmondson et al., 2019; Roberts et al., 2020), and the crack dimensions (width, length and depth) would be measured from a scale aligned 3D mesh model (Kalfarisi et al., 2020). However, to set the ground sampling distance (GSD) around 0.5-mm, the camera or the drone should be at close-range (about 1.5-m) to the target objects' surfaces (Kalfarisi et al., 2020; Roberts et al., 2020). That means the drone-carried camera is unable to complete the roadway image acquisition tasks without traffic regulation. Otherwise, flying a drone at an altitude of 60-m (with GSD=3.6-cm) would be suitable for cracking detection (Dadrasjavan et al., 2019) but not precise enough for measuring a crack's width.

Hyper Spectral Camera. Hyper spectral cameras (HSC) are generally used to measure the spectral range of 350nm-2500nm, which contains spectra beyond the human vision range (400nm-700nm). In the range of 450nm-550nm, the spectral response is sensitive to the change of metal oxides, thus the areas of cracking and potholes (where the interior materials of pavement, including minerals and hydrocarbons, are exposed) have a different spectral response from the areas of undamaged pavement surfaces (which contains metal oxides). The accurate HSC imagery should be captured when pavement surfaces are clean, such as rushed by rains (Abdellatif et al., 2019). The resolution of the HSC, like 1000×1000-pixel in (Abdellatif et al., 2019), is much smaller than cost-effective optical digital cameras, which leads to the HSC not being suitable for cracking quantification beyond close-range as well. In addition, infrared thermography has low resolution; otherwise, it can be carried by a drone to survey a highway at midnight when the traffic volume is low.

Satellite Imagery. High resolution satellite imagery, such as the RapidEye satellite imagery (5-m resolution), is useful in road network evaluation and has been used to extract road networks from forested areas in Western Canada (Kearney et al., 2020). In addition, one study (Ashtiani et al., 2019) utilized Google Earth DEM to estimate the reclaimed asphalt pavement (RAP) stockpiles volume in Washington State. Google Earth contains satellite and aerial images and has the resolution range from 15-m to 15-cm (Google, 2020; Wikipedia, 2020), which makes it a suitable data source for pavement evaluation if the high-resolution images are available at the target areas.

3. 2 Laser Scanner

Terrestrial Laser Scanner and UAV LiDAR. Laser scanner technique is based on light detection and ranging technology (LiDAR). The most commonly used system is the terrestrial laser scanner (TLS), which extends its coverage area with multiple scanning stations on the target area (Barbarella et al., 2019; Puppala & Congress, 2019). Another approach is using mobile LiDAR systems without the setting-up procedures of TLS at each singular scanning station, such as the vehicle mounted mobile LiDAR with an accuracy of 10-mm (Gézero & Antunes, 2019), and the UAV LiDAR with an accuracy of 15-mm when flight altitude is at 30 m (Li et al., 2019).

The scanned results from LiDAR systems are point clouds (Barbarella et al., 2019; Edmondson et al., 2019; Gézero & Antunes, 2019; Li et al., 2019; Puppala & Congress, 2019), which can be used in measuring distances between two aligned point clouds for monitoring vertical deformations on bridge approach and deck (Puppala & Congress, 2019). In addition, a point cloud can be used to create 3D mesh models, including triangulated irregular network (TIN) (Li et al., 2019) and DEM (Barbarella et al., 2019), for extracting pavement geometrical features, translated to 3D imagery that are named as surface height plot (Edmondson et al., 2019) for extracting pavement textural features, and used to extract the road cross-section profiles for identifying pavement rutting (Gézero & Antunes, 2019).

Laser Line Profile Sensor. Laser line profile sensor technique is ideal for quickly getting high precision range information between pavement surfaces and the sensor, which is the core module for commercially available laser crack measurement systems, such as PaveVision, Pathway, Dynatest, and Fugro-Roadware (Serigos et al., 2012, 2015;

A. Zhang et al., 2019). The laser line profile sensor can be mounted on a vehicle, about2.13-m above ground (Zhou & Song, 2020a, 2020b), to have lane-wide coverage (about 4-m) (A. Zhang et al., 2019; Zhou & Song, 2020a, 2020b). The sensor has a depth (range) resolution of 0.1-mm, and the generated range image has a transverse spacing of about 1-mm, and a longitudinal spacing of about 2-mm (Zhou & Song, 2020a, 2020b).

3. 3 Other Non-destructive Techniques

Ground Penetrating Radar. Ground penetrating radar (GPR) has been widely used as a non-destructive testing technique for pavement thickness measurement (Sukhobok et al., 2019) and pavement distress detection (Tong et al., 2020). A GPR system transmits electromagnetic waves with a specific frequency that can penetrate pavement structures. Portion of the waves are reflected when it hits pavement distresses such as cracks, water-damage pits, and uneven settlements; then, these reflected waves are received by an antenna and present abnormal GPR signals differently from the background of undamaged pavement (Tong et al., 2020).

The GPR system can be mounted on vehicles and UAVs too, but a GPR imagery (covers a pavement section with multiple GPR signals) is only able to show either longitudinal or transverse profiles of the pavement structures. Moreover, due to GPR sensors relying on close proximity, the UAV requires operation at a very low level and at a very consistent altitude (VulcanUAV, 2018).

Planar Tomography. Planar tomography is a special case of laminography in which the X-ray source and the detector move synchronously and parallel to the object, whereas the object remains stationary. A 3D volume data of the studied object can be reconstructed by a fast shift-average algorithm (Moosavi et al., 2020). Cracks can be detected with the template matching method (Ehrig et al., 2011). However, this technique is not a reasonable approach for pavement crack detection, because the detector was unable to be installed under a roadway without destruction.

4. Neural Network Modeling for Pavement Evaluation

The pavement surface of a roadway section is a relatively flat plane, which makes it feasible to use 2D imagery, such as top-view and drone photogrammetric orthophoto (Dadrasjavan et al., 2019), to represent the pavement spectral features (Red, Green, Blue), and 3D imagery, such as surface height plot (Edmondson et al., 2019), depth map (Roberts et al., 2020), and range image (Zhou & Song, 2020a, 2020b), to represent the pavement elevation feature. 2D and 3D images can be aligned to the same pixel coordinate, and merged as integrated features (Dadrasjavan et al., 2019; Li et al., 2019). Based on those 2D/3D data sources, the NN modeling approaches, CNN-based classification(Ali et al., 2019; Fan et al., 2019; Maniat, 2019; Protopapadakis et al., 2019; Q. Yang et al., 2020; Zhou & Song, 2020a), and fully convolutional network (FCN)-based pixelwise segmentation(Alipour et al., 2019; Augustaukas & Lipnickas, 2019; Dung & Anh, 2019; Ji et al., 2020; Z. Liu et al., 2019; Song et al., 2020; Zou et al., 2019) are the most common data analysis methods in the reviewed studies for achieving the pavement evaluation objectives of cracking detection, classification and quantification.

4.1 Patch and Object Classification-based NNs

1D Structured Data Approach. Artificial neural network (ANN), or neural network (NN) is an approach to implement machine learning, which has the architecture of multiple layers, including an input layer, hidden layers, and an output layer. By using different hidden layers to connect the input and output layers, the NN can generate anything from numerical values to free-form elements like images, texts, and sounds, while other machine learning methods, such as support vector machine (SVM) (Dadrasjavan et al., 2019; Li et al., 2019) and random forest (RF) (Li et al., 2019), only output numerical values as classification results.

Multilayer perceptron (MLP) is a class of feedforward ANN, which typically has 1D vector input data, such as a GPR trace with 128 samples (Tong et al., 2020) or 300 samples (Sukhobok et al., 2019). The hidden layers usually are fully connected layers (FC or dense layers), dropout layers, and activation functions. The output layer contains a SoftMax activation function to generate a 1D binary class vector for classification tasks, where the size of the output vector depends on the number of classes, such as normal signal and abnormal signal-2 classes (Tong et al., 2020), and pavement thickness (equal to the samples)-300 classes (Sukhobok et al., 2019). Then, the additional Argmax function is required to return the index of the maximum value in the binary class vector as the final numerical value (classification) output (Jiang et al., 2020).

Furthermore, one study (A. Zhang et al., 2019) developed a recurrent neural network (RNN) termed "CrackNet-R" for fully automated pixel-level crack detection on 3D imagery of asphalt pavement. Its key idea is generating a pixel sequence (with the minimum average elevation) as a timely sequence for each pixel in a 3D image, which means the kth input pixel (u,v) is the kth time step; each pixel's probability (of being an element of crack) is determined based on timely probabilities predicted for all pixels' sequences; then, the crack detection result is generated from the mapped pixel probabilities.

2D Imagery Data Approach. Beyond structured data, the most common type of input data for NNs in the reviewed studies is 2D imagery data , which results in CNNs and FCNs being the most widely used data analysis method for pavement evaluation. A CNN starts with a convolutional layer, while its hidden layers contain multiple max-pooling layers, convolutional layers and FCs. A CNN typically ends with a FC with SoftMax activation function for conducting classification tasks, which generates the numerical value (classification) output as the same as MLP (Jiang et al., 2020). That is the major difference from FCNs, because a FCN typically does not contain FC, but it uses a convolutional layer with Sigmoid activation function as the network's end layer for generating the same sized output results as the input images (Jiang & Bai, 2020).

CNNs can be used with sliding window scheme (or overlapping small patches (Jiang et al., 2020; Protopapadakis et al., 2019)) to perform crack and non-crack binary classification tasks (Ali et al., 2019; Maniat, 2019; Protopapadakis et al., 2019; Zhou & Song, 2020a) and pavement cracking categories classification tasks(Maniat, 2019) in each small-patch of a large resolution 2D/3D image. Moreover, when the size of the window patches are very small, like 13×13-pixel (Protopapadakis et al., 2019), the CNN-based image patch classification results would be properly annotating cracks on the large resolution images (Protopapadakis et al., 2019; Zhou & Song, 2020a). Moreover, one study (Fan et al., 2019) also utilized the bilateral filter to smooth 227×227-pixel small patches with cracks, and implemented a k-means clustering based image segmentation algorithm to achieve a pixel accuracy of 98.70%.

Object-oriented Approach. Faster region-based convolutional network (Faster R-CNN) is a NN architecture proposed for object detection (Ren et al., 2017), which has been used for crack detection (Huyan et al., 2019; Kalfarisi et al., 2020). The Faster R-CNN has a similar design as Fast R-CNN (Girshick, 2015), both use the regions of interest (RoIs) to find the target object alternative to the brute force approach of searching all window patches in the whole image (Girshick, 2015). The difference is that in Fast R-CNN RoIs are extracted from the original input image, while in Faster R-CNN RoIs are derived from the feature-maps with a region proposal network (Girshick, 2015; Ren et al., 2017). These networks have two output vectors per RoI, the SoftMax probability which is the same as CNNs to indicate the probability of a RoI being a crack, and the bounding-box regression offset (Girshick et al., 2014) which indicates the location and region of the detected crack object. With the post-process, such as the structured random forest edge detection (Dollar & Zitnick, 2013), the crack can be annotated in Faster-RCNN (Ren et al., 2017) detected cracking regions (Kalfarisi et al., 2020).

Moreover, the network in network (NIN) architecture (Lin et al., 2013) has similar SoftMax and regression ending branches as Faster R-CNN and Fast R-CNN, which has been utilized in studies (Tong et al., 2020) for crack, water-damage pit, and uneven settlement abnormal signals detection on 1-m pavement GPR signals (like 2D images). In this NIN, the FC with SoftMax function is used to classify the abnormal signals; and, the (fully connected) regression layer is used to obtain a crack's peak location and width, water-damage pit's depth, width, and length, and uneven settlement's depth, width and length.

4.2 Pixelwise Segmentation-based NNs

Classical FCNs Approach. The reviewed studies adopted several classical FCN architectures in identifying cracks with digital images, such as FCN (Shelhamer et al., 2017), U-net (Ronneberger et al., 2015), SegNet (Badrinarayanan et al., 2017) and DeepLabv3+ (Chen et al., 2018), which were designed for image semantic segmentation tasks. Study (Alipour et al., 2019) developed the "CrackPix" for pixelwise crack detection based on FCN and reached a pixel accuracy of 92.1% for detecting concrete cracks in images of bridge surfaces, building walls and slabs, and sidewalk surfaces. U-net is a FCN architecture for biomedical image semantic segmentation, which has been adopted in concrete crack detection (Z. Liu et al., 2019), and pavement crack detection that reached a pixel accuracy of 98.92% and an Intersection of Union (IoU) of 0.4850 (Augustaukas & Lipnickas, 2019); U-net has been used as the generator for "CrackGAN" (K. Zhang et al., 2020); and, U-net has the advantage of reaching higher accuracy with smaller training data sets (image and manually annotated ground truth cracks) (Z. Liu et al., 2019; K. Zhang et al., 2020). SegNet is a deep convolutional encoder-decoder architecture for pixelwise segmentation, which has been adopted in identifying road networks in the large forested area from the RapidEye satellite imagery; and, the segmentation results are a pixelwise annotated road and non-road binary image (Kearney et al., 2020). Moreover, DeepLabv3+ has been utilized for crack detection on asphalt pavement (Ji et al., 2020).

FCNs have more complex architecture than CNNs, especially in hidden layers. FCNs may: use convolutional and deconvolutional layers to generate and explain feature-maps; use max-pooling and up-sampling layers to resize feature-maps and keep the main features after convolutional and deconvolutional layers; use activation function ReLU in hidden layers for faster model training; use dropout layers to prevent overfitting; and, use merging layers to combine the feature-maps (tensors) from two different layers as a new feature-map (tensors) (Chollet, 2020; Jiang et al., 2020; Jiang & Bai, 2020), such as the element-wise addition layers used in FCN (Shelhamer et al., 2017) and channel concatenation layers used in U-net. Considering the limitation of GPU memory, the modern FCN models would still be trained with small size image data sets, but on model prediction stages, the well-trained model could process images of any size. For image segmentation, using SoftMax function in the ending convolutional layer of a FCN achieves the probability of each pixel belonging to the predefined classes, such as crack and non-crack (Badrinarayanan et al., 2017; Song et al., 2020). Thus, the sliding window scheme used along with CNNs is unnecessary, and the additional filtering and segmentation post-processes after crack patches and objects are detected by CNNs and Faster-RCNN would be skipped. For example, the Mask region-based CNN (Mask-RCNN) (He et al., 2020) completed crack detection and segmentation simultaneously (Kalfarisi et al., 2020), because the Mask-RCNN has an additional branch of fully convolutional layers than Faster-RCNN and Fast-RCNN for generating crack instance segmentation results.

Modified FCNs Approach. Beyond adopting classical FCNs, the reviewed studies also developed several FCNs by modifying classical FCNs. One study (Dung & Anh, 2019) developed a convolutional encoder-decoder for concrete crack image semantic segmentation with an average precision of 89.3% in testing. The encoder block contains convolutional and max-pooling layers, while the decoder block contains up-sampling layers and both convolutional and deconvolutional layers, which is different from DeconvNet (Noh et al., 2015) (only use deconvolutional layers in decoder) and SegNet (only use convolutional layers in decoder). The end convolutional layer using SoftMax function is the same as SegNet.

"DeepCrack" developed in study (Zou et al., 2019) is based on SegNet, but is different from the original SegNet. It added skip-layer fusion (contains channel concatenation, convolutional, deconvolutional, and crop layer) to connect the encoder and decoder network. Its output is a 1-channel prediction map that indicates the probability of each pixel belonging to the crack by using a cross-entropy loss.

"CrackSeg" developed in (Song et al., 2020) is focused on road crack detection and achieved a precision of 98.0% and a mean IoU of 73.5%. This network has a multiscale dilated convolution module (Yu & Koltun, 2015) for generating rich crack features, and also has an up-sampling module to restore crack feature-maps to the input image size, and then predict the crack spatial distribution with the SoftMax function. The comparisons of "CrackSeg" and other methods on the same "CrackDataset" (Song et al., 2020) showed the "CrackSeg" has the best performance in pavement crack detection followed by DeepCrack, DeepLabv3+, PSPNet (Zhao et al., 2017), U-Net, and SegNet.

Novel NNs Approach. Study (F. Yang et al., 2020) proposed a novel network architecture named feature pyramid and hierarchical boosting network (FPHBN) for pavement crack detection. FPHBN contains four modules: a bottom-up module for hierarchical feature extraction, a feature pyramid module (using top-down architecture) for merging context information to lower layers, a hierarchical boosting module to adjust sample weights, and a side networks module for supervision learning (F. Yang et al., 2020). Moreover, beyond the "CrackGAN" (K. Zhang et al., 2020), the generative adversarial network architecture (GAN) also has been utilized in study (Y. Liu et al., 2020) to enhance motion blurred concrete crack images (captured by drone on high-rise building façades).

5. Literature Review Summary, Discussion and Recommendations

5.1 Summary

The reviewed RSNNPE studies conducted research in identifying pavement distresses of cracking, rutting, pothole, subsidence, water-damage, and uneven settlement with 2D/3D imagery acquired by remote sensing and non-destructive testing techniques. Among them, the cracking detection attracted the attention of most researchers, because it can be conducted by using the most cost-effective and convenient device, smart phones (Huyan et al., 2019; Roberts et al., 2020), to capture pavement surface images which can be used to create 3D mesh model by SfM and TIN for pavement distresses visualization and quantification as the building walls cracking study in (Kalfarisi et al., 2020). That will have the same effect as using LiDAR technique to acquire 3D point cloud and converting to 3D mesh model in (Li et al., 2019).

Additionally, the reviewed cracking detection research (using optical cameras) has the limitation that only focuses on identifying cracks themselves from 2D images, but skipped the task of pavement assessment in flexible pavement visual survey. The pavement longitudinal cracking needs to be measured in linear feet per 100-ft. station, and the transverse cracking needs to be measured in terms of number of transverse cracks per 100-ft. station (Stacks, 2019).

Furthermore, compared to pavement crack image data sets collected from university campuses (Ji et al., 2020; Z. Liu et al., 2019; F. Yang et al., 2020), the "CrackDataset" (Song et al., 2020) that consists of pavement images of 14 cities in the Liaoning Province, China, is much better to present all pavement distresses features with a high traffic volume.

5.2 Discussion and Recommendations

Drone Photogrammetry based Data Acquisition. The reviewed study (Dadrasjavan et al., 2019) showed a feasible approach of using key frames extracted from a drone's video to generate an orthophoto of the surveyed roadway and then detecting cracks using the generated orthophoto. The coverage of an orthophoto is much larger than a single frame image, detecting and annotating pavement cracking on orthophotos would yield out a better visualization results, and it would be more feasible to conduct project level or network level pavement evaluation. In addition, when the high-resolution satellite images or aerial images are available for the target road project or network in Google Earth imagery (or other free access satellite imagery), the pavement cracking assessment would be more efficient with them by skipping the time-consuming and labor-consuming aerial imagery acquisition operations by the infrastructure management agency-self. For example, study (Jiang et al., 2021a) presented the experimental results of using Google Earth imagery for visual condition surveying of Interstate 43 (I-43) in Milwaukee County. Moreover, Google Street View is a good data source for road network pavement cracking detection, which has been verified in studies (Maniat, 2019; Mohammed, 2017).

For obtaining the detailed shape of pavement surfaces, such as accurate depth resolution (0.1-mm), transverse and longitudinal spacing resolution (1 to 2 mm) as the laser line profile sensor technique (Zhou & Song, 2020a, 2020b), the drone should be flying in close-range to pavement surfaces. According to the online GSD Calculator (Propeller Aero, 2018), a drone's (DJI Phantom 4 Pro V2.0, build in camera) flight height at 2, 4, 7, 14, 18, and 36-m, have the corresponding GSDs of 0.5, 0.11, 0.19, 0.38, 0.49, and 0.99-cm/px, respectively. Thus, the minimum altitude for guaranteeing cracking quantification accuracy needs to be determined for different types of sensors, including optical camera, HSC, thermal imaging camera or infrared night vision camera. The safest altitude for minimizing impacts to drivers needs to be evaluated in future research. Otherwise, the cracking quantification is hard to be conducted without traffic regulation when using drone photogrammetry.

Data Preparation. The reviewed studies with NN modeling are either input spectral features (RGB imagery), or input elevation features (3D imagery) (A. Zhang et al., 2019), then convolutional layers are used to generate complex feature-maps based on the input images. However, the traditional method, SVM classifier, is preferred to input structured combination features. In study (Dadrasjavan et al., 2019) a set of spectral features (RGB, and mean), textural features (contrast, correlation, energy, and homogeneity), and geometrical features (extent, eccentricity, minor axis length major axis length, and orientation) were generated from the drone photogrammetric orthophoto. The results showed using the combination features had an accuracy of 92% in crack/non-crack classification. Only using textural features had the lowest accuracy of 81% as cracks are not significantly different from non-cracks in asphalt pavement. Using spectral and structural features separately had the accuracy of about 85%, because cracks in color and shape are different from non-cracks (Dadrasjavan et al., 2019). The CrackForest (Shi et al., 2016) is a RF classifier for road image crack detection, which used an integral channel feature (3 color, 2 magnitude and 8 orientation channels). In addition, a RF classifier used multiple features to reach an accuracy of 92.3% in potholes/subsidence/undamaged pavement classification (Li et al., 2019), where multiple features were extracted from the UAV LiDAR point cloud, which include point cloud elevation, reflection intensity, multiscale roughness index, multiscale Gaussian curvature, and several object-oriented geometric features. Thus, for NN modeling methods, concatenating RGB 3-channel and an elevation 1-channel to form a 4-channel input image may have better performance in pavement distress detection, classification, and segmentation. For example, study (Jiang et al., 2021b) showed the experimental results of adding features of points' elevation or points' normal directions to the RGB feature can increase the performance of U-Net-based pixelwise segmentation in pavement cracking detection compared to the RGB feature alone. Moreover, the detectable pavement distresses would not be limited to cracking, and could also include potholes, subsidence, rutting and others, because the geometrical features are available in the integrated 4-channel images.

The crack image deblurring approach proposed in (Y. Liu et al., 2020; Nishikawa et al., 2012) could be considered when the images are captured with camera movement. In addition, when the pavement evaluation data source is satellite imagery, such as Google Earth Imagery, applying SRGAN (Ledig et al., 2016), a GAN for image super-resolution (SR), to enhance the satellite imagery should be considered, where the high quality image can be captured by drone for training the SRGAN.

NNs Selection. The output of NNs would be a pixel probability (of classification of pavement distresses) map (using SoftMax function in the ending convolutional layer), and the additional post-process is required to annotate the class labels to each pavement distress object in the original input image (as pixelwise semantic segmentation results). In addition, NNs' output would be a pixel probability (of damaged/undamaged, which is referred to a specific pavement distress) map (using Sigmoid function in the ending convolutional layer), then the post-process is required to classify the pixel probability map by clustering (Oliveira & Correia, 2013) or threshold segmentation (Shao et al., 2019). The quantification can be conducted by measuring the pavement distress objects' width, length, and area (if the image is captured in close-range with a small GSD cm/px), and depth (if elevation in 3D imagery is available). Moreover, the image processing methods proposed in the reviewed studies can be used to refine crack skeletons by the weighted median filtering (Shao et al., 2019), edge detection (Roberts, Prewitt, Sobel, and Laplacian of Gaussian) and frequency (Butterworth and Gaussian) domain techniques (Dorafshan et al., 2019), and measure crack width with a high accuracy of 93.7% by the segment-based method (Weng et al., 2019).

Furthermore, the differences of overall accuracy between the CrackSeg, DeepCrack, DeepLabv3+, PSPNet, U-Net, and SegNet are not significant in pavement crack segmentation. Thus, using U-Net to conduct pavement cracking detection in road network is better as U-net requires much fewer model training data sets than other FCNs, which can be separately trained for concrete and asphalt pavements, different weather and illuminate conditions, and different photography devices.

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ID 51

An Analysis of the Contractor's Project Performance based on Field Performance Rating

Md Shah Jamal[1] and Ahmed Abdelaty, PhD[2*]

[1,2]University of Wyoming, Laramie, Wyoming, 82072, USA
aahmed3@uwyo.edu

Abstract

Project schedules are affected by several factors, and contractor's project performance is one of them. In many cases, contractors develop a schedule that is not accurate enough to represent work sequencing. Besides, their project delivery methods create plenty of challenges to track and monitor project progress. This paper illustrates the project performance of contractors based on seven different factors obtained from the contractor's field performance rating by one State Highway Agency (SHA). The purpose of this study is to analyze the field performances of the nineteen contractors that delivered thirty public transportation projects during the last three years in one state. The authors collected the contractor's project performance reports from one SHA. The performance reports summarize the overall contractor's performance throughout the project. This study contributes to the body of knowledge by identifying areas of improvement of the contractor's performance based on the analysis of performance reports. The study also presents recommendations to the contractors to improve future transportation projects.

Keywords

Project Performance, Schedule Delay, Public Transportation Projects.

1. Introduction

Contractor's project performance depends on the overall field performance rating during the construction period. Contractors are responsible for the overall success of construction projects, including achieving cost, schedule, quality, and safety goals (Russell et al., 1997). The traditional pre-qualification or contractor selection, common in the construction industry, includes weighting specific criteria such as financial stability, experience, completed projects, achieved quality, and key personnel (Yasamis et al., 2012). Combining a contractor's quality performance assessment with a contractor's technical and economic performance assessment provides a better understanding of the contractor's overall capabilities (Yasamis et al., 2012). Clients often focus on stakeholder satisfaction and needs, but contractors aim to minimize project costs and duration (Bryde & Robinson, 2005). In practice, the definition of project performance is often based on the client's needs (Chan & Chan, 2004). Going by previous studies undertaken by researchers, it was found that various types of criteria are considered in evaluating the construction project performance (Idrus et al., 2011). However, there is no standardized approach or guideline for determining the performance of construction projects (Idrus et al., 2011). The primary purpose of this study is to analyze the contractor's overall performance based on seven different factors adopted by one SHA during the construction period. The data collection is mainly from one SHA in the USA and the nature of these thirty projects represent multiple types of work including new construction, maintenance and rehabilitation. This paper aims to identify the strengths and weaknesses of several contractors to complete the project from the SHA's perspective. Finally, the study presents a list of recommendations to improve the project delivery process.

2. Literature Review

Project performance determines the desired outcome through feedback and evaluation of the contractor's key personnel and field performance. Previous studies have determined the criteria to measure the contractor's project performance, including several factors such as cost, time, quality, client satisfaction, user expectation, friendliness of environment, health and safety, and quality of workmanship (Songer & Molenaar, 1997; Lim & Mohamme, 1999, Indus et al. 2011, and Chan, 2004). Other factors included labor dependency, project management, resource availability, flexibility.

Similarly, studies by Yasamis-Speroni et al. (2012) and Bryde et al. (2005) used factors such as quality, team integration, scope, schedule, procurement, risk, and owner satisfaction to evaluate the performance of construction projects effectively. In addition, Ng et al. (2002) developed a dynamic e-reporting system that evaluates the contractor's performance based on financial stability, work progress, quality, safety, resources, management capabilities, communication, cooperation, integrity, and claims, and contractual disputes.

On the other hand the study of Hashem et al. (2018) determined the contractor's project performance from the statistical analysis of the project delivery method, competency trust, organizational trust, and relational trust (Hashem et al. 2018). Based on the literature review, several studies had different evaluation criteria regarding contractor performance. However, all these factors are based on cost, schedule, quality, and owner satisfaction. Thus, this research will also use similar performance criteria to determine areas of strength and weaknesses regarding contractor's performance. Performance criteria was established by SHA which was the scope of work of the researchers.

3. Research Methodology

The authors conducted the research in two phases. The first phase is the data collection, and the second phase is the data analysis. The data collection is mainly from one SHA in the USA. The data analysis is qualitatively analyzing the project performance reports for thirty public transportation projects. The qualitative analysis resulted in identifying problems that affect project performances. Finally, a list of recommendations is presented to overcome common problems discovered in the project performance reports.

3. 1 Data Collection

The research team collected the daily work report, baseline schedules, and contractor's field performance reports from one SHA. The field performance reports evaluate the contractor's performance based on the pursuit of the work, conformance with contract specification, traffic control and mobility, and timely and complete submittal of documents. The performance report also includes an evaluation of cooperation with the SHA personnel, property owners, utility, mitigating cost and schedule delay, and superintendence of the project.

The authors sorted out thirty different projects out of forty-nine delivered by nineteen different contractors in the last three years. Then, these projects were evaluated based on baseline schedules, daily work reports, and construction reports. The projects' types of work ranged from new construction to maintenance and rehabilitation. These projects included a variety of activities such as crushing and stockpiling crushed surfacing material, fencing, median cable barrier, draining, milling plant mix, lane rental, bent cap replacement, drilled shaft foundations, installing signs, rockfall mitigation, pavement markings, and bituminous pavement surfacing, bridge rehabilitation, and miscellaneous works. The total value of the thirty projects was approximately $107.4 million. The range of the total amount of the thirty projects was $243,387.00 to $1,103622.00.

3.2 Data Analysis

The authors analyzed the contractor's project performances through seven different factors listed in Table 1. For each evaluation criterion, the authors went through the performance reports and summarized the weaknesses or deficiencies identified by the SHA. The analysis was done by analyzing the language used in the field performance rating. The SHA assigns a rating for each factor of the seven factors and a written description for each criterion met or unmet. The authors used the written description on the field performance report the determine the challenges faced by contractors. Upon completion of the project, contractors got an opportunity from the SHA to review the performance report for accuracy. Contractors can achieve the maximum rating by satisfying all the criteria described by the SHA.

The first criterion is the pursuit of the work, which refers to pursuing the work with sufficiently trained labor, materials, and equipment. The assessment included the skill level of the workforce, the condition of equipment to accomplish the job, and active progress on critical path items each day following the approval of the baseline schedule.

The second criterion evaluated by the SHA is conformance to contract specifications, plans, materials quality, temporary and final products, and services. This also included supplemental specifications, notification clauses, special provisions, dispute resolution processes, federal, state, and local laws. The third criterion evaluated by the SHA was the effective use of worksite traffic control maintainer to monitor and correct traffic control deficiencies. This criterion also rewards the initiative to identify and fix traffic control and mobility concerns regardless of timing.

The fourth criterion is the evaluation of timely submittal of documents in an accurate manner, including all required information and details to prevent withholding pay estimates in work. This also includes documents originating from suppliers and subcontractors. The fifth criterion is to evaluate the level of coordination between contractors and SHA personnel responsible for administering the contract and inspecting the completed work. The sixth criterion is the contractor's ability to mitigate schedule delays and cost overrun. Finally, the SHA evaluates the superintendent's performance based on the initiative and management of all aspects of the projects. After evaluating all items, the maximum rating attainable would be 100 points.

4. Results and Discussion

A significant difference was observed after analyzing the field performances of the thirty projects and nineteen different contractors. Table 1 provides the overall project performances based on seven different factors. The names of the projects were given acronyms A_n, where n is a value between 1 and 30. Generally speaking, the total point data were more spread out, whereas cooperation with the SHA personnel was more consistent. In addition, inferior performances were noticed in the pursuit of the work, traffic control and mobility, and timely and complete submittal of documents factors. The following subsections discuss the challenges faced by contractors for each factor.

Table 1. Contractor's Project Performance Report

	Performance	Average	Maximum	Minimum	Standard Deviation	Median	Mode
1	Pursuit of the Work	14.93	20	0	5.8	14	20
2	Conformance with contract specification (plans and quality control excluding traffic control)	15.23	19	5	4.02	14	19
3	Traffic Control and Mobility	13.2	16	0	3.64	13	16
4	Timely and Complete Submittal of Documents	12.1	15	0	4.34	15	15
5	Cooperation with the SHA Personnel, Property Owners and Utility Companies	11.2	12	8	1.24	12	12
6	Mitigate Cost and Time Overrun	7.47	8	4	1.48	8	8
7	Superintendence of Project	8.57	10	3	2.33	10	10
8	Total points	83.53	100	50	13.14	84.5	100

4.1 Contractors Project Performance

The contractor's project performances showed that the maximum field performance rating was 100 out of 100, whereas the lowest was 50 (see Figure 1). Out of the thirty projects, around 13% achieved full credit, and more than 50% obtained more than 80% overall score. Approximately 17% of projects scored between 70 to 79, and the rest, 20%, were below 70. The name of the contractors was given acronyms X_n where n is a value between 1 and 19. Contractor X_1 completed four projects which were A_1, A_4, A_7, and A_{15}. Contractor X_2 did projects A_3 and A_{21} whereas, contractor X_3 completed projects A_{12}, A_{18}, and A_{20}. Projects A_8, A_9, A_{14}, A_{28}, and A_{29} were completed by contractor X_4, and contractor X_5 completed A_{23} and A_{24} projects. Although the last and first projects' scores of the contractor X_1 were the same (92), the middle two projects' performances were 84 and 78, respectively. X_1 contractor's cooperation with the SHA personnel, property owners, and utility companies was consistent in all four projects. Still, there were ups and downs in other factors. In the case of contractor X_2, they achieved 20 points less in their last project (80) than the previous one (100). X_2 contractor failed to complete the project before the deadline, and they obtained only 3 out of

20 in the pursuit of the work factor. Contractor X_3 got full credit from the three projects (see Figure 1). Contractor X_3 was consistent in all three projects. On the other hand contractor X_4, gradually improved from the oldest (67) project to the latest (97). However, 80% improvement (50 to 90) was noticed regarding contractor X_5's overall project performance from the previous project to the recent one.

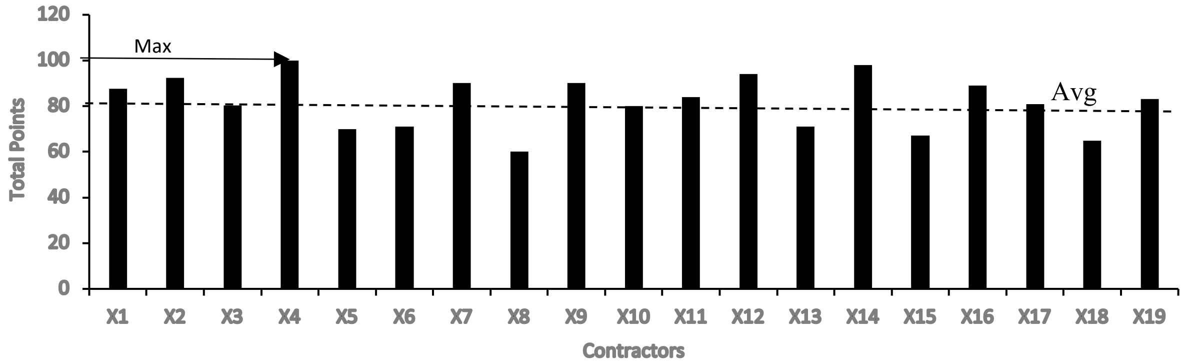

Fig. 1. Contractors Project Performance

4.2 Pursuit of the work

Figure 2 shows the scores earned for all 30 projects regarding the contractor's pursuit of work. Around 46% of the total projects did well and finished physical work and the punch list items before the stipulated completion date. The contractor of project A_1 was active in getting the work done through the project's duration but had several unskilled crew members. The SHA charged liquidated damages to project A_3 for ten days for a total of $19,250 for failure to complete all work before the completion date. Projects A_4 and A_7 met all critical dates outlined in the special provision for construction requirements. The contractor of project A_9 missed a few critical dates, and their crew members were unskilled. In the case of project A_{10}, there was no superintendent on the site, and there were no regular meetings. Due to weather and other projects, they did not complete punch list items within ten working days as stipulated by contract. The contractor of projects A15 and A23 worked with a minimal crew, and they could not complete the punch list items on time.

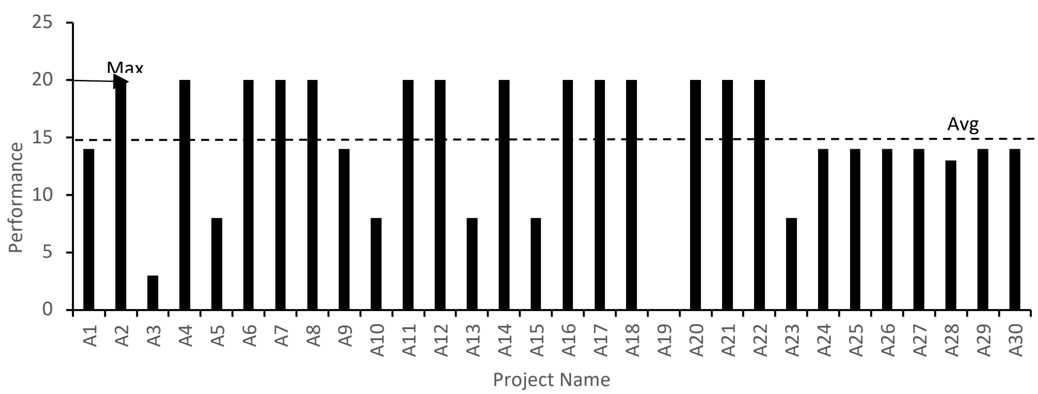

Fig. 2. Pursuit of the Work

Unfortunately, Project A19 failed to meet the previous target due to being 35 days behind the completion date. The superintendent of project A24 had difficulty scheduling equipment and labor to keep the project on schedule. Materials and some truck parts were difficult to get due to COVID-19 for project A26. Finally, projects A27 and A30 had some quality issues with concrete finishing.

4.3 Conformance with contract specification (plans and quality control excluding traffic control)

There were no quality control issues for 36% of projects, whereas 27% of contractors worked hard to complete the project according to the plans and specifications (Figure 3). However, there were minor quality issues on some of the completed work. During removal, there was damage to existing items that had to be replaced at no additional cost to the SHA. Contractor A_2 had issues with both gradations and densities of the materials used for the subbase. The projects A_6 and A_{11} had multiple days when concrete was not conforming with specification, and the SHA had to reject numerous loads. Because of the excellent communication and quality work, SHA received a great finished product of project A_7. The contractor of project A_{10} reworked the crushed base many times to get some sections accepted by the SHA.

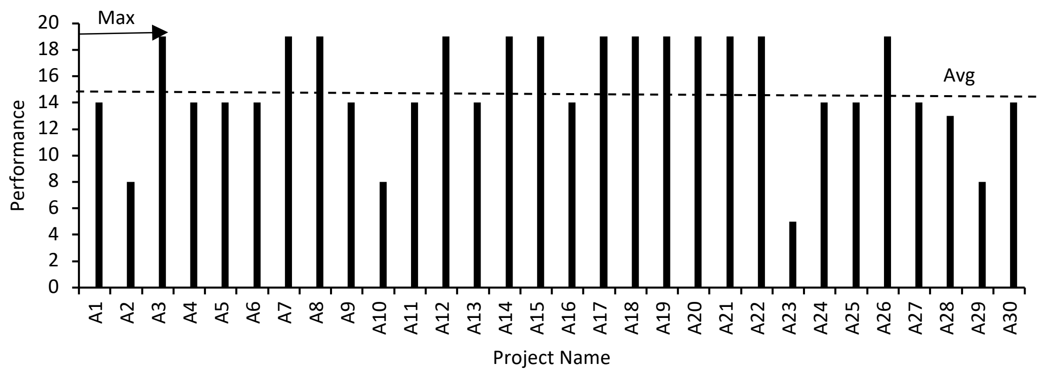

Fig. 3. Conformance with contract specification (plans and quality control excluding traffic control)

4.4 Traffic Control and Mobility

In total, 40% of projects obtained full credit ensuring all traffic controls were adequately set up and maintained throughout the job. Figure 3 shows the scores for traffic control and mobility for each project. In the case of projects A_2 and A_7, there were a lot of issues with traffic control. The contractor did not submit diaries concerning the temporary traffic signals to the SHA on time. The work of project A_4 started without proper traffic control in place. The SHA had to direct around 16% of contractors multiple times to take corrective actions on the traffic control. Unfortunately, the performance of project A_8 was not acceptable due to the unavailability of the traffic maintainer, a faulty device, or lack of proper setup of the traffic control on multiple occasions. Inappropriate traffic control was set up a couple of times in projects A_9 and A_{28}. On the other hand, there was a long-term temporary traffic control issue in project A_{13}. Traffic control of projects A_{16}, A_{25} and A_{29}, was placed and performed satisfactorily with minimal SHA direction. The traffic control subcontractor of project A_{23} was charged for liquidated damages on several issues.

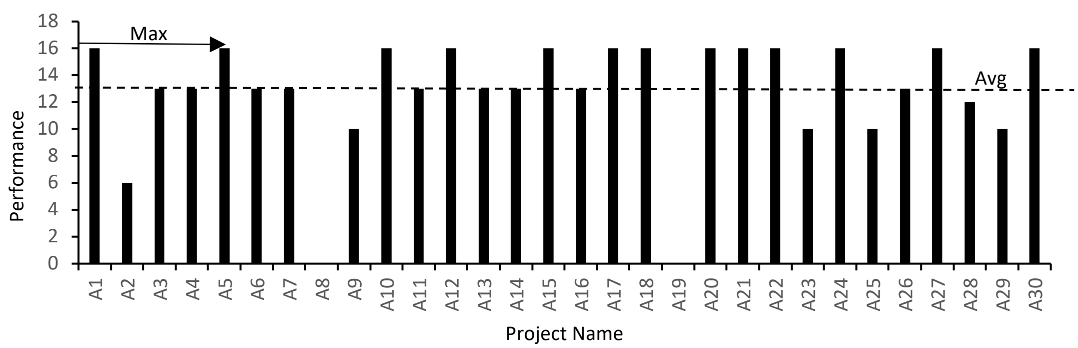

Fig. 4. Traffic Control and Mobility

4.5 Cooperation with SHA Personnel, Property Owners and Utility Companies

Most of the projects (70% of the thirty projects) achieved full credit communicating with the SHA and other parties involved with the project (see Figure 4). The contractor of project A_2 worked with landowners and took care of their concerns, such as dust control and restoration of their plan site. Some items and topics of project A_5 were not always clearly communicated to the SHA. The contractor of projects A_6 and A_{11} had a complaint from a member of the traveling public and wanted corrective action. The contractor of project A_{10} worked well with the SHA but had some conflicts with landowners regarding installing mailboxes and fence material. The contractor cooperated with onsite SHA personnel of project A_{16}, and they should improve communication regarding communicating work schedules and changes with more advanced notice. Coordination of project A_{25} was acceptable, but improvements were made to notify SHA when plans had changed. The contractor A_{27} cooperated well with all, but they could not deliver the project as stipulated in the schedule.

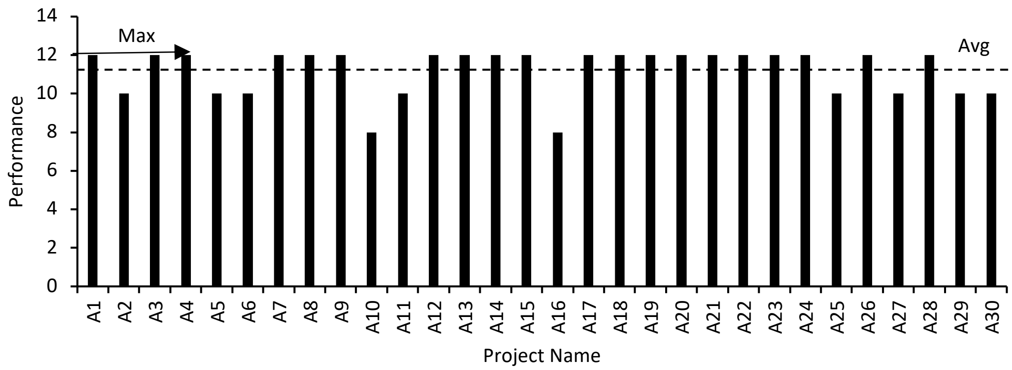

Fig. 5. Cooperation with SHA Personnel, Property Owners and Utility Companies

4.6 Timely and Complete Submittal of Documents

Contractors did not delay submitting documents of 63% of projects (see Figure 4). Project A_1 struggled to get the necessary information to the SHA. Overall, Contractor of the project A_2 did well with certification and documentation. There were only a few instances where the SHA had to ask for certifications or testing results several times. Project A_5 had averaged an approximately nine calendar day delay in processing the monthly estimate due to not submitting documents in a timely fashion. The contractor of project A_7 always submitted the work schedules and payrolls timely, but the contractor did not get full credit because of inaccurate submittals. Due to missing certificates, the authority had to withhold payment on a couple of items of project A_9. There were delays to the submitted documentation of projects A_{17} and A_{29}. The SHA did not receive most of the schedules of the project A_{27} in time, and the contractor was too late to notify the SHA, adequately helping out with an inspection.

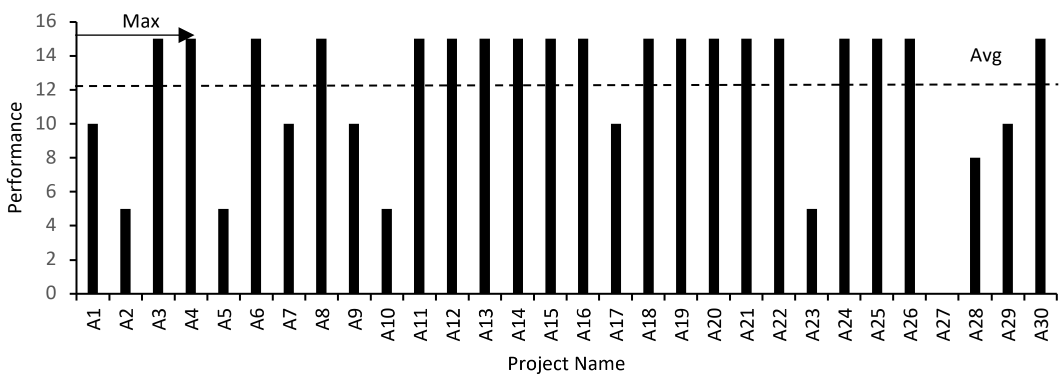

Fig. 6. Timely and Complete Submittal of Documents

4.7 Mitigate Cost and Time Overrun

The contractors worked diligently to avoid time overruns for 60% of projects (see Figure 5). Contractors of projects A_1 and A_{22} worked to prevent additional charges but required changes to the requests for additional funds. The SHA had to remind them that they needed specific bid items for change orders on multiple occasions. The contractor of project A_2 completed their work on time, despite several challenges such as the availability of the personnel due to COVID-19. Project A_3 was in overtime, and the contractor worked diligently to reduce the number of overtime charges on this project. The SHA provided proper documentation for project A_4 change orders. There had been no change orders on project A_5. Still, the contractor could not hit some critical dates due to repairs to out-of-specification items. The contractor of projects A_{10} and A_{15} did not have a superintendent on site. Project A_{10} had a foreman, and the contractor of Project A_{15} worked with a minimal crew. For these reasons, they were not able to complete the project timely. Project A_{19} did not document information accurately when asking for more time or additional money. When the SHA requested additional information from project A_{23}, it was not provided in a timely manner.

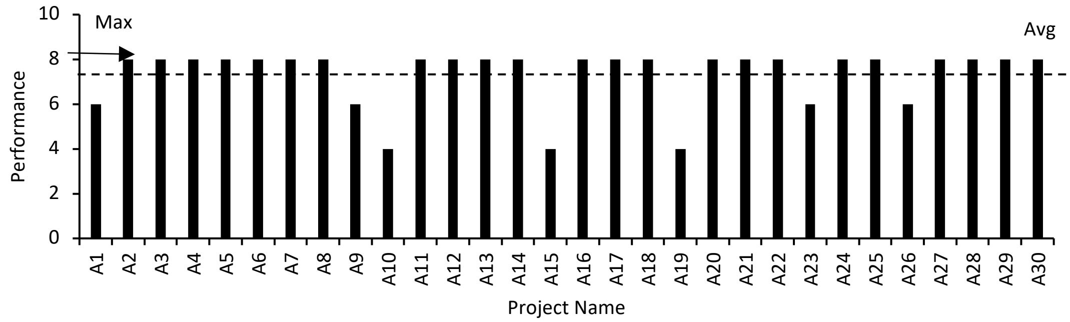

Fig. 7. Mitigate Cost and Time Overrun

4.8 Superintendence of Project

Superintendents were always available for 70% of the projects and were knowledgeable of completing the work (see Figure 5). Several superintendents were assigned to project A_1, and some of them were more organized and better understood the schedule, plans, and specifications. That being said, they were always available for collaboration and could work through difficulties on the project. Although superintendents were present in project A_8, the constant change of superintendents towards the project's closeout phase created poor communication with the SHA personnel. The contractor of project A_{10} had a person on site that was a go-between the office manager and the field activities. All things that need a decision on the field need to be run by someone in the office. However, the onsite superintendent of the project had little knowledge of the specification and plans. Communication was lacking when it came to notifying the resident engineer office of the schedule of project A_{30}. In the case of project A_{29}, the superintendent was routinely available and executed the direction of the engineer. The superintendent of project A_{22} was not available on the site rather than via phone. As a result, projects A_8, A_{10}, A_{22}, A_{29}, and A_{30} had delays in completing the projects in time.

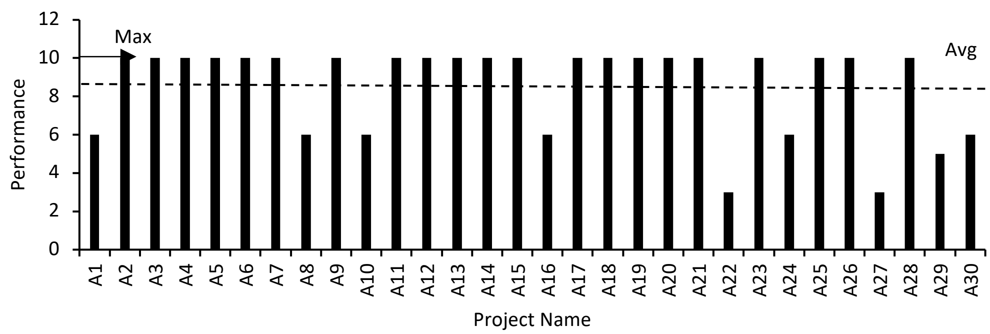

Fig. 8. Superintendence of Project

5. Conclusions and Recommendations

The paper presents the overall field performances of 30 different transportation projects delivered by 19 contractors in one state. There were issues related to the project performance of the contractors regarding the pursuit of work, traffic control and mobility, and timely and complete submittal of documents. The main weaknesses were failure to meet schedule requirements, lack of traffic maintainer and proper set up of the traffic control devices, using faulty traffic control devices, and failure to submit proper schedule documentation to notify the SHA with delays. Most contractors exhibited effective communication with SHA and mitigating cost and time overrun. COVID-19 has played a vital role in project performances for the past two years. Due to the pandemic, most contractors faced a scarcity of materials and personnel.

The primary recommendations for future projects are discussed as follows. (1) The contractor should not assign unskilled crew members to projects because hiring unskilled labor was a common comment in the project performance report. (2) Baseline schedules should be developed and used for the project control and not just to satisfy contract requirements. In some projects, the baseline schedule was merely a list of activities with no clear and logical sequence between activities. Also, some schedules had activities with unrealistic durations (i.e., more than 60 days). The SHA agency should enforce minimum requirements regarding baseline schedules and project updates. (3) Contractors should submit acceptable daily work reports and schedule updates of the project in a timely fashion. (4) The SHA should require a revised baseline schedule with every approved change order to estimate schedule slippage accurately. However, this will not provide its full potential until the SHA requires minimum standards for developing baseline schedules. (5) The SHA should require a dynamic logistics and site layout plan that outlines the project phases when applicable. Damage to completed work was observed and noted in the performance reports. This could be improved by requiring contractors to have mobilization and logistics plans, which can help improve and maintain good communication with the SHA personnel and project stakeholders. (6) The contractor has to submit diaries concerning traffic control to the SHA on time. Many performance reports indicated that contractors lacked timely submission of diaries and work reports. (7) SHA should require a communication management plan for all projects involving public stakeholders and utility companies. This would force contractors to plan for communication and coordination issues with different project stakeholders. There was one case in which a contractor changed the location of a drilled shaft without notifying the SHA. This would have been avoided with a proper project communication management plan. (8) Finally, the SHA should require a staffing management plan to help contractors plan for superintendents, labor availability, and requirements. It is evident from the analysis that some projects had labor and personnel issues due to COVID-19 and poor planning. The challenges and recommendations discussed in this paper are limited to 30 projects from one SHA. It may be difficult to genralize this research's findings and recommendations across other SHAs. Further research should be conducted on projects from different SHAs to identify common challenges and recommendations to improve contractors' performance.

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COVID-19 Vaccination Hesitancy and Perceived Risk of Infection Among Construction Workers

Fahim Ridwan Nabil[1], Mostafa Namian[2], Jamel R. Pittman[3]

[1,2,3] East Carolina University, Greenville, North Carolina, USA
namianm19@ecu.edu

Abstract
The number of cases for COVID-19 is increasing across the United States. Construction workers are also affected by the COVID-19 as most of the construction work is done in person. Construction work is full of different hazards, and COVID-19 has introduced additional health hazards to the workers. Identifying hazards is an essential element to avoid injuries, illnesses, and accidents. Significantly less research has been done to determine how construction workers perceive COVID-19. The goal of this research is to observe based on vaccination status how construction workers perceive COVID-19. A questionnaire was prepared to test the research goal, and in-person interviews were conducted to get workers' responses. Workers who are working on the construction projects were only interviewed. Based on the data analysis work, it was observed that unvaccinated workers do not think COVID-19 is a risk or threat to them. Vaccinated employees (M=7.13, SD=1.84) had a significantly different assessment of COVID-19 risk than unvaccinated workers (M=5.60, SD=1.74), t(41)=2.801, p<0.01. The research finding indicates that more workshop and safety awareness programs are needed to create awareness among construction workers. The study's findings can assist safety practitioners and experts in implementing safety procedures that encourage workers to adopt a safety mindset.

Keywords
COVID-19, Risk Perception, Pandemic, Vaccination, Construction Hazard.

1. Introduction
Wuhan, China, saw an outbreak of acute atypical respiratory illness in December of 2019 ,and during the Chinese new year the virus quickly spread from Wuhan to other parts of the world (Yuki et al., 2020). A new coronavirus was found to be the reason behind the respiratory illness, and as a result of its high similarity (80%) to SARS-CoV, the new coronavirus was renamed the severe acute respiratory distress syndrome coronavirus-2 (SARS-CoV-2, 2019-nCoV), which caused ARDS and significant mortality in 2002–2003 (Ksiazek et al., 2003). The illness caused by this virus is widely known as COVID-19. On January 30, 2020, the World Health Organization (WHO) labeled the issue a public health emergency of international significance. Later on March 11, 2020, WHO marked the issue as a global health pandemic (BBC, 2020; WHO, 2020). The first reported COVID-19 case in the U.S. was on January 23, 2020, and since then, the number of cases has proliferated (CDC, 2022). Due to the surge of COVID-19 infection in the U.S., on March 13, 2020, the president declared a national emergency concerning the COVID-19 (Presidential Actions, 2021). As of February 2022, the number of total confirmed cases for COVID-19 is 75,937,801, and the total number of deaths is 894,810 (CDC, 2022). Figure 1 illustrates the reported daily number of deaths in the U.S. due to COVID-19 from the start of the pandemic till February 2022. COVID-19 was identified as the leading cause of death in the U.S. (Woolf et al., 2021).

The emergence of an unusual COVID-19 pandemic brought the world to a stop. Like all other industries construction industry was not exceptional from this pandemic. As the construction industry is mostly labor orientated, it was hit hard by the pandemic. Works had to be stopped due to the transmission of the virus. There are several trades that

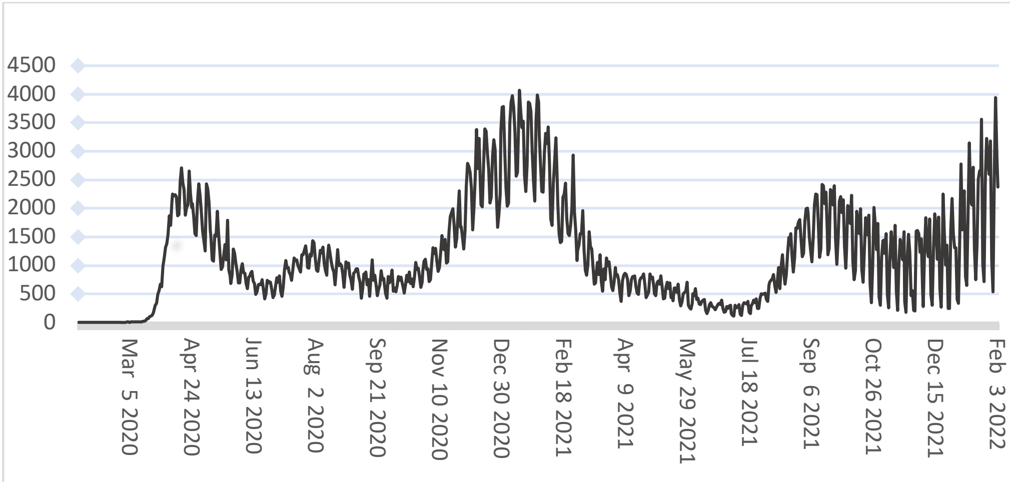

Fig. 25. COVID-19 Deaths in the U.S. (CDC, 2022).

are regarded essential in the 20 states that adhere to Cybersecurity & Infrastructure Security Agency (CISA) standards, and construction was one of them (NCSL, 2021). As the construction work resumed, to undertake tasks or supervise the job appropriately, workers began to work in the job site during the pandemic as most of the construction work needed to be done on-site (Gamil & Alhagar, 2020). Construction workers had the highest positive rates for asymptomatic cases when tested, according to a research study of over 730,000 COVID-19 tests indicated among all occupants (Allan-Blitz et al., 2020). These occupations were essential workers, including healthcare workers, first responders, corrections officers, senior caretakers, grocery store, and food service employees. Another study found that construction workers were five times more likely to be hospitalized with COVID-19 than employees in all other industries, including those who could work from home (Pasco et al., 2020). These two studies can give an idea about the general scenario of COVID-19 infected construction workers, but there is no definite census available for construction workers, which can represent the actual number of workers who have been infected by the COVID-19. A recent research study observed that 41% of unvaccinated workers are hesitant to be vaccinated (Nabil et al., 2022).

A hazard is a circumstance that puts people's lives, health, property, or the environment at risk. Chemical, biological, environmental, health, natural, and other calamities, as well as fire and other workplace risks, fall under the broad umbrella term of hazards. The construction industry is already present with different kinds of hazards. The number of reported fatalities in 2021 is 1008, which is 4.991% lesser than the reported number of deaths in 2020 (U.S. BLS, 2022). Construction workplaces have around six times as many fatalities per employee and twice as many permanently disabling injuries compared to manufacturing industries (Helander, 1991). Because of the COVID-19 pandemic, this situation has worsened significantly and now poses a significant threat to construction workers' health. As revealed by different studies, the significant number of cases found among construction workers, COVID-19, poses a serious concern (Allan-Blitz et al., 2020; Pasco et al., 2020).COVID-19 is a biological hazard in the workplace and poses a risk to the health and safety of workers (Amaechi et al., 2022). A proper understanding of the COVID-19 biohazard among the construction workers can prevent the transmission and can be used as an effective control tool to stop transmission.

Workers' risk-taking behavior may be influenced by their subjective perceptions of risk and the workplace environment, which in turn may affect objective measures of risk and safety. Understanding how construction workers perceive dangers, especially those that aren't readily apparent, is therefore critical for any workplace safety policy. Workers may engage in risky behavior if their perceptions of risk are inaccurate(Arezes & Miguel, 2008; Namian et al., 2018). However accidents are preventable if they are identified by the construction workers for most of the cases (Albert & Hallowell, 2012). The majority of risk perception studies have looked at the likelihood of an accident occurring. Therefore, there is a lack of knowledge of how workers perceive "invisible" dangers of COVID-19 in the workplace. The current study aimed to determine the COVID-19 safety risk perceived by the construction workers.

2. Research Method

The research goal was achieved in three phases: Phase I was the questionnaire preparation. The data collection work was conducted in North Carolina construction projects in phase II. For phase III, the collected data were integrated and statistically analyzed using SPSS. The data analysis is divided into two sections. One is the descriptive analysis of demographic information, and another is risk perception. The details are as follows in the below sections.

2.1 Questionnaire Preparation

A questionnaire was prepared to observe the risk perception of COVID-19 by the construction workers. After preparing the questionnaire, it was submitted to Institutional Review Board (IRB) for approval. No personal identifiers were used in the survey. The questionnaire was divided into three sections: demographic information, Vaccination attitude, COVID-19 contraction, and Risk perception of COVID-19. Section one of the survey collected participants' demographic information. Section two asked about the vaccination status and COVID-19 contraction-related questions. The last section had questions about perceiving the risk of COVID-19. Likert scale was used in the risk perception to determine the perception and attitude towards COVID-19. Sample questions that are used in the survey are shown in Table 1.

Table 24. Example questions for COVID-19 Safety Concerns on Construction Sites Perceived by Construction Workers.

Section	Example questions
Demographic	"Construction Experience" "What is your current job title/specialty?" "Type of Current Project you are currently working on."
Vaccination attitude and COVID-19 contraction	"Have you ever been tested positive with COVID-19?", "How severe was your COVID-19?", "How many days did it take to recover from COVID-19.", "Have you received your COVID-19 vaccine?"
Risk perception COVID-19	"COVID-19 can affect my safety performance.", "All individuals are universally susceptible to be infected by COVID-19.",

2.2 Data Collection

After getting the IRB approval, the researchers conducted a data collection. Data collection was held in person. No survey link was distributed online to avoid non-response bias. Participants were selected from construction sites randomly. During the research, 43 construction employees from ten different projects in North Carolina were questioned. The participants were actively engaged in the construction trade during the time of the interview. There is no response or completion rate in the survey as they were in person.

2.3 Data Analysis and Result

2.3.1 Descriptive Analysis (Demographic and Vaccination Attitude)

All the interviewed participants were from different parts of North Carolina. Though some of the participants also have worked in other states at some point in their career. Table 2 represents the participant's age and construction experience. The participant's maximum age was sixty-one years, and the minimum was twenty-one years. Among 43 participants, 40 were male, and only 3 participants were female, accounting for only 7% of the total number of participants. When participants were asked about whether they had contracted COVID-19, only 25.4% said they had contracted COVID-19, and 74.6% said they never contracted COVID-19.

Table 2. Distribution of age and construction experience of the participant.

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Age (years)	43	40	21	61	37.63	10.983
Construction experience (years)	43	40	0	40	14.17	9.115

The results show that a quarter of the participants were affected by COVID-19. As part of the questionnaire, participants were also asked whether they have OHSA 10/30 certification. OSHA 10/30 is a training program provided by the Occupational Safety and Health Administration for 10 or 30 hours of instruction about common job-related health and safety hazards (OSHA, 2022). 67.4% said they have OHSA 10/30 Certification, and 32.6% said they don't have any certificate. Table 3 gives an idea of the general characteristics of the participants.

Table 3. Distribution for general characteristics construction workers.

Characteristics	Number	%
Gender		
Male	40	93%
Female	3	7%
COVID-19 Contraction		
Positive	11	25.6%
Negative	32	74.4%
Vaccination		
Vaccinated	22	51.2%
Not Vaccinated	21	48.8%
OHSA 10/30 Certification		
Yes	29	67.4%
No	14	32.6%

2.3.2 Risk Perception Analysis

Independent samples T-Test was done to study the risk perception of the construction workers. Groups were created based on the workers' vaccination status, and all the perception questionnaires were test variables. The risk perception capacity of the two groups was calculated and analyzed.

An independent samples t-test was conducted to compare the perception of COVID-19 risk between vaccinated and unvaccinated workers. Results revealed that there was a significant difference in the perception of COVID-19 risk between vaccinated workers (M=7.13, SD=1.84) and unvaccinated workers (M=5.60, SD=1.74), $t(41)=2.801$, $p < 0.01$. Workers who are vaccinated tend to think COVID-19 is a risk for them.

Table 4. Analysis result risk perception based on vaccination status.

Experimental condition	n	Mean	SD	Std.Error Mean	p-value
Vaccinated	22	7.1250	1.83509	0.39124	0.008
Unvaccinated	21	5.5952	1.74190	0.38011	

3. Research Implication

Workers' safety attitude and risk perception play a critical role in preventing casualties at construction workplaces. The current study shows a relationship for perceiving COVID-19 as a threat among vaccinated and unvaccinated construction workers. As COVID-19 is an invisible threat to construction workers' health, safety, and environment, this study will help the researcher understand the construction worker's attitude toward making the construction workplace safer. The results shows that strong relationship between risk perception and vaccination status reveals that unvaccinated workers tend not to consider COVID-19 a threat. Therefore, awareness and safety programs can be organized targeting unvaccinated construction workers to raise awareness. In addition, the study will help safety managers, owners, and project managers better understand workers' attitudes towards COVID-19.

4. Conclusion

The construction industry is one of the most dangerous industries to work in. Workers in the construction industry fail to recognize many risks in their workplaces and frequently underestimate the related safety risk of those hazards detected. The safety attitude of construction employees has been found to significantly impact their performance (Namian et al., 2016). This research studies the perspective of construction workers on how they perceive the COVID-19 threat. The research study aims to serve as a reference in improving construction workplace safety culture.

Construction projects are full of hazards. It is ranked as the most dangerous industry which experienced the most workplace fatalities (NSC Injury Facts, 2020). COVID-19 has introduced a new threat to the construction workplace, which can cause illness, injuries, or fatalities (Koh, 2020; Wolff et al., 2021). The frequency of injuries in the construction workplace increases when hazards remain unrecognized by the construction workers (Carter & Smith, 2006). Therefore, if workers can identify COVID-19 as a safety hazard, there is a chance of having lesser contraction of COVID-19 among construction workers.

In this study, forty-three workers were interviewed across the same state. Four questions were used in the study to evaluate the risk perception of COVID-19. The results from the data analysis showed that there is a strong correlation between the vaccination attitude and risk perception of COVID-19. The result suggests that vaccinated workers acknowledge COVID-19 as a threat in the construction workplace. The limitation of the research is all data were collected from a single state North Carolina. The data might have been different if the researchers could get data from several states across the U.S. In addition, the sample size of the study was relatively small. A bigger sample size is always preferable in any research project. But due to COVID-19 restrictions, not all worksites were accessible by the researchers.

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Evaluation of Building's Life Cycle Carbon Emissions Based on BIM and LCA: A Case Study of Affordable Housing in Morocco

Hanane Bouhmoud[1,2*], Dalila Loudyi[1], Salman Azhar[2]

[1] Faculty of Science and Technology of Mohammedia – Hassan II University of Casablanca, BP 146 Mohammedia 28806, Morocco
[2] McWhorter School of Building Science, Auburn University, 216 M. Miller Gorrie Center, Auburn, 36849, Alabama, USA
hb.bim.phd@gmail.com

Abstract
Morocco is undertaking tremendous actions toward reducing the impact of climate change especially in terms of energy efficiency and building sector adaptation. However, until now neither Building Information Modeling (BIM) has been used in this context nor an analysis of Building's Life Cycle Carbon Emissions (BLCCE) of affordable housing has been conducted in Morocco. This paper aims to propose an approach using BIM and Life Cycle Assessment (LCA) to calculate and analyze the carbon emissions in different stages of building lifecycle of affordable housing named 'social housing'. For this purpose, an affordable housing parcel containing full-residential and mixed-use buildings was considered as a case study. Consequently, beside emphasizing the BIM capability to facilitate Embodied Carbon (EC) emissions, this study revealed that, concrete, bricks, steel, ceramic tiles, and paint are the most contributing materials in emitted EC with an approximative share of 90%. Meantime, glass is an impactful material for mixed-use buildings as it contributes to 8% of the total EC. Furthermore, this paper discloses that for social housing, the operational stage contributes to 98% of the BLCCE where 73% among it is due only to fossil energy consumption (butane), and full-residential buildings produce 11.6% more BLCCE than mixed-use buildings.

Keywords
BIM, Carbon footprint; CO_2 emission; Life Cycle Assessment; Embodied carbon; Operational Carbon; Green building

1. Introduction and Local Context:
Reducing greenhouse gas (GHG) emissions is a worldwide concern for which several inter-countries agreements have been signed. For instance, Kyoto Protocol and Paris Agreement display the commitments of industrialized countries and economies to limit and lessen their GHG emissions in accordance with agreed individual targets (Martha Benduski, 2020). In 2009, Morocco announced its commitment to engage strategies toward adopting more ecological solutions namely enhancing the energy efficiency and producing at least 52% of national electricity based on renewal sources by 2030 (Habous, 2009). For this purpose, Morocco prepared the related legal context through several laws and codes, namely the law N°13.01 in 2010 that regulated the production and use of renewal energy. Meanwhile, they built Noor Ouarzazate platform, one of the biggest mega-power solar plants in the world with a production of 580 MW of Concentrated Solar Power (CSP), and launched Noor Midelt platform, in 2018, a mega-power solar plant that is expected to produce more than 1600 MW of CSP (Masen, 2019). In the same vein, the kingdom committed, in 2015 as part of Paris Agreement, to reduce its GHG emissions by a minimum of 17% by 2030 compared to the status quo and a maximum of 42% under the condition of obtaining foreign financial aids (UNFCCC, 2020).

Building sector is a significant economic sector in Morocco as it contributes to an average of 6.6% of the national gross domestic product and offers almost 1 million permanent jobs and annual 30000 temporary jobs. Yet, because building sector is one of the most contributing sectors in climate change, as it is responsible for 33% of global carbon emissions and 40% of worldwide energy consumption (Peng, 2016) Morocco engaged several actions toward reducing the impact of this sector. Indeed, Morocco mandated utilizing only solar water heaters for all construction projects that benefit from incentives given by the government including affordable housing. Moreover, in 2014, upheld by foreign investment funds, Morocco launched and mandated energy efficiency codes, mainly the "building energy efficiency code" and "thermal construction regulations in Morocco" that entered into force in 2015 (AMEE, 2014). Thus, to facilitate its implementation, a software, named BINAYATE, was developed based on the thermic characteristic of a large material database including local building materials, and made available for architects.

In 2015, Morocco adopted the "2030 agenda of the sustainable development goals" and joined the "global alliance for buildings and construction" working for efficient and resilient buildings to reach a Net-Zero buildings by 2050. In the same year, Morocco upgraded the law N°13.01 through the law N°58.15 to regulate the direct injection of low voltage in the cities' electrical network which will allow reducing the energy bill (Moroccan Government, 2016). However, its implementation remains dependent on the upgrading of the electrical network infrastructure and the standardization of electricity suppliers. Furthermore, in 2016, monumental actions were undertaken in the same vein, namely creation of the "Moroccan buildings alliance for the climate", where almost all key actors of the national Architecture, Engineering, and Construction (AEC) industry were signatories of the creation agreement, release of the climate change mitigation, and adaptation plan for housing sector, and submission of the project "Improving the energy performance of Moroccan housing" to the Nama Facility (DHPV, 2017). Likewise, the country launched the national strategy for sustainable development of eco-construction that synthetizes and addresses the actions to be undertaken and its timeline to meet the goals that Morocco committed to, either as a member of the aforementioned organizations or as a self-active country in this area (Meriem Houzir, 2016).

However, despite the approved benefits of Building Information Modeling (BIM) in enhancing buildings sustainability, Building's Life Cycle Carbon Emissions (BLCCE) evaluation (Banteli & Stevenson, 2017), and decision making (Chen & Pan, 2016), it has not been considered in any of the undertaken actions by Morocco toward reducing building sector impact on climate change. Therefore, this study aims to address following objectives:

1. Highlight the capability of BIM to fasten and facilitate calculating carbon emissions in different stages of a building lifecycle in early stage of design phase, and help reducing building sector impact on climate change,
2. Provide a reference of carbon emissions and footprint of the most common types of affordable housing adopted in Morocco (full-residential buildings, mixed-use buildings, and parceling),
3. Reveal the top impactful building materials on the environment in terms of EC emissions,
4. Disclose the most contributing components in operational carbon emissions,
5. Access BLCCE of considered affordable housing types based on Life Cycle Assessment (LCA) approach.

The remaining of this paper is structured into 5 sections. The following section lays out a literature review of similar studies, existing BIM-based practices, and BIM added-value related to building carbon emission assessment. Next section describes the adopted research methodology. The 3rd section provides a description of the chosen case study and the reason behind this choice. In the 4th section, this paper outlines the case study results that are discussed in the following section. Finally, the related conclusions and recommendations are stated.

2. Literature Review

Several studies have emphasized BIM potential on validating hypothetic approaches and enhancing the efficiency of designing, assessing and decision making regarding the best solutions for sustainable buildings. For instance, Li et al. (2021) pointed out the capacity of BIM in performing many assessment and simulation works of a facility without having to construct it physically, and showed through a BIM-based approach that prefabrication helps in reducing EC emissions. Wang et al. (2018) used BIM technology to validate that using onsite-recycled materials diminish buildings carbon footprint. Abanda et al. (2017) developed a BIM-based framework that automates integration of the UK new rules of measurement in building design stage. Mousa et al. (2016) used BIM to create an automated tool that enables both assessment of Operational Carbon (OC) and real-time detection of carbon emission problems. Raza et al. (2019) reviewed the BIM benefits exposed in the literature and affirmed that BIM allows achieving energy efficiency and saving operational cost at design stage as it helps in testing the best sustainable solutions such as putting occupancy sensors, adapting the orientation of the building, and using different types of insulation on walls and windows. As shown in Table 1, several scholars used integrated BIM models to evaluate the amount of BLCCE generated by different categories of buildings in construction stage (EC), operational stage (OC) which is assumed to last 50 years, and demolition stage (Demolition Carbon – DO). However, no study has been undertaken in any African country.

Table 25: Literature review of similar studies

Reference	Building type	Building description	Country	Findings
(Lu et al., 2019)	Hospital	4-storey building with reinforced concrete structure and 6367 m^2 as Gross Floor Area (GFA)	China	Reinforced Concrete (RC) and Heating Ventilation and Air Conditioning (HVAC) are top carbon emitter, where RC emits 50% of EC and HVAC emits 54% of OC. Among the BLCCE, EC represents 8% and OC 91%.
(Gardezi et al., 2014)	Residential building	1-storey low-cost building	Malaysia	Brick, steel (all types included), and RC are the top contributors in EC emission, with respectively 37%, 26%, and 22%
		Apartment unit	Korea	More than 82% of the total EC was emitted by steel and concrete, with respectively 424.2 and 584.2 kg-CO_2/m^2 as footprint
(Khan et al., 2019)	Commercial building	4-storey building	Pakistan	Top contributing materials in EC emission are steel, concrete, brick, and aluminum with respectively 34%, 20%, 15%, and 12% of the sum of EC
(Shah et al., 2019)	Educational building	4-storey building with a framed structure and 2362 m^2 as covered area	Pakistan	Brick, steel, and concrete are the most impactful materials in terms of EC emission as they are responsible for 38%, 36%, and 14% respectively
(Peng, 2016)	Office building	15-storey building with a reinforced concrete structure & 16873 m^2 as GFA	China	For the BLCCE, OC, EC, and carbon emitted in demolition stage (DC) represent 85%, 13%, and 2% respectively
		Not specified	USA	OC represents 90% of total BLCCE, and EC represents the remaining 10%
			Japan	The BLCCE is divided into 82% for EC, 14% for OC, and 3-4% for DC
			Australia	OC represents 85% of total BLCCE, and EC represents the remaining 15%

3. Research Methodology

The authors used a case study method to meet the objectives of this study. As shown Fig. 1, the adopted research workflow is based on BIM technology and LCA approach and developed through 6 main steps. (1) After investigating the local context and conducting a literature review, the authors adopted an affordable housing parceling as a case study. (2) Based on Autodesk Revit, they develop BIM models of different buildings composing the parceling, and (3) extract the quantities of the most used materials: reinforced concrete, steel, bricks, glass, mortar, ceramic tiles, wood, and paint. Then, (4) based on LCA approach, they calculate the EC based on the material emission factors issued from ICE (Hammond & Jones, 2011), and the OC based on (FM6PE, 2016). Whereas the DC is assumed to be 10% of EC (Peng, 2016). Next, (5) they present the results from the 3 previous steps, then (6) discuss the findings, and draw conclusions and recommendations.

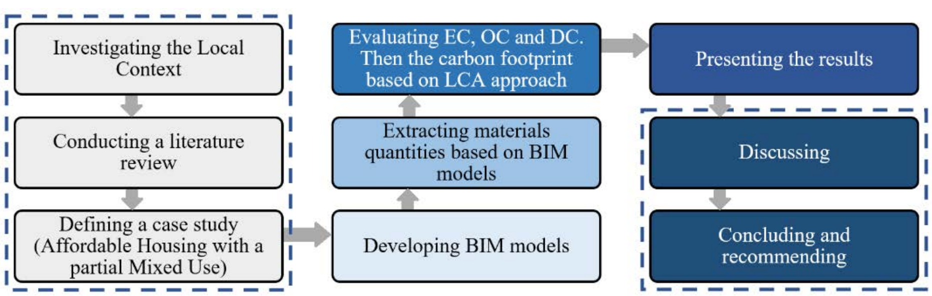

Fig. 13: Research methodology workflow

4. Case Study Outline

According to a thoughtful study conducted by housing ministry, more than 55% of Moroccan housing demand is for social (affordable) housing, called social housing, and 30% of it is concentrated in the region of Grand Casablanca (Bouhmoud, 2018). As a result, the housing ministry set additional incentives and established predefined requirement specifications for social housing development. Therefore, as a case study, the authors considered a parceling of social housing project. This parceling was realized in 5 years on a field of 61300 m² in Casablanca – Morocco with a covered area of 80564 m^2 and was arranged in 65 repetitive 5-storey buildings split into 43 type A-buildings and 22 type B-buildings where both types have concrete structures (see the master plan of the parceling, and BIM models of both buildings type A and B in Fig. 2). Building type A is a full residential building with a covered area of 1232m², whereas building type B is a mixed-use building where the ground floor is designed as a commercial area and upper floors as a residential housing and it has a built covered area of 1254m². The total 65 buildings included 1212 affordable apartments (3 rooms + kitchen + bathroom) and 110 commercial areas.

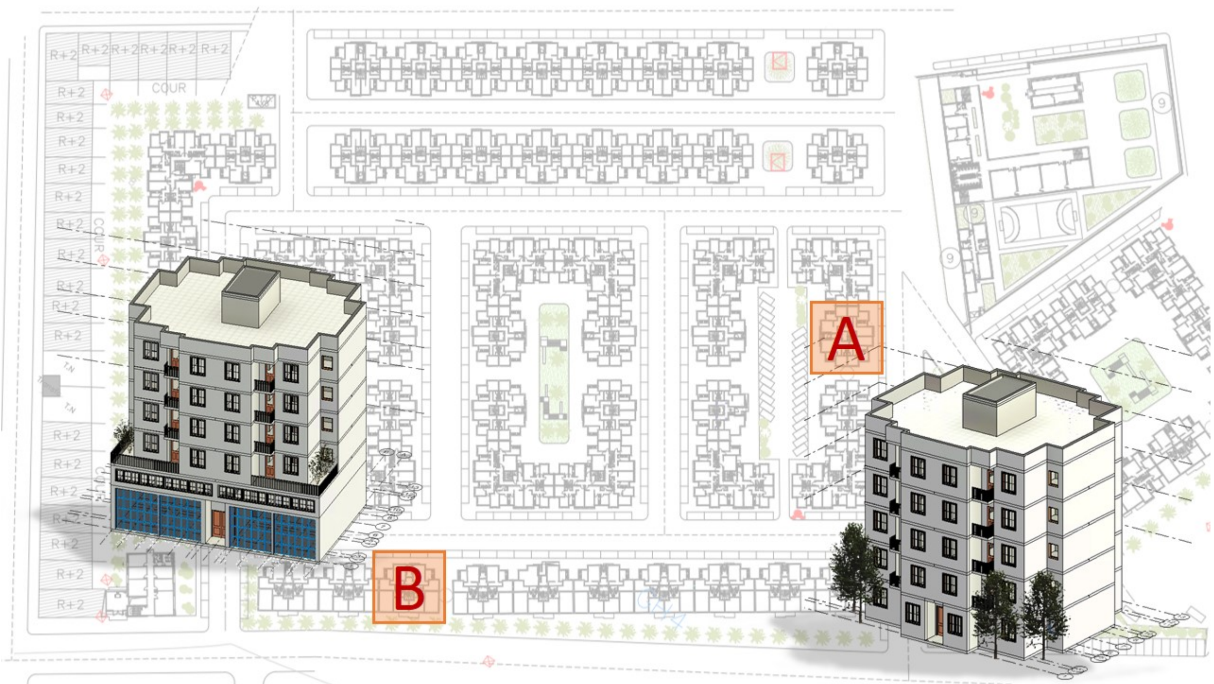

Fig. 14: Master plan of the parceling and BIM models of the repetitive buildings type A and B

5. Results

5.1 EC of Buildings type A and B Due to Used Material

Table 2 reveals the EC generated by materials (EC_m) for both buildings A and B. It illustrates the extracted materials quantities from BIM models, CO_{2-eq} factors of these materials, their densities, and the resulted amount of CO_{2-eq} generated by the total quantity of each material. The EC footprint of each type was calculated referring to their built area.

Table 26. EC emission and related carbon footprint of buildings type A and B.

Materials	Density	CO_2 factor (CO_{2-eq}/Kg)	Unit	Building type A			Building type B		
				Quantity	EC emissions	Share	Quantity	EC emissions	Share
Concrete	2.5 T/m³	0.107	M³	363	97103	29%	398	106465	29%
Steel	7.8 T/m³	2.77	Kg	21657	59990	18%	24244	67156	19%
Brick 7+10	0.76 T/m³	0.24	M²	1029	41292	21%	984	39486	17%
Brick 7+7				777	19841		568	14504	
Brick 7				806	10291		709	9053	
Aluminum	2.7 T/m³	9.16	Kg	428	3920	1%	938	8592	2%
Glass	2.5 T/m³	0.91	M²	84	11510	3%	207	28216	8%
Mortar	1.1 T/m³	0.13	M²	6647	15728	5%	5992	14259	4%
Ceramic tiles	2.0 T/m³	0.70	M²	1423	39833	12%	1470	41149	11%

Paint	1.2 T/m^3	0.87	M^2	6647	34695	10%	5992	31276	9%
Wood	0.45 T/m^3	0.55	M^2	203	2507	1%	168	2074	1%

5.2 Operational Carbon of Buildings Type A and B

Table 3 provides the annual operational carbon (OC_{annual}) emissions of both building's types. They were evaluated by summing the produced OC from the monthly average of consumed energy either electrical or fossil (butane), used water, and produced wastes. To evaluate the total OC, the operational stage was assumed to last 50 years as it is mentioned in the literature review.

Table 27. OC emission of buildings type A and B.

	Type	Average consumption per month												Annual Value	Emitted OC by building (CO_{2-eq})	
		01	02	03	04	05	06	07	08	09	10	11	12		Annual	Operational stage
Electrical energy (kwh)	A	2500	2500	2400	2200	2200	2000	1900	1900	2200	2200	2400	2500	26900	17590	879500
	B	2625	2625	2520	2310	2310	2100	1995	1995	2310	2310	2520	2625	28245	18470	923500
Fossil Energy (kg)	A	720	720	720	720	1200	960	960	1200	720	720	720	720	10080	403100	20155000
	B	636	636	636	636	1020	828	828	1020	636	636	636	636	8784	351270	17563500
Water use (m^3)	A	120	120	120	120	140	140	140	160	120	120	120	120	1540	57740	2887000
	B	101	101	101	101	117	117	117	133	101	101	101	101	1292	48440	2422000
Domestic Wastes (kg)	A	3720	3360	3720	3600	4960	4800	4960	5580	3600	3720	3600	3720	49340	71230	3561500
	B	3441	3108	3441	3330	4743	4440	4588	5239	3330	3441	3330	3441	45872	66220	3311000

5.3 BLCCE and Carbon Footprint of Buildings Type A and B:

Table 4 synthesizes the emitted CO_{2-eq} of all stages of each building type. The OC emissions of each where it is equal to the sum of evaluated emitted carbon in the three stages of each building lifecycle as follows:

$$BLCCE = EC + OC + DC \quad with \begin{cases} OC = 50 \times OC_{annual} \\ DC = 10\% \times EC \end{cases} \qquad (1)$$

Table 28. BLCCE and related carbon footprint of buildings type A and B.

Stage \ Building type	Building type A			Building type B		
	Total emission (CO_{2-eq})	Share	Carbon footprint (CO_{2-eq}/m^2)	Total emission (CO_{2-eq})	Share	Carbon footprint (CO_{2-eq}/m^2)
Construction stage	337183	1.2%	273.7	362703	1.5%	289.3
Operational stage	27483000	98.7%	22307.6	24220000	98.4%	19314.2
Demolition stage	33718	0.1%	27.4	36270	0.1%	28.9
BLCCE	27853901		22608.7	24618973		19632.4

5.4 BLCCE and Carbon Footprint of the Parceling:

The total amount of emitted carbon by the case study during each stage of its lifecycle is the sum of carbon emitted by all included buildings as shown in equation (2). Hence, the total BLLCE of the parceling is evaluated by summing the emissions of all stages. Table 5 provides the BLCCE and carbon footprint of the parceling as well as its breakdown into the 3 different stages, related shares, and their carbon footprint.

$$C_i = 43 \times C_i(building\ type\ A) + 22 \times C_i(building\ type\ B) \quad with \quad C_i = EC, OC\ or\ DC \qquad (2)$$

Table 29. BLCCE and related carbon footprint of the project.

Stage	Total carbon emission (kilo CO_{2-eq})	Share	Carbon footprint (CO_{2-eq}/m^2)
Construction stage	22478.3	1.3%	279.0
Operational stage	1714609	98.6%	21282.6
Demolition stage	2247.8	0.1%	27.9

BLCCE	1739335.2	21589.5

6. Discussion

The study showed that for both full-residential affordable housing (type A) and mixed-use affordable housing (type B), concrete, bricks, steel, ceramic tiles, and paint are the most contributing materials in emitted EC with a total proportion of 90% for type A and 85% for type B (Fig 3). However, the commercial units of building type B reduced the impact of brick, mortar, and paint in favor of glass impact. Whereas the EC emissions of the earlier 3 materials counted for 36% and EC emission of the glass counted for 3% for building type A, the 3 materials emitted only 30% of total EC emissions of building type B and the glass was responsible for a portion of 8% (Fig 3).

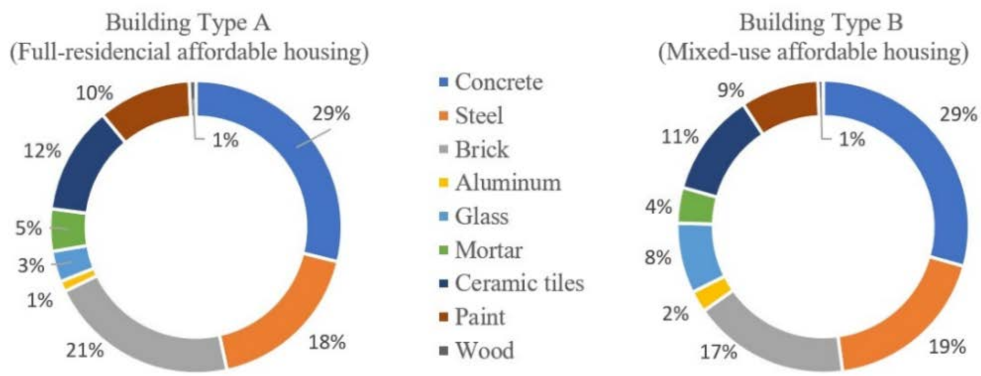

Fig. 15: Contribution of used materials in the total EC emissions and Comparison of their distribution by building type

As shown in Fig.4, fossil energy is the top contributor in terms of OC emissions as it represents 73% for both types of buildings, tailed by domestic generated wastes and consumed water with almost 13.5% and 11% of the total OC respectively. Meantime, energy, all types included, is responsible for 77% of all OC emissions which explains that most of the undertaken actions toward reducing building impacts on the climate change are associated either to reducing energy consumption or replacing it by a renewable one.

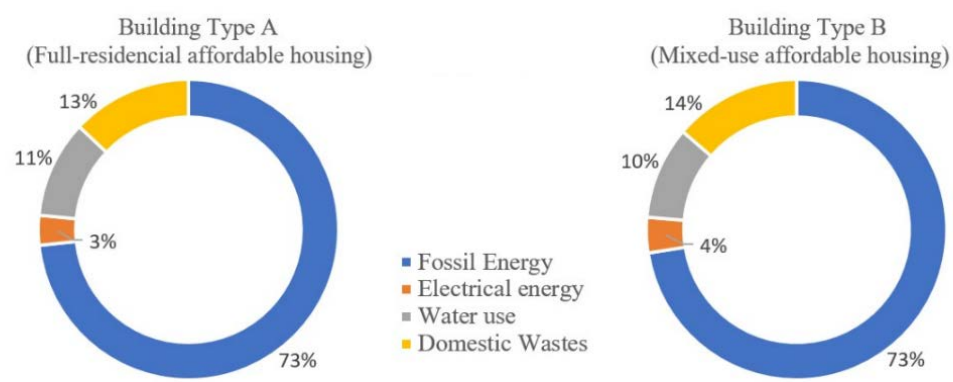

Fig. 16: Contribution of sources of OC in the total OC emissions and Comparison of their distribution by building type

The study discloses that for affordable housing, the carbon footprint of full-residential buildings in either construction or demolition stages is 7.6% less than that of mixed-use buildings (Fig 5.a), contrary to the operational stage where the carbon footprint of full-residential buildings is 11.9% higher than mixed-use buildings (Fig 5.b). Since BLCCE is mostly generated during the operational stage as this stage is responsible for more than 98% of all emitted carbon (Tables 4 and 5), the difference between BLCCE caused by full-residential buildings and these caused by mixed-use buildings has almost the same value with a percentage of 11.6% (Fig 5.c).

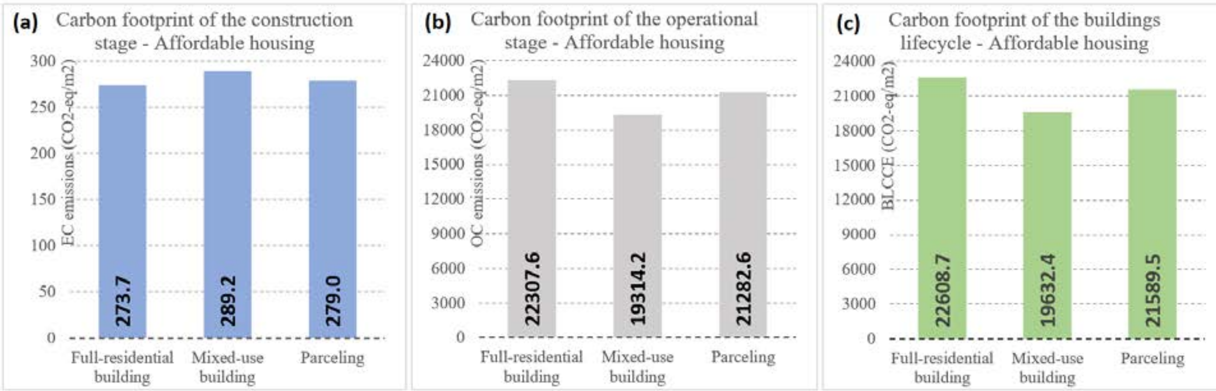

Fig. 17: Carbon footprint of construction stage, operational stage, and building lifecycle of different types of affordable building housing

7. Conclusions and Recommendations

By combining BIM technology and LCA approach, this study provided evidence of the BLCCE evaluation and analysis of affordable housing projects in Morocco based on a case study of a parceling that contains full-residential and mixed-use buildings. As a result, this paper discloses that for affordable housing:

- Concrete, bricks, steel, ceramic tiles, and paint are the most emitting materials of EC by full-residential buildings with a contribution of 90%. Meantime, in addition to these 5 materials, glass is an impactful material for mixed-use buildings where they contribute to 93% of the total associated EC,
- Energy consumption is a top contributor in OC emissions, namely fossil energy that generates 73% of total OC,
- While the carbon footprint of either construction or demolition stages of full-residential buildings is 7.6% less than that of mixed-use buildings, the carbon footprint of the operational stage of full-residential buildings is 11.9% more than that of mixed-use buildings,
- The operational stage is responsible for at least 98% of the total BLCCE.

The study showed that Morocco is more focused on operational stage of BLCCE as the already and ongoing actions toward reducing the climate change impact are more about replacing the current consumed energies by proper energies such as solar one. In the same vein, Morocco provided an open calculator to easily assess the impact of all responsible sources for OC emissions. Hence, the study findings go along with the Moroccan climate change policy. However, adopting BIM as a working practice could significantly help in achieving Morocco's climate goals which could be more achievable if the country adopts an efficient strategy toward a mandatory BIM implementation. In fact, the literature confirmed the large potential of BIM technology to design low-carbon or zero-net buildings and neighborhoods as well as guarantee sustainable management and maintenance of new or existing buildings and facilities.

On the other hand, the absence of a local database of carbon factors of materials and statistics related to construction – demolition wastes and transportation were the top faced challenges for this research. In fact, omitting the EC emitted by transportation, equipment and workforce could be a limitation of this study. As highlighted in the literature review, the choice of materials and equipment could considerably reduce building carbon emissions, hence developing the missing databases and statistics could be the topic of further studies and would enable both designers to select less impactful materials on the environment and contractors to use more eco-friendly construction processes especially in terms of waste management and transportation.

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ID 54

Development of Reinforcement Schemes for Cold-Formed Steel Joists with Large Web Openings

Ken S. Sivakumaran

Department of Civil Engineering, McMaster University, Hamilton, Ontario, Canada L8S 4L7
siva@mcmaster.ca

Abstract

The floor joists of cold-formed steel (CFS) structures may use large web openings and a cost-effective way to alleviate the detrimental effects of a large web opening is to affix appropriate reinforcements around the opening regions, to restore the original strength and stiffness of the member. The primary aim of this paper is to define the "Flexural Zone" and the "Shear Zone" and establish construction guidelines for the reinforcement schemes for cold-formed steel joists with large web openings in these corresponding zones. To that end, a total of twenty-three laterally braced CFS joists were simply supported and subjected to uniformly distributed loads until failure for flexural tests, which considered solid sections, circular and square web openings (65% of web depth) and sections with reinforced web openings. The reduction in the flexural strength of a cold formed steel joist section due to a large web opening is less than 15%. Twenty-seven joist sections were subjected to short span, mid-span point load, shear tests to establish the shear resistances of sections having a large web opening and a reinforced web opening. The reduction in the shear strength of a CFS section with a web opening may be as high as 60%. Thus, the residual shear strength of a joist with a large opening may be as low as 40%. A Virendeel type reinforcement system can restore the original shear strength of a cold-formed steel joist section. Based on these studies it is established in this paper that; The mid 40% region of a joist (0.30L and 0.70L) can be defined as "Flexural Zone" and will need flexural reinforcements. The regions outside the mid 40% region of a joist can be defined as "Shear Zone" and will need the shear reinforcements.

Keywords

Cold-formed Steel Joists, Construction Guidelines, Experimental, Large Web Openings, Openings Reinforcements.

1. Introduction

Cold-Formed Steel (CFS) structural members are currently widely used in small to medium size building construction, including housing projects, perhaps because the cold-formed steel design can be a cost-effective option, as compared to hot-rolled steel or other traditional construction materials such as reinforced concrete, masonry, wood, etc. Cold-formed steel floor joists are widely used in the floor construction of detached one- and two- family dwellings, townhouses, and other attached single-family dwellings. Typical cross section of such joists is a lipped channel shape. In order to keep the floor height of these structures to a minimum, the floor joists of such structures may use large web openings, which can provide the necessary pass-through space for ductwork, piping, drainage and other similar systems. Appropriate use of web openings can enhance the aesthetic appeal and can result in efficient construction of cold-formed steel floor systems. The depth of these large web openings, however, can be a substantial proportion of the beam depth. Thus, these large web openings can significantly decrease the joist strength and the failure characteristic of the entire member. Various studies exist on the flexural, shear, web crippling strengths of cold-formed steel sections having a large web opening. The current North American cold-formed steel design standard (CSA, 2016) also provides guidelines to account for the effects of such openings on the member design strength, which may be considerably low due to the presence of the large web opening. However, a cost-effective way to alleviate the detrimental effects of a large web opening is to affix appropriate reinforcements at strategic locations around the opening regions, so as to restore the original strength and stiffness of the member. Currently available Cold-formed Steel Design Standard (CSA, 2016) and Standard for Cold-Formed Steel Framing – Prescriptive Method for One and

Two Family Dwellings (AISI, 2019) provisions, however, either do not apply or do not provide adequate guidelines to facilitate the design and construction of reinforcements for floor joists with large web openings. Objectives of this investigation are to establish the effects of a large web opening on [a] flexural strength and [b] shear strength of cold-formed steel lipped channel shaped floor joists, and then to establish effective and economical reinforcement schemes for such large web openings that would restore the original flexural and the shear strengths of such floor joists, so that the original design of the joist need not be changed. Details of the first part of the investigation, establishment of reinforcement schemes for large web openings in flexural zones, has been published by Acharya, and Sivakumaran (2022), and is summarized below in Section 2. Details of the second part of the investigation, establishment of reinforcement schemes for large web openings located in primarily shear zones, has been published by Acharya, Sivakumaran and Young (2013), and is summarized below in Section 3. The primary aim of this paper is to define the "Flexural Zone" and the "Shear Zone" and establish construction guidelines for the reinforcement schemes for cold-formed steel joists with large web openings in these corresponding zones.

2. Flexural Strength of Joists with a Large Web Opening

This section discusses the flexural strength of cold-formed steel joists having a large web opening. A total of twenty three CFS joist sections [1.092 mm (43mils) thick, 203.2 mm (8") deep joist sections] were subjected to flexural tests. These tests considered solid sections, sections with unreinforced web openings and sections with reinforced web openings. Circular and square openings with 127mm (5") diameter and side, respectively, were considered for the study. The opening depth considered herein is 64.6% of the flat width of the web, and these openings were located at the center of the test specimen span. The objective of this part of the experimental investigation was to assess the effectiveness of a reinforcement schemes for flexural zone. The flexural tests were carried out on 2,743mm (9') long simply supported test specimens. Pinned and roller supports were used at the ends of the test specimen. Since, most of the CFS floor joists in practice are expected to carry uniformly distributed loads that are transferred from the floor deck, the test setup was designed to produce uniformly distributed loads on the test specimen. Such a uniformly distributed load was assumed have been created by using a series of six identical hydraulic jacks of maximum capacity of 10 ton each, connected to a single hydraulic pump. This arrangement results in equal loads on all jacks at all times.

First part of the investigation considered the flexural strength of [a] sections with no openings, [b] sections with a large circular opening, and [c] sections with a large square opening. Three identical tests were done for each case, thus, this part included nine tests. The second part of the investigation considered reinforced web openings. Three identical tests each considered the flexural strength of sections with reinforced circular and square openings, respectively. The reinforcement scheme considered herein involves screw fastening (No. 8 self-drilling screws) of bridging channels (depth 38mm, thickness 43mils) of length determined by the width of the opening plus one half of the depth of the opening on either side and plus a minimum edge distance for screws (10mm). As a result, the total length of the reinforcements was 274 mm. The reinforcement scheme consisted of two bridging channels, one along the top edge of the opening, and the other along the bottom edge of the opening. The bridging channels were screw fastened along the edges of the opening (12.7 mm(½") from the edge) at a spacing of 31.75 mm (d/4, where d is depth of the openings).

Table 1 summarizes the test results, which includes the moment resistances of the CFS sections with and without the reinforcments, sample photographs and descriptions of the the failure modes. The reduction in the flexural strength of a CFS joist section due to a large web opening (up to 65% of web height) is less than 15%. The test specimens with the proposed r/f scheme failed outside the opening and the reinforcement. The circular and square openings with reinforcement resisted 5% and 3% more moments, respectively, than the corresponding solid sections. Thus, the proposed reinforcement scheme is capable of restoring the original flexural strength of a CFS section.

It must be pointed out that the current steel framing standard (AISI, 2019) specifies two different patching schemes for a large web opening, where (a) the web openings maybe reinforced with a solid steel plate having the same size and the shape of opening, and (b) the web openings maybe patched with a CFS joist sections having same size and shape of openings. These patching schemes and other reinforcement schemes were also attempted during the course of this investigation. However, the associated results are not given herein and may be found in the paper by Acharya, and Sivakumaran (2022).

Key Observation: 1 -The reduction in the flexural strength of a cold formed steel joist section due to a large web opening (up to 65% of web height) is less than 15%.

Key Observation: 2 -The reinforcement scheme presented in this study can restore the flexural strength of cold formed steel joist sections having a large web opening (up to 65% of web height).

Table 1: Flexural strength of CFS joists with a large web opening

Test Designation	Moment at Opening Region (kN-m)	Reduction in Moment Capacity	Sample Pictures	Failure Mode
F-N	Test 1: 4.47 Test 2: 4.37 Test 3: 4.37 **Average: 4.40**	**0.00 % [Reference Test]**		Compression flange local buckling at mid-span
F-C	Test 1: 4.22 Test 2: 4.21 Test 3: 3.97 **Average: 4.13**	**-6.13 %**		Compression flange and web local buckling at opening location mid-span
F-S	Test 1: 3.68 Test 2: 3.92 Test 3: 3.75 **Average: 3.78**	**-14.09 %**		Compression flange and web local buckling at opening location mid-span
F-CRC Bridging Channel Reinforcement	Test 1: 4.60 Test 2: 4.59 Test 3: 4.66 **Average: 4.62**	**+5.00 %**		Compression flange and web local buckling out of reinforced region
F-SRC Bridging Channel Reinforcement	Test 1: 4.69 Test 2: 4.45 Test 3: 4.48 **Average: 4.54**	**+3.18 %**		Compression flange local buckling out of reinforced region

3. Shear Strength of Joists with a Large Web Opening

It is impossible to create a pure shear zone for "shear testing" because of the presence of a moment whenever there is a shear force. In practice though, a shear test is performed by creating a high shear and low moment region. Here, a 914mm (36") short span, with mid-span point load was considered as an appropriate test setup to achieve high uniform shear and low moment region. One end of the test specimen was pin-supported, whereas the other end was roller-supported in order to allow for any horizontal movements. The overall load was applied at the centre of the span using the 600kN capacity Tinius Olsen test machine and was divided into two equal loads at equal distance from the support, using a spreader beam. The test arrangement as described above results in uniform shear forces and increasing moments between the support and the load point. The concentrated loads at the load points and at the supports may cause web-crippling failure, prior to the anticipated shear failure. In this investigation the load and the support reactions were transmitted to the web of the specimen through steel brackets. Furthermore, the vertical planes of the steel brackets were fastened to the webs of the test specimens using self-drilling screws, which was to help transfer the concentrated loads effectively into the web. The study considered mono-symmetric 203.2mm (8") deep 1.092 mm (43mils) thick galvanized lipped channel CFS sections. Mono-symmetric section is generally liable to torsional loadings, due to the fact that the shear center does not coincide with the centroid of the section. However, it is not convenient to apply a load through the shear center of a single channel section, as its shear center is outside of the section. Therefore, in this investigation two lipped channel sections with a length of about 1220 mm (48") were set face-to-face to form the test specimen. In this arrangement the torsional effects are counterbalanced by each other, since torsional restraints were provided at several locations utilizing different elements. The steel brackets that were used to prevent web crippling at the load and the support locations provide some torsional restraints at these locations. In addition, 6mm (1/4") thick steel plate strips were attached to the non-bearing flanges at load and at support locations which enhanced the torsional resistance at these locations. Short span specimen subjected to single mid-span load experiences high shear as well as high moment at the load location. Thus, this test setup simulates the high shear zones, as well as high shear-high moment conditions, which is the worst possible load-structural scenario, that exists at the over-the-support location in a continuous span joist.

Three identical tests were conducted for each case, and this paper presents the results for fifteen such tests. Solid section as well as circular and square openings with 127mm (5")-diameter and 127mm (5")-side, respectively, were considered for the study. The opening depth considered herein is 64.6% of the flat width of the web, and these openings were located in the shear span and at the mid-height of the test specimen. Table 2 summarizes the test results. The reduction in the shear strength of a cold-formed steel joist section due to the presence of a large web opening (up to 65% of web height), and in the presence of high moments, may be as high as 60%. In other words, the residual shear strength of a joist with a large opening may be as low as 40%.

Table 2: Shear strength of CFS joists with web opening in high moment regions

Test Designation	Peak Shear at Opening Region (kN)	Reduction in Shear Capacity	Sample Pictures	Failure Mode
S-N	Test 1: 12.23 Test 2: 12.56 Test 3: 12.49 **Average: 12.43**	**0.00 % [Reference Test]**		Primarily shear failure mixed in with flexural failure.
S-C	Test 1: 7.37 Test 2: 7.45 Test 3: 7.48 **Average: 7.43**	**-40.22 %**		Shear diagonal failure
S-S	Test 1: 5.10 Test 2: 5.27 Test 3: 5.06 **Average: 5.14**	**-58.65 %**		Shear diagonal failure
S-CRC Bridging Channel Reinforcement	Test 1: 12.77 Test 2: 12.86 Test 3: 13.22 **Average: 12.95**	**+4.18 %**		Shear + flexural failure out of the opening
S-SRC Bridging Channel Reinforcement	Test 1: 12.44 Test 2: 12.61 Test 3: 12.47 **Average: 12.50**	**+0.56 %**		Shear + flexural failure out of opening

The shear reinforcement scheme under consideration, which was used for both circular and square openings, is different from the flexural reinforcement scheme presented earlier, and it involves screw fastening (No. 8 self-drilling screws) of bridging channels [depth 38mm (1-1/2"), thickness 54 mils] along all four edges of the opening. Note that the bridging channels are 54mils thick whereas the main joist section is of 43mil (1.092 mm) thick. The shear reinforcements consisted of horizontal and vertical reinforcements. Horizontal reinforcements consisted of two bridging channels of length determined by width of the opening plus one half of the depth of the opening on both sides and a minimum edge distance for screws (10mm). Therefore, the total length of the horizontal reinforcements was 274 mm (10.7"). Vertical reinforcements included two bridging channels of length equal to the depth of the web of receiving channel 203mm (8 inch). One horizontal reinforcement was fastened along the top edge of the opening, and the other one was placed along the bottom edge of the opening. The channels were screw fastened at a spacing of 31.75 mm (1.25") (d/4, where d is depth of the openings) close to the opening edges within the opening region, starting from the central screw. Vertical reinforcements were placed closer to the vertical edges of the openings. Four screws were fastened at the corner of horizontal and vertical reinforcements to create a joint. This system produces a Vierendeel type reinforcement system. Associated test results are shown in Table 2. The circular and square openings with shear reinforcements resisted about 4% and 0.5% more shear, respectively, than the corresponding solid sections

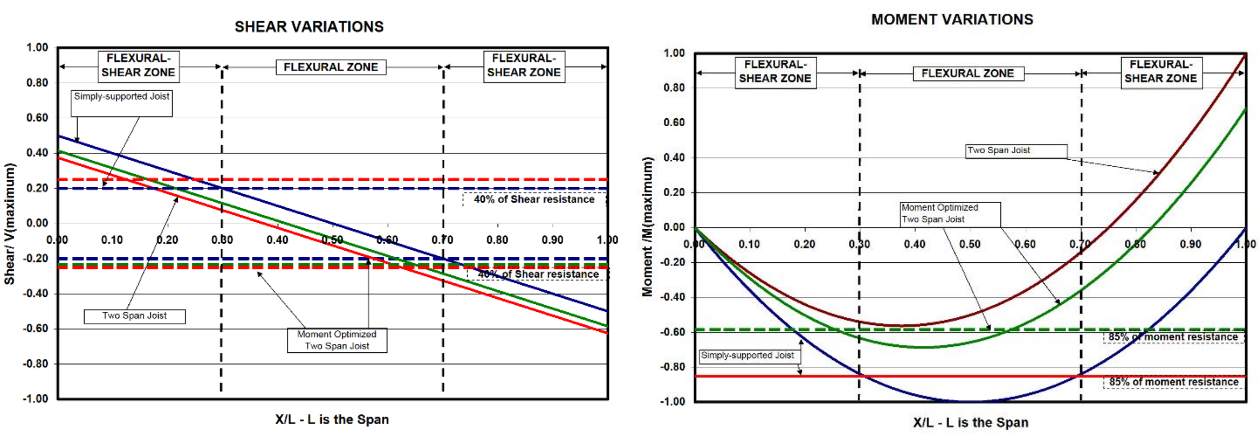
(Reference Test). It is clear from the sample photographs that the specimens with the proposed shear reinforcement scheme failed at locations outside the reinforced opening location. Thus, it may be concluded that the proposed shear reinforcement scheme, a Vierendeel type reinforcement system, for web opening can restore the original shear strength of a cold-formed steel joist section.

Key Observation: 3 -The reduction in the shear strength of a cold-formed steel joist section, in the presence of high moments and due to the presence of a large web opening (up to 65% of web height), may be as high as 60%. In other words, the residual shear strength of a joist with a large opening may be as low as 40%.

Key Observation: 4 -A Vierendeel type reinforcement system proposed herein for web opening is capable of restoring the original shear strength of a cold-formed steel joist section.

4. Definition of the "Flexural Zone" and the "Shear Zone" and the Associated Reinforcement Schemes

In the analysis and design of cold-formed steel joists for house construction, it is reasonable to assume that; (1) the floor joist is subjected to uniformly distributed loads (2) the design of a floor joist is governed by the largest moment and that the moment resistance is equal to or more than the largest moment caused by the loads (3) the whole joist has a uniform cross-section, thus its moment resistance and the shear resistance are constant for the whole length of the joist, and (4) when a floor joist is selected based on moment resistance requirements, the shear resistance of that joist will be equal or more than the corresponding largest shear in the joist ($V_{resistance} \geq V_{loads}$)



[A] **[B]**

Fig. 1 [A] Shear Variations on Floor Joist, [B] Moment Variation on Floor Joist

Figure 1[A] shows the non-dimensional shear variation in a floor joist having different structural arrangements (simple support, continuous support, etc.). If the joist is simply supported, then the maximum shear (V_{max}= 0.50wL= V_{design}) occurs at the supports. Shears greater than 0.4V_{design} exist outside 0.30L and 0.70L, where L is the span length. The shears within the region 0.3L and 0.7L (mid-span region) for this structural arrangement will be less than 0.4V_{design}. If the joist is continuous over two or more spans (shown as two span joist), then the maximum shear (V_{max}= 0.625wL= V_{design}) occurs over the support. Shears greater than 0.4V_{design} exist outside 0.125L and 0.625L, where L is the span length. Choosing 0.30L and 0.70L region (mid-span region) the shear within this region for this structural arrangement will be less than 0.49V_{design}. If the joist has an over-hang and the joist had been designed such that the moment over the support is equal to moment at the mid-span (moment optimized two-span joist), then the maximum shear (V_{max}= 0.585wL= V_{design}) occurs over the support. Shears greater than 0.4V_{design} exist outside 0.18L and 0.65L, where L is the span length. Considering the region between 0.30L and 0.70L (mid-span region) the shear within this region for this structural arrangement will be less than 0.52V_{design}. Considering the three possible structural arrangements and choosing 0.25L and 0.75L region (mid 50% region) the shear within this region will be less than 0.60V_{design}. Considering the three possible structural arrangements and choosing 0.30L and 0.70L region (mid 40% region) the shear within this region will be less than 0.52V_{design}. Choosing 0.35L and 0.65L region (mid 30% region) and considering the three possible joist structural arrangements, the shear within this region will be less than 0.44V_{design}.

Figure 1[B] shows the non-dimensional moment variations in a floor joist subjected to uniformly distributed loads. If the joist is simply supported, then the maximum moment ($M_{max}= wL^2/8= M_{design}$) occurs in the mid-span. Focusing on the mid-span region, moments greater than $0.85M_{design}$ exist between 0.305L and 0.695L, where L is the span length. If the joist is continuous over two or more spans, then the maximum moment ($M_{max}= wL^2/8= M_{design}$) occurs over the support. Focusing on the mid-span region, no location experiences moments greater than 0.85 M_{design}. If the joist has an over-hang and the joist had been designed such that the moment over the support is equal to moment at the mid-span (moment optimized two-span joist), then the maximum moment ($M_{max}= 0.686wL^2/8= M_{design}$) occurs over the support and in the mid-span region at 0.41 L. Focusing on the mid-span region, moments greater than $0.85M_{design}$ exist between 0.255L and 0.575L, where L is the span length. For all other structural span arrangement for the joist the maximum moment occurs either in the mid-span or at the support. Furthermore, it can be stated that regardless of the joist structural arrangement, focusing on the mid-span, moment more than $0.85M_{design}$ may exist between 0.255L and 0.695L, where L is the span length. Considering all possible structural arrangements and choosing 0.25L and 0.75L region (mid 50% region) the sagging moments within this region may be more than $0.84M_{design}$. Considering all possible structural arrangements and choosing 0.30L and 0.70L region (mid 40% region) the sagging moments within this region may be more than $0.92M_{design}$. For simply supported joists the moments within this region may be more than $0.84M_{design}$. Choosing 0.35L and 0.65L region (mid 30% region) and considering all possible joist structural arrangements, the sagging moments within this region may be more than $0.98M_{design}$. For simply supported joists the moments within this region may be more than $0.91M_{design}$.

Noting that, in general, the shear resistance ($V_{resistance}$) of a CFS joist designed based on governing moments is greater than the peak shear force due to corresponding uniformly distributed loads, and assuming that the reduction in the shear strength of a CFS joist section due to a large web opening (up to 65% of web height) would be less than 50%, it can be observed that the for all possible structural arrangements, the shear force within the mid 40% region of a joist (0.30L and 0.70L) will be less than 50% of the shear resistance of the joist. Thus, the openings in the mid 40% region of a joist will not need the shear reinforcements, however, such openings will need the flexural reinforcements. Since the shear forces outside the mid 40% region of a joist (0.30L and 0.70L) may be more than 50% of the shear resistance of the joist, and may be subjected to high moments, openings located in regions outside the mid 40% of the joist will need the shear reinforcements. Since the shear forces within the mid 40% region of a joist (0.30L and 0.70L) is less than 50% of the shear resistance of the joist no shear reinforcements are needed. However, since the moments within the mid 40% region of a joist (0.30L and 0.70L) is more than 85% of the moment resistance of the joist, openings located in regions within the mid 40% of the joist will need the flexural reinforcements. Therefore, the mid 40% region of a joist (0.30L and 0.70L) can be defined as "Flexural Zone" and will need flexural reinforcements for openings in this region. The regions outside the mid 40% region of a joist (0.30L and 0.70L) can be defined as "Shear Zone", and openings located in regions outside the mid 40% of the joist will need the shear reinforcements.

5. Conclusions

The floor joists of Cold-Formed Steel (CFS) structures frequently require large web openings, which can enhance the aesthetic appeal and the constructional efficiency of floor systems. The test program considered flexural resistances and the shear resistances of CFS sections with large web openings. The tests considered circular and square openings. The reduction in the flexural strength of a cold formed steel joist section due to a large web opening (up to 65% of web height) is less than 15%. The reduction in the shear strength of a cold-formed steel joist section due to the presence of a large web opening (up to 65% of web height), and in the presence of high moments, may be as high as 60%. In other words, the residual shear strength of a joist with a large opening may be as low as 40%. Since the shear forces outside the mid 40% region of a joist (0.30L and 0.70L) may be more than 50% of the shear resistance of the joist, and may be subjected to high moments, openings located in regions outside the mid 40% of the joist will require shear reinforcements. Since the moments within the mid 40% region of a joist (0.30L and 0.70L) is more than 85% of the moment resistance of the joist, openings located in regions within the mid 40% of the joist will require the flexural reinforcements. Thus, the mid 40% region of a joist (0.30L and 0.70L) can be defined as "Flexural Zone", and will need flexural reinforcements for openings in this region. The regions outside the mid 40% region of a joist (0.30L and 0.70L) can be defined as "Shear Zone", and openings located in regions outside the mid 40% of the joist will need the shear reinforcements. The effectiveness of the reinforcements for floor joists of Cold-Formed Steel (CFS) having large web openings depends on the reinforcement type and its length, screw spacing and screw pattern.

Based on the results presented in the previous sections, the following key observation was made. The flexural reinforcement scheme, consisting of two parallel channels fastened along the compression and tension edges of the opening, considered in this study can restore the flexural strength of cold formed steel joist sections having a large web opening. Thus, the reinforcement details shown in Figure 2[a] are proposed for the flexural zone. The shear reinforcement scheme, a Vierendeel type reinforcement system, for web opening is capable of restoring the original shear strength of a cold-formed steel joist section. Thus, the reinforcement details shown in Figure 2[B] are proposed for the shear zone.

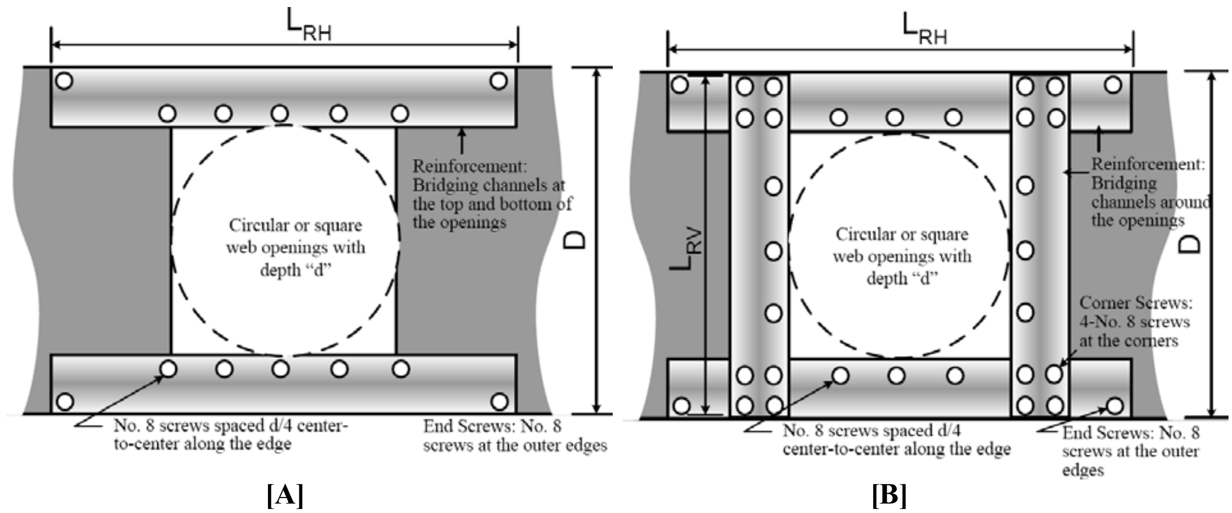


Fig. 2 Proposed Reinforcement Scheme for [A] Flexural Zone, [B] Shear Zone

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A Critical Review of Wood Waste Cement Composite Properties (The Mechanical and Physical Properties) and its Use as Building Construction Material

James Toyin Olaonipekun[1], Modupe Mewomo Cicilia[2], Sina Makanjuola Abayomi[3], Margaret Oyewole Damilola[4].

[1,2,4] Durban University of Technology, South Africa.
[3] Federal University of Technology, Akure Nigeria.
mewomom@dut.ac.za

Abstract

The gradual unreplaceable exploration of the natural aggregates has called for the attention of researchers and built professionals to devise suitable materials which can be used as a replacement for those aggregates. This has called for an inward investigation on using waste raw materials such as wood waste as supplementary for fine aggregate or pozzolana. Wood waste cement composites are great byproducts that can be used as building materials that are freely or cheaply available. Before any new material could be considered suitable in construction, the properties need to be known to see its suitability for construction works and the area it would be best suited for. This study aims to investigate the mechanical and physical properties of wood waste cement composite and its use as building construction material, through a critical literature review of selected published articles between 2005 to 2021, focusing on the property of wood waste cement composite. The findings reveal the physical and mechanical properties of raw sawdust and properties of selected Portland cement. The findings of this study will go a long way in assisting built professionals in making intelligent choices on how to use processed and unprocessed wood by-products as a partial substitute for cement and sand.

Keywords

Wood Waste, Physical Property, Mechanical Property, Cement, Construction.

1. Introduction

Over the years, there has been a great concern abo about generating sustainable building materials capable of reducing greenhouse gas emissions (carbon dioxide emissions) within the building (Ding 2014). Carbon dioxide emissions are the primary cause of global climate change (Terrenoire et al., 2019). It is widely understood that the world must reduce emissions as quickly as possible to avoid the worst impacts of climate change. Researchers have been on the watch to derive the possibility of getting such suitable materials from waste or by-products. This reduces CO^2 emission and the high concentration on primary natural building materials, like sand, granite, cement. The high demand for those materials may lead to their scarcity in no time. However, one of the possible ways of sourcing suitable raw material in the construction industry is by progressing from using finite and limited building resources to easily renewable or recycling generated by-products raw materials (Terpakova et al. 2012). Sand and granite are the primary constituents of concrete; the rising in construction industry activities increases the demand for the primary natural aggregate, which gradually reduces such aggregate resources. Batool et al. (2021), through their studies, find out that the natural aggregate (sand) is universally dug out from lakes, riverbeds, and other sources is to the tune of almost 11 billion tons each year. Due to this, numerous countries like Nigeria (Lagos- Lekki Aja area) have enforced limitations on the dredging of such aggregate from waterways and sea areas to decrease the unpleasant influences on the natural environment. The actions have set the construction industry and researchers on the move to look out for suitable alternative materials. Due to these challenges, the construction industry and building material science experts have sought cheap, sustainable, and eco-friendly waste materials that are substitutes for construction works (Bołtryk &

Pawluczuk 2014). Preference has been on waste materials that could be recycled and aid the reduction of carbon dioxide emissions.

There has been a global concern on how to manage solid waste. Generally, society has been looking for legitimate ways of transferring solid waste in substantial urban communities since appropriate dumping destinations for this waste are progressively rare, due to the spread and improvement of vast urban focuses. The consideration of recycling waste materials and industrial by-products was seen as one of the ways to optimally convert the waste to valuable materials (Shahjalal & Billah 2021; Foti & Cavallo 2018; Foti et al. 2019). However, sawdust, as an example of waste material, is produced as industrial waste on a large scale that needs to be disposed of carefully into the environment (Batool et al. 2021). The high demand for wood products in different sectors in large quantities and processing forms part of daily activities. Processing the wood generates a high volume of sawdust by-products (Aigbomian & Fan, 2013). Evidence has proven that composite wood waste could be used as a partial substitute for cement (pozzolana) (Tamanna et al. 2020). In addition, it could be used as a partial replacement of fine aggregate (Hassen & Hameed 2020). Therefore this paper aims to document the mechanical and physical wood waste cement composite properties through a critical review of the literature within the context.

2. Research Methodology

A critical paper-based review approach was adopted using the content analysis method to study the state-of-the-art wood waste composite to discover its suitability for construction works. Criminale & Langar (2017) linked content analysis to literature. It was explained as a flexible method that can be exploited to analyze text data, which scholars have used for an unlimited period. To achieve this study's aim and objective, the flow chart shown in Fig. 1 will be employed in this research.

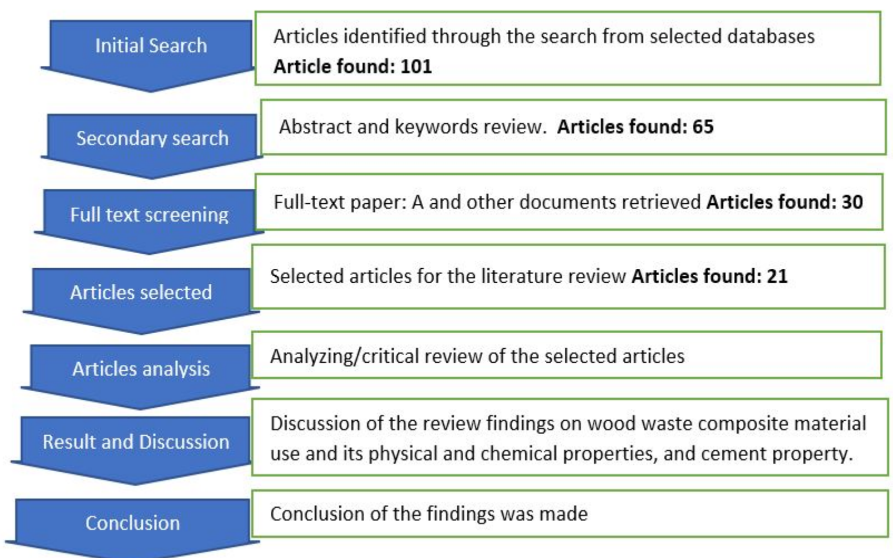

Fig. 1: Research flow chart diagram.

The steps employed in this research involve two processes; the first process was the collection of relevant academic publications on wood waste and cement properties and their uses. Using keywords: "wood waste property," "Sawdust physical property," "Sawdust mechanical property," "Cement property," and "Composite cement materials." The search conditions were used to locate relevant documents, which were repeated in selected academic databases or search engines of Elsevier (Science Direct, Scopus), Google Scholar, and Web of Science. The exploration brought about 150 published papers. The adoption of inclusion and exclusion criteria gives the population of 70. The retrieved papers consisted of journals, book chapters, and conferences, excluding papers not written in English, editorials, and forums. In addition, the retrieved papers' abstracts were read to ascertain their relevance to the current research. Exclusion criteria such as the absence of author(s)'s details, missing year of publications, duplications/ repeated paper entries, and paper written in language order than English were adopted. Adopting the exclusion criteria in the filtration of the retrieved articles produced a final population of 21 (n=21), considered in this paper. The next pace involves analyzing relevant materials retrieved during the search and discussion. Finally, the last phase encompasses the conclusion to encourage built professionals to use wood-waste composite as supplementary building materials.

3. Results and Discussion

3. 1 Cement Property

Recent research conducted by Ige (2013) in Nigeria focused on comparative analysis of portland cement. The study was conducted on five (5) cement brands commonly available in the country during the study. The study was conducted to determine each cement characteristic: setting time, strength characteristics, workability, soundness, and fineness. After that, check if they meet the minimum required standard stipulated by the British Standard Institute. Table 1 shows the fineness analysis result of the selected brands of cement. Ige (2013) noted that the results agreed with the stipulated standard. The author confirmed that the best fineness result comes from Dangote cement. The fineness of cement significantly impacts the pace of hydration and rate of strength growth. Because finner cement has a larger surface area for hydration, it develops strength more quickly (Ige 2013). Fig. 2 shows the result of the comprehensive strength for each cement brand. These indicated that the comprehensive strength progresses as the curing days increase. Dangote cement had the highest crushing strength on the 28th day of the five brands. While Diamond cement gained early strength ahead of the other cement. These findings were in agreement with the result

Table 1. Selected brand of cement fineness analysis.

S/N	Brand of cement	Weight of cement before sieving (g)	Weight of residue (g)	Weight of fine cement after sieving (g)
1.	Elephant	100	5.5	94.5
2.	Pure chem	100	3.5	96.5
3.	Bur ham	100	3.0	97.0
4.	Diamond	100	2.5	97.5
5.	Dangote	100	2.2	97.8

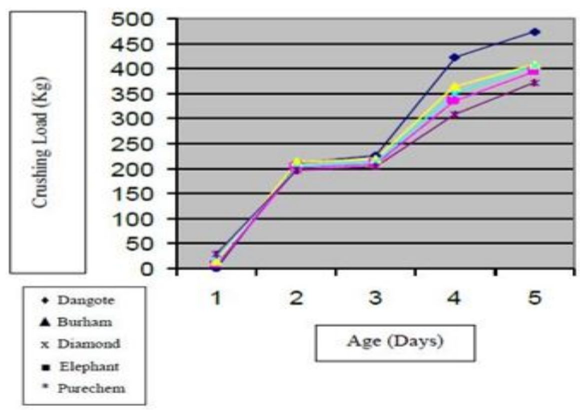

Fig. 2: Comprehensive strength analysis of selected cement.

of Zhang et al. (2019) defined "Metal oxides" as crystalline solids encompassing a positive metal ion and an oxide anion. They usually react with water to form bases. Faleye, Ogunnubi & Olaofe (2009) researched the Nigerian market; the authors focused on four (4) selected cement samples. The findings presented reports on Elephant, Dangote, Pure Chem, and Diamond cement using chemical analysis of metal oxides. Table 2. Presents the chemical analysis of the selected cement samples. The mean values and percentage coefficient of variance shown reveal that Elephant have the highest CaO. Dangote has the least CaO and the highest MgO, K2O, SO_3, and $A1_2O_3$, while Pure Chem has the least K_2O, SO_3, and MgO. "The clinker soluble alkalis such as K_2O and Na_2O have an important influence on cement quality and performance. The influence of the soluble alkali content is strongly dependent on the SO_3 contents" (Faleye, Ogunnubi & Olaofe 2009). The authors noted no risk of heat cure concrete failure since the percentage of SO_3 in all samples is less than 3.5 percent, which is the top limit for SO_3 concentration. Physical Characteristics of the samples: setting time, loss on ignition, insoluble residue, specific surface area, and Factors considered for the cement valuation: Lime saturation factor, Silica ratio, Alumina ratio, free lime were presented in Tables 3 and 4, respectively. The period when a part of cement paste resists penetration by examining defined weight and cross-section is known as the setting time of cement. (Ige 2013). Therefore, Dangote would first show the resistance while Pure Chem would show it last. The mean values for lime saturation factor, silica ratio, free lime and alumina ratio were 90.1 + 3.02, 2.23 + 0.10, 1.69 + 0.13 and 1.43 + 0.79 respectively as seen in Table 4. The physical characteristics and other relevant elements for evaluating the cement samples are included in Tables 3 and 4. Dangote had the smallest insoluble residue (4.7) and fastest setting time (195 seconds), whereas Pure Chem has the largest specific surface area (412m2/kg) and the lowest percentage loss on ignition (5.5). Furthermore, the findings concluded that the comprehensive strength result shows Dangote cement has the highest strength. At the same time, the least was Pure Chem in the selected cement samples. Their observation noted that Dangote cement comprises the least setting time and specific surface area; this powerfully affects early compressive strength. These findings agreed with the recent study of Ige (2013), where the author considers five brands of cement available in the Nigerian market during the study. The brand contains the initial four brands studied by Faleye, Ogunnubi & Olaofe (2009), with the addition of "Bur ham cement."

Table 2. Selected cement sample chemical oxide properties %.

SAMPLE	CaO	Fe_2O_3	SiO_2	Al_2O_3	MgO	SO_3	K_2O
Pure chem	62.2	3.59	20.77	5.63	1.21	2.19	0.22
Dangote	59.6	3.22	20.62	6.01	3.65	2.46	0.71
Diamond	61.4	3.23	20.55	5.56	2.22	2.38	0.42
Elephant	62.6	3.20	20.34	5.09	1.74	2.19	0.29
Mean	61.45	3.31	20.57	5.57	2.21	2.31	0.1
S.D	1.33	0.91	0.19	0.38	1.05	0.14	0.22
CV%	2.16	5.74	0.2	6.82	47.51	6.06	53.66

(Faleye, Ogunnubi & Olaofe 2009)

Table 3. Cement samples physical property.

Sample	LOI (%)	IR (%)	SSA (m^2/kg)	SETTING TIME (sec)
Diamond	5.5	23.9	380	200
Pure Chem	6.0	34.5	412	200
Dangote	8.5	4.7	358	195
Elephant	8.0	33.1	392	210
Mean	7.0	21.6	385	201
S.D	1.47	11.99	22.42	6.30
CV%	21.0	55.51	5.82	3.13

SSA - Specific surface area (m^2/kg), IR - Insoluble residue (%), LOI - Loss on ignition (%) (Faleye, Ogunnubi & Olaofe 2009)

Table 4. Factors considered for the cement valuation.

SAMPLE	LSF	SR	AR	F/CaO
Pure chem	90.1	2.25	1.57	2.58
Dangote	86.3	2.23	1.87	0.95
Diamond	90.2	3.23	1.72	5.56
Elephant	93.7	2.34	1.59	1.34
Mean	90.1	2.32	1.69	1.43
S.D	3.02	0.10	0.13	0.79
CV%	3.35	4.31	7.69	55.2

LSF - Lime saturation factor, SR - Silica ratio, AR - Alumina ratio, F/CaO - Free lime (Faleye, Ogunnubi & Olaofe 2009)

3.2 Mechanical Properties of wood waste

For decades, many ways have been exploited to characterize the engineering properties of wood-based composites material performance. Wherein, mechanical means stands to be one of the essential properties to be considered. Ganesan, Rosentrater & Muthukumarappan (2008) noted that the mechanical properties of wood waste are powerfully influenced by moisture content and the size of the particle distribution. The size of the particle affects the flowability of some materials, "it is used as a measure of the quality of the granular product that influences its end-use value" (Stasiak et al. 2015). The difference in flowability of particles may lead to errors during mixing and weighing, thus resulting in the inconsistency of the end product (such as briquettes or pellets). The blend material must exceed the initiate flow, representing the strength of the flow function (FF). FF grainy materials' values can be considered free-flowing, cohesive solid, cohesive, and easy flowing. In addition, frictional collaboration with construction materials is an additional feature of the mechanical properties of granular materials deposited in bulk in silos and controlled in technological processes. "This behaviour is described by friction coefficient which is the tangent of inclination of the linearized relationship between shear stress and normal stress during sliding of a sample of granular material against the plane surface of construction material" (Stasiak et al. 2015).

The mechanical composition of wood-based composites rests upon a range of factors: the kind of adhesive binder used, forest management regimes, wood species, the density of the final product, and the geometry of the wood elements. However, mechanical properties have been widely accepted and used to assess wood-based composites required for nonstructural and structural applications (Cai Senalik & Ross 2021). Wherein properties and elastic strength are the leading measures considered in selecting the material or product specifications or establishing the design. The elastic properties include comprehension, tension, and modulus of elasticity in bending (Cai Senalik & Ross 2021).

Kumar & Kumar (2015) studied the mechanical properties; flexural, split tensile and compressive strengths, of fiber reinforced concrete strength characteristics, using wood waste ash as a partial substitute of cement with different percentages at (0, 10, 20, & 30%) and crimped steel fibers at different percentages (0,0.5,0.75 & 1%), tested on 28 and 60 days of casting. The compressive strength result shows the effect of adding wood waste ash and steel fibers at different design mixes. Wherein 20% and 0.75%, respectively, volume was seen as the optimum content volume (in addition, those volumes were also seen as optimum volume for the split tensile and flexural strength). With the addition of wood waste ash at 20%, there was an increase of 11.3% compressive strength over plain cube concrete tested. Also, the authors observed that there was a 10.2% increase in the compressive strength over plain concrete with a 0.75% increase in fiber. The main effect of adding wood waste ash on comprehensive strength is to reduce the quantity of cement used, since it serves as a partial substitute of cement, also to reduce concrete weight, while steel fibers were added to achieve optimal strength. Wood waste-based composites may be used for construction: for several nonstructural and less concentrated structural elements, such as support for building structures, furniture components, and panels for both interior and exterior uses. However, it is very important to have Knowledge of these products based on their proper use by looking at the mechanical properties of the products (Cai, Senalik & Ross 2021).

3.3 Physical Property of Wood Waste

Mangi et al. (2019) noted that the physical properties of wood waste are the way it behaves towards external influences apart from applied forces and its elementary characteristics. This includes moisture content, density, grain and texture, thermal behaviour, dimensional stability, etc. Knowing the physical properties is essential because they can substantially influence the strength and performance of the material exploited in the structural applications: the more the increase in the amount of sawdust, the lower its workability (Adebakin et al. 2012; Moreira, Macêdo & Souza 2012; Oyedepo, Oluwajana & Akande 2014; Awal, Mariyana & Hossain 2016).

Awal, Mariyana & Hossain (2016) researched the properties of sawdust concrete. The authors focused on the physical and mechanical properties. Their research presented the physical result as seen in Table 5. The slump test value varies based on the amount of sawdust used; this indicated that the higher the quantity of sawdust in the fresh design mix, the lower the slump tested. “Slump values of 40, 15 and 5 mm were obtained for mix ratios of 1:1, 1:2 and 1:3 respectively, and were found to fall within the medium, low and no-slump ranges according to Euro code Standard classifications (BS EN 206-1)” (British Cement Association 2002). In addition, the authors “study concludes that sawdust concrete can be used as lightweight concrete with a satisfactory strength performance.” Tamanna et al. (2020) carried out a critical review on wood waste ash use for construction. Several authors investigated the physical properties such as compacted bulk density, specific gravity for wood waste ash. It was found to be 760 & 2.13 kg/m3, respectively. The authors noted that wood waste ash chemical composition varied; this could be traced to the combustions process and where they are produced. Udoeyo et al. (2006) research on the possibility of using wood waste ash (WWA) as a partial substitution for cement, wherein Physical and mechanical properties were investigated (Comprehensive strength, flexural strength, water absorption, and slump test value, the findings reported that at “mix proportion 1:2:4:0.56 (cement: sand: coarse aggregate: water-cement ratio), concrete containing 5 and 10% WWA recorded the highest compressive strength of 28.66 ± 0.70 and27.54 ± 0.34 MPa respectively at 90 days of age and the reduction occurred”.

3.4 Sawdust Production, Uses for Construction, Non-Construction, and Disposal.

3.4.1 Sawdust production.

Sawdust is the by-product generated by processing logs of wood at the sawmills. The volume generated through the sawmilling operation is influenced by the efficiency of the sawmilling machine and operator. This could be calculated based on the quantity and quality of plank recovered through the operation, equated to the generated wood waste. Nevertheless, wood waste comprises sawdust, bark, split wood, trimming, sander dust, and planer shavings (Ekhuemelo & Atondo 2015). The authors researched in Benue State, Nigeria, their findings review that the operator experience with the use of the machine likewise influences the amount of sawdust produced. Kambugu et al. (2005) conducted research at Uganda softwood plantation. It was observed that the lack of appropriate machines for each stage of sawing operation on the logs of wood sawing leads to excessive sawdust production in the sawing process. It is essential to use suitable machines or tools for the right job.

3.4.2 Sawdust used for non-construction.

The following are the common use of sawdust for non-construction works; As a wood filler, used to smoke meat or fish, to start up a fire, used to pack fragile goods to avoid damage, and use as organic fertilizer (Kara 2021), for mulching, soil composting and bedding for livestock and poultry (Rominly et al. 2017). It forms Pyrite when mixed with water set to be frozen, its use was to preserve ice frozen during summer in icehouses, "it forms a slow-melting and much stronger form of ice," it is used in aid cleaning of dropped fluids, this enhances easy sweeping or collection of all spilled liquid in an area (Kumar et al. 2014). Despite all these various uses of wood waste, those are yet to meet acceptable use since 90% still end up in landfills as millions of tons are generated virtually every day.

3.4.3 Wood waste cement composite uses in building construction.

Wood waste cement composite was tested for construction use long ago. Kumar et al. (2014) reported that the use of sawdust Crete in concrete is over 40 years. Literature also reviewed that it has been used for various construction works apart from concrete. This includes concrete blocks and bricks, particleboards, cladding, partitioning floor panels, and ceiling (Mwango & Kambole 2019).

Table 5. Physical Property of Sawdust (Kumar et al. 2014).

Properties	Value
Free swell index	80
Soil classification	ML
Optimum moisture content (%)	19.80
Maximum dry density (g/cc)	1.40
Specific gravity	2.15
Soaked CBR (%)	2.95
Un-soaked CBR (%)	5.2
The angle of internal friction	30^0
Cohesion C (KN/m^2)	7

Table 6. The chemical property of Sawdust (Kumar et al. 2014)

Constituents	Percentage (by Weight)
Loss on ignition	4.76
CaO	3.50
SiO_2	87
MgO	0.24
Al_2O_3	2.5
Fe_2O_3	2.0

Hassen & Hameed (2020) reported the findings of (Ravindarajah et al. 2001). They studied the partial replacement of sawdust in manufacturing lightweight load-bearing blocks using cement mortar, adding calcium chloride, lime, and fly ash. It was discovered through the result that "up to 12% (by weight) addition of sawdust, the compressive strength of concrete blocks will be above 12.5 MPa (required quality for load-bearing blocks)". Similarly, Cheng et al. (2013) researched the introduction of waste sawdust as a partial substitute of fine aggregate in concrete. The orthogonal test was applied to evaluate heat lagging properties, and heat preservation. In addition, a design mix for the sawdust was applied at a different percentage. The results showed that at 5% sawdust replacement, the compressive strength is liable to meet the C25 concrete grade. The insulation property and heat preservation are also significantly better than traditional concrete. However, an increase in the sawdust content shows a gradual decrease in the compressive strength, wherein there will be a development in the thermal properties. Bdeir (2012) studied the mechanical properties (compressive strength and hardness) of the partial replacement of sand with sawdust cement mortar, using sawdust as a replacement of sand; the author used different designed percentages to replace sand with sawdust at different mix ratios. The author observed and concluded that there is a reduction in hardness values and the compressive strength because of increased higher percentages of sawdust.

Moreira et al. (2012) "studied the possibility of making lightweight concrete blocks by replacing part of the fine aggregate with treated sawdust in two ways: first by washing with an alkaline solution (lime) and the second way by immersing the sawdust in an aluminum sulfate solution." The outcome showed the significant difference in the two methods used to treat: using lime judged with the treatment carried out with aluminum sulfate. Hassen & Hameed (2020) reported the findings of (Abdulla, Salih & Salih 2013), in which they "studied the effect of adding treated sawdust by dam lock material and untreated one on the proportion of Ferro cement as partial replacement of fine aggregate." Dynamic and static loads were evaluated for samples put to the test under thermal conductivity. The outcomes disclosed that the best replacement mix ratio of sawdust for fine aggregate was at 30%; this shows an improvement in thermal conductivity and workability of mortar mixes. Xing et al. (2015) studied the possibility of using poplar sawdust in concrete using the Vibro-compaction method to make the lightweight concrete block. Through partial replacement of sand with sawdust. The mechanical properties, thermal conductivity, and compression strength of concrete blocks were investigated.

Gopinath et al. (2015) investigated the mechanical properties and physical properties of concrete, such as slump test, and compression strength, through partial replacement of the cement with sawdust ash and fine aggregate with sawdust. The results justify using sawdust for habitable buildings' structural members such as beams, finishing, foundations, slabs, columns, and foundations. The significant economic impact is also an advantage.

Table 7. B.S.S mesh screening sawdust characteristics.

	Sawdust				
Mode (mm)	500	355	250	212	150
Average particle size (mm)	153.43	205.143	1.253	1.836	298.95

Table 8. Uses of sawdust in construction

S/N	Sawdust Composites used in construction	Reference
1.	They are used to produce oriented strand boards (OSBs), plywood, fiberboards, and particleboards.	(Abdulkaree et al. 2017; Atoyebi et al., 2018; Mwango & Kambole 2019).
2.	Use as floor panels.	(Chanhoun et al. 2018; Cai Senalik & Ross 2021; Mwango & Kambole 2019).
3.	Used for cladding and partitioning	(Antwi-Boasiako et al., 2018; Chanhoun et al. 2018)
4.	Used for Mortar Solid, Concrete block or Bricks	(Mangi 2019; Aigbomian & Fan, 2013; Turgut 2007; Turgut & Gumuscu 2013; Hassen & Hameed 2020; Ravindarajah et al. 2001; Awal et al., 2016).
5.	Use as pozzolana	(Gopinath et al. 2015; Kumar & Kumar 2015; Tamanna et al. 2020; Udoeyo et al. 2006)
6.	Use as partial replacement of fine Aggregate.	(Cheng et al. 2013; Hassen & Hameed 2020; Bdeir 2012; Moreira et al. 2012; Xing et al. 2015; Gopinath et al. 2015)

3.4.4 Disposal

Abdulkaree, Raji & Adeniyi (2017) reported that massive amounts of sawdust are produced yearly through sawmills processing. The means of disposal of those wood by-products has always been a challenge to the wood industry. This has resulted in a negative impact on the environment and economy.

Conventional means for disposing of sawdust worldwide include open burning, sometimes dumping in landfills, and open dumping. Open burning emits a lot of greenhouse gases into the air. Carbon dioxide, particulate matter, and methane are examples of these compounds commonly connected with air pollution and can cause severe respiratory problems. The conversion of such waste as a building material will help eliminate such pollution within the environment.

4. Conclusions, Suggestions, and Further Study.

This study was able to justify some of the properties of wood waste cement composite, looking at the mechanical and physical properties (Fineness, comprehensive strength, setting time, loss on ignition, insoluble residue, specific surface area, flexural, split tensile, and the chemical properties of selected portland cement, also its use as building materials from selected published articles from 2005 to 2021. The findings of this study noted the following:

- In Nigeria, Five (5) cement samples were reported by scholars, while findings noted four (4) of them were seen as frequently available in the Nigerian construction market. It was concluded that all the cement met the minimum requirements of portland cement, wherein Dangote cement had the highest strength of crushing on the 28th day. While Diamond cement gained early strength ahead of the other cement.
- Various scholars considered the following mechanical properties; flexural, split tensile, and compressive strengths. Wherein Comprehensive strength was considered most in mechanical property. Findings reveal the impact of adding wood waste ash and crimped steel fibers on the comprehensive strength. 20% and 0.75%, respectively, mix volume was seen as the optimum content volume.
- The physical properties of wood waste were attributed to its behaviour towards external influences apart from applied forces and its elementary characteristics. These include moisture content, density, grain and texture, thermal behaviour, water absorption, slump test value, dimensional stability, etc. The following assumptions were practically agreed on: the more the increase in the amount of sawdust, the lower its workability; the higher the quantity of sawdust in the fresh design mix, the lower the slump tested
- Ten (10) common use of sawdust for non-construction works were identified. Also, six (6) common use of sawdust composites about construction were identified in Table 8, which are: Used in the production of oriented strand boards, plywood, fiberboards, and particleboards; Use as floor panels; Used for cladding and partitioning; Used for Mortar Solid, Concrete block or Bricks; Use as pozzolana; Use as partial replacement of fine Aggregate.

This study is limited to selected articles closely related to the aim and objective of the study. Further research can be conducted to check the fire resistance, moisture absorption rate, and split tensile wood waste composite. Same original study in the area of cement property could be studied in other countries.

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Developing a VR Research Instrument for Participatory Design of Educational Spaces

Dr. Poorang Piroozfar[1,2,3,4], Mr. Imran Farooqi[1], Mr. Simon Boseley[3], Mr. Alex Judd[3], Dr. Eric R. P. Farr[2,3,4]

[1] School of Environment and Technology, University of Brighton, Brighton, BN2 4GJ, UK
[2] Digital Construction Lab, University of Brighton, Brighton, BN2 4GJ, UK
[3] MAVRiC Research and Enterprise Group, Shoreham-by-Sea, BN43 6AX, UK
[4] NONAMES Design Research and Studies, 1249 F Street, San Diego, CA 92101, USA
A.E.Piroozfar@brighton.ac.uk

Abstract
Virtual Reality has a proven track record of benefits in the AEC industry. Participation of end-users in the design process has been advocated as a means to improve spatial quality in design. There is limited evidence of application of VR to promote design participation. This becomes even more important when the end-users of space are from different backgrounds. Design of educational spaces is challenging and demanding due to a multitude of reasons. This makes participation of higher importance in the design of such spaces. Traditionally paper-based methods have been used to facilitate participatory design of educational spaces. However, with the fast pace of migration to virtual environment solutions, VR applications seem to be a viable solution. Despite this, there is limited evidence of previous research in this area. This paper uses games engines to develop a virtual interaction environment to facilitate participation in design of educational spaces. A critical review of literature was used to set the boundaries of this research, interrogate the principles of participatory design, define a set of variables, and investigate the areas where VR can be applied as well as design features and aspects which can be comprised in participatory design of educational spaces. To enrich the scops and application of the knowledge claim of this research, the last section was also investigated through primary data collected from an expert survey conducted with school teachers. The development of the VR experiment is explained in this paper which will be verified as a part of future research. This will help close the loop on User Experience (UX) research process which has been utilized in this study.

Keywords
Virtual Reality, Participatory Design, Design Collaboration, Educational Spaces, Classroom Design

1. Introduction
Virtual Reality (VR) offers several proven benefits and has numerous potential areas for further development in the AEC industry. While its contribution to THE? improvement of current practices in the AEC industries is manifold, one of the common denominators for justification of need for and necessity of wider adoption of VR technologies is their role in facilitating collaboration. The scholarship on design on the other hand, has advocated it as a task which can be enhanced through collaboration. Therefore, it will not be unfounded/uncompelling to assume that participation in design can benefit from VR capabilities. This explains some 'cookie cutter' software applications which have started to emerge recently. Such approaches to application of VR in design, although easy, affordable and sometimes even intuitive to use, quite understandably try to remain as generic as they can. They are not niche or tailored to the specifics of a project and often very difficult to calibrate, manipulate, adjust or tune to fit the specific purpose of a project. On the other hand, there is a major gap in research documenting particular yet customizable workflow development aspects of such applications. This is probably due to the diversity in context, content, aspiration as well as methodologies in different design approaches and schools of thought. Such research is important because it investigates how a participatory approach to design can be nurtured and institutionalized using VR technologies. The factors affecting the design process are numerous and their weighting, significance and occurrence are varied. It is however of paramount importance that limited scope research in this area is initiated to lay the foundation for further developments and more all-inclusive investigation of what VR technologies can offer to enhance participatory design research. As an attempt to do so, a research project has been designed to investigate how the process of participation

of a space end-user stakeholder group (teaching staff) can be improved in the collaborative design practice of an educational space (a classroom). The contribution of the research project is multifaceted, part of which is reported in the current paper. The paper contributes to the state-of-the-art VR research through outlining a procedural workflow in designing a VR experiment for participatory design. A critical review of literature helped set out the boundaries of this research, interrogate the principles of participatory design and design collaboration, define a set of variables (and constants) in designing a classroom, and investigate the areas in which VR was best situated to help achieve research aim and objectives. The main focus of this paper is the VR development process of the experiment. The design of the research, the data collected and collated for, and the areas, factors and variables used in the development of the experiment are all covered in our other paper within the same collection. The findings indicate that different generations of teaching staff with varied prior experience of, and exposure to, VR technologies welcomed a niche experiment in VR, designed to facilitate their collaboration in the design process of their classroom. The views about how they would have preferred to have control over or be able to manipulate or customize the design layouts of their classes were expectedly varied. Due to COVID restrictions we were not able to validate the designed instrument with teacher participants. Had this been possible, the research would have been a step closer to delivery of a VR tool which could have enhanced the design participation experience of an end-user stakeholder group.

2. Literature Review

2. 1 Design Collaboration and Participatory Design

Reviewing 94 articles published on design collaboration between 1986 and 2018, Azmi et al. (2018) identified four themes: teamwork, BIM, evidence-based design (EBD) practice, and modality supported collaboration design (MSCD). They suggest that digitally-supported collaboration is associated with improving the efficiency of the design process but has not been critically reviewed and integrated, specifically in terms of different complex issues, such as group cognitive action, reasoning, and sharing of tacit knowledge. Their review indicates very limited attempts on extended reality (XR) as a digital tool to support design collaboration. Sharing of tacit knowledge in collaborative design facilitated through VR is what this paper aims to contribute to/address. Design collaboration is a deep-rooted concept in different design disciplines and in the AEC industry. Several terms are either associated with or interchangeably used together with collaborative design such as participatory design, cooperative design, multi-disciplinary design, concurrent engineering, co-design, co-creation, simultaneous engineering, and integrated design, to name but a few. Collaborative design is concerned with how different parties work together and/or with clients or end-users. It helps satisfy the design intents, enhance the design process, and improve the quality of the final product. It has been suggested that some of the practical, political, and theoretical challenges of participatory design might be relevant to contemporary design thinking (Bjögvinsson et al., 2012). Issues pertaining to design collaboration might imbue highly differentiated types of approach among designers in search of a common design goal (Idi & Khaidzir, 2018). While some researchers believe that the key to a successful collaboration across multiple teams each with a different attitude towards the project is structure and organization (Chiu, 2002), others argue that unstructured collaboration can be more effective (Latch Craig & Zimring, 2000). While engaging ordinary people in creative design through participation in the design of their local communities has been advocated (DiSalvo et al., 2012), it has been noted that participants that lack some basic understanding of the project may shy away from collaboration (Hussain, 2010), and inability of technical members to communicate in a non-technical fashion may disrupt the participatory design process (Godjo et al., 2015). Moreover, logistic complications can make participatory design inefficient (Bodker, 1996). Hagen and Robertson (2012) examine how social technologies are characterized by being designed through use, which in turn lead into new forms of participation.

2. 2 Virtual Reality

The body of VR scholarship has enjoyed a substantial growth over the last few years due to prevailing game industry trends, wider availability of and accessibility to VR technology, proving VR's major benefits in the AEC industry and last but not least for the necessity to move into virtual interaction environments (VIE) as a result of Coronavirus international pandemic. VR has been used to study novice designers' spatial cognition in collaborative design (Rahimian & Ibrahim, 2011), as an interaction design tool in healthcare training (Matthews et al., 2020), for collaboration in children's design processes (Ryokai et al., 2022), experience design (Sherman & Craig, 2003), participatory design experimentation with the elderly (Kopeć et al., 2019), semantic-based taxonomy in product design (Makris et al., 2012), group debriefing in safety education (Luo et al., 2021) and to investigate how immersion and interactivity drive VR learning (Petersen et al., 2022). However, there is very limited, if any evidence, of previous work on participatory design of educational spaces in general or a classroom in particular.

2. 3 Classroom Design

It has been argued that 'space' has a special 'language' of its own (Lawson, 2001). Canter (1977, p.158) argues that "a place is the result of relationships between actions, conceptions, and physical attributes". Malaguzzi explores the idea of space as a means of promoting social relationships between people, choices, and activities, as well as influencing organization and cognitive learning. He asserts that users echo their ideas, values, and cultures through the space, creating a territory of characteristics and traits (Edwards et al., 1993). Referring to Piaget's idea that children require a cognitive style of learning to develop all the skills necessary to become a fully developed adult, this study focuses on the concrete operational stage – the third in Piaget's theory of cognitive development. Child-centered classrooms and 'open education' are direct applications of Piaget's views.

A comprehensive literature review on the impact of school environments carried out for the Design Council points out 'temperature/air quality', 'noise', 'light', 'color' and 'other school build features' under 'The school built environment'. The research then carries on to also add 'furniture and equipment', 'arrangement and layout', 'display and storage' and 'ICT' more specific to the classroom under 'The physical environment of the classroom' (Higgins et al., 2005, pp.14-28). They suggests that: i) There is strong, consistent evidence for the effect of basic physical variables (air quality, temperature, noise) on learning; ii) Once minimal standards are attained, evidence of the effect of changing basic physical variables is less significant; iii) There is conflicting evidence, but forceful opinions, on the effects of lighting and color; iv) Other physical characteristics affect student perceptions and behavior, but it is difficult to draw definite, general conclusions; v) The interactions of different elements are as important as the consideration of single elements; vi) Much of what is known about student comfort, particularly in terms of furniture, has yet to be translated into actual school environments; vii) Since different room arrangements serve different purposes, it is necessary for classrooms to have some degree of flexibility; iix) Some improvements to environment may save time, which is then available for learning; ix) 'Ownership' of space and equipment by both teachers and students is important; x) Ownership and engagement are ongoing elements, so there has to be a balance (in display of student work, for example), between permanent and fresh elements; xi) Some physical elements in the classroom improve comfort, well-being and probably attitude - and so, perhaps, improve achievement (Higgins et al., 2005, pp.22, 28).

3. Research Design and Methodology

This paper presents the developmental workflow of a VR experiment for participatory design of educational spaces (classrooms) for teaching staff. A critical review of the literature on participatory design, application of VR technologies, and the design of educational spaces (classrooms) was used to address the latest development in the three areas that this research aims to triangulate. While the main study has used a mixed methodology, this paper is concerned with how the findings of the literature review, combined with findings of the expert users' survey were utilized to construct the VR experiment. All data collection procedures where human participants were involved were designed and conducted following GDPR requirements. The research project was vetted and approved by the University of Brighton's Tier 1 Research Ethics Committee. This paper focuses on the development of the experiment, building upon project collaboration and data synchronization principles, through 3D object modeling, texturing and hierarchy, data transfer, variant sets, locomotion, and user experience (UX). The research instrument designed in this study uses two stage of data collection – secondary, through the review of literature and primary through the survey carried out with school teachers and aims to facilitate the UX through interactive VR technologies. Classical UX process in software development was adopted but had to be limited to the development of the tool due to COVID restrictions. Closing the loop in the UX research process which would involve testing the UI with selected group of users, collecting feedback on the tool, focus group discussion to investigate users' needs, wants and preferences further and deeper will need to be explored as a part of the future development of this research once the pandemic restrictions are all over.

4. Experiment Development

4. 1 Introduction

The higher-level mechanics were established through conceptualization of how the VR application, or Virtual Interaction Environment (VIE), would function for the user. In discussion of VIE requirements it was apparent that there were two aspects to classroom layout arrangement: Large and/or multifaceted, groups of objects and furnishings requiring pre-set layout which otherwise would be time consuming in manual placement; and the variable placement of singular one-off objects, independent from overarching layout organization. The approach to this was led by the concept of 'static and dynamic objects', informing several aspects of experiment development including but not limited to: organization and handling of 3D objects, user locomotion, user experience (UX).

Static objects consisting of non-moveable components such as desk and chair layouts, ceiling lighting, windows, and doors etc., were handled through 'placement by selection' or 'Variant Sets'. Although to some extent this approach is 'immersion breaking' and contrary to some VR UX principles, alternative approaches other than pre-set selections were not viable due to over-complexity of interaction.

Dynamic objects on the other hand consisted of items such as bins, specialized lighting, mobile whiteboards and screens, storage and other class/subject specific items. A 'Drag and Drop' system was developed to provide such functionality of manual placement and readjustment, although not fully implemented in the final build of the VIE, such a system was deemed fitting. Dynamic interaction contributes towards a greater sense of immersion (Dalgarno et al., 2002). Moreover, dynamic interaction's advantages over a static approach include more life-like control and sensory feedback (visual, haptic, auditory).

This study will include windows, shading devices, lighting (natural and artificial), color and storage and display areas as well as furniture layout as essential and common factors in classroom design for the design of a VR experiment as a participatory design tool for school teaching staff.

4. 2 Project Collaboration & Data Synchronization

A key aspect of development and collaboration was that it be carried out via remote working, something which evidently has become increasingly necessary and convenient with the onset of a global pandemic. GitHub (GH), the cloud-based version control development software, was used for this purpose to allow for file sharing and backup of data. Furthermore, GH has built-in source control for Unreal Engine (UE): The game engine used to create the VR application.

4. 3 3D Object Modeling, Texturing and Hierarchy

Although UE has such capabilities, dedicated 3D modeling software Trimble SketchUp (TSU) was used for the creation of 3D components (architecture, furnishings & objects). Although not deeply complex in functionality when compared to most of its competitors, it is nonetheless an industry standard application.

In order to facilitate efficient management of 3D components at a later stage, it was important that an object hierarchy be established. Parametric manipulation of these components benefitting from such systematic grouping typically involves object modification (scale, texture, location) or forms of scripting/programming (VR interaction, design variations etc.). Such tasks are streamlined when a centralized approach is taken to the organization of components and their parent components. These hierarchies implemented in TSU (Fig. 1) are maintained via use of the Datasmith (DS) plugin for UE, which acts as a cross-platform bridge for these assets to UE.

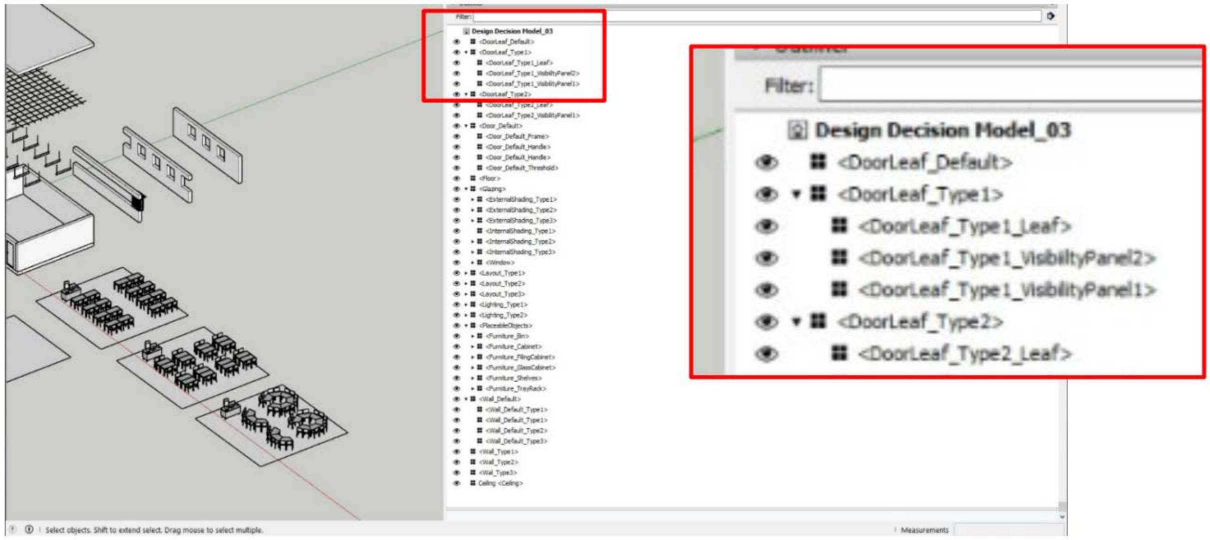

Fig. 1. Example of hierarchies generated within Trimble SketchUp

For texturing, object materials were left untextured (default white) in TSU to be fully textured in UE. Natively, UE allows for greater depth and realism, due to the advanced in-built renderer and set of tools. Although TSU has comparable tools and capability through utilization of 3rd party plugins/extensions such as VRay, this process was carried out inside UE so as to minimize potential data loss during bridging, which becomes a greater concern at later stages where larger file sizes are involved (e.g. high resolution textures). Dedicated material libraries such as 'Megascans' were used to facilitate quick application of Physically Based Rendering (PBR) textures which otherwise would have to be sourced and formatted layer by layer.

4. 4 Transferring Data

Datasmith (DS) is a collection of tools and plugins that bring entire pre-constructed scenes and complex assets created in a variety of industry-standard design applications into UE (Unreal Engine, 2022). DS was utilized to facilitate the import of the 3D modeling, texturing and hierarchy into the VIE (Fig. 2). It was found that materials applied in TSU using 3rd party software such as VRay, may not be imported. This is likely due to the system file locations for the 3rd party software being disjointed from DS's targeted default location. In light of this, the decision to import textures separately within UE to create materials, was preferred due to UE's inherent optimization capabilities that would help improve runtime performance, especially where stereoscopic rendering is utilized.

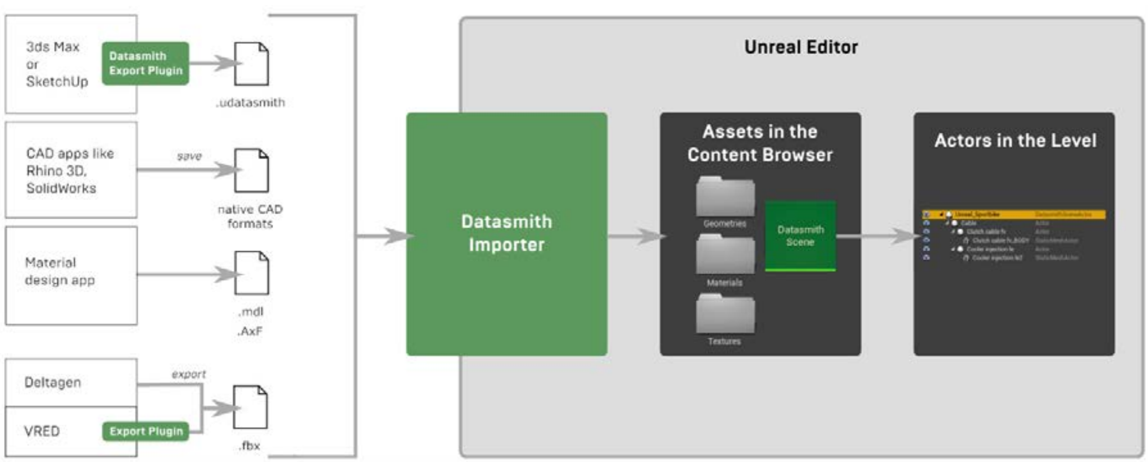

Fig. 2. Overview of Datasmith Import Process (Unreal Engine, 2022)

4. 5 Variant Sets

The VIE had various design categories, each with item variations. These item variations were established within TSU as children of a parent component. Following a DS import, which retained this hierarchy, a script in UE was procured to enable the user to cycle through variations and allow for only one instance per hierarchy to be visible at any particular point in time. The script was facilitated by UE's Variant Set capabilities which streamlines this process by associating an instance(s) with a visual status, established using a predefined Boolean value. These variant sets were then subsequently served by the widgets as part of the UX design, allowing the user to operate the variant sets at runtime.

4. 6 Locomotion

To enable users to move around the VIE, a parabolic raycast teleportation system was implemented; this was the preferred option to joystick controlled continuous movement as it can reduce symptoms of motion sickness caused by the use of head mounted displays (HMD) (Nisha et al. 2019) and is described closer to the 'comfortable' rating from 'Oculus comfort rating' (Oculus, 2021). The teleport system utilizes a reticle to identify where the user will be teleported to. They are constrained to an area using a navigation mesh parameter, 'bouncing back' the user from the boundary they are aiming at.

It was important to consider the navigation as the application runtime progresses, as there will be more obtrusive objects i.e., classroom desks and storage cupboards. A system providing predetermined teleport snap points was explored, however it was concluded that it would not give the teachers the full immersive experience of design elements required for collaborative understanding.

A snap rotation was deemed the most suitable option for user rotation as it would reduce the risk of motion sickness whilst also creating a more logical navigation. This was facilitated by moving the joystick along the X axis which will rotate the user by 22.5 degrees in the direction it is pressed.

4. 7 User Experience (Data Collection and Input stages only)

Most teachers surveyed (8/10) stated that they were aware of VR; however most had second-hand experience with it. Considering this, it was deemed appropriate to create a visual tutorial explaining the User Interface (UI) items. In addition to this, by using the Oculus Quest (OQ) controllers for the in-game hand models, it allowed users to visually acknowledge the actions associated with the buttons on the controls.

When initially planning the UI for applying design changes within the application, three options were explored: 1. Wrist widget, 2. Prompted object widget 3. Radial widget. The wrist widget, allocated on one hand, contains a singular design element and the associated variations on one slide; the following design element is accessible by clicking the next arrow. It was concluded that users are less likely to become overwhelmed and feel tedious of the application if they were aware of their progress, which is challenging to communicate using a radial or prompted object widget. This also acts as a navigation tool and assists users, should they need to go back to a previous design element to make changes.

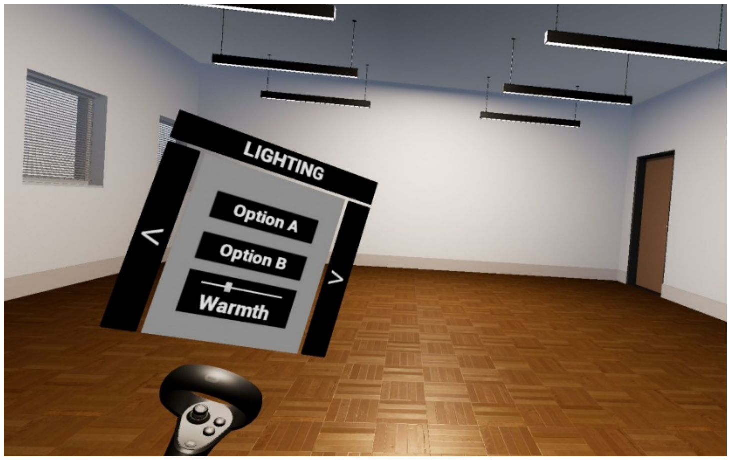

Fig. 3. Design of User Interface for the choice of lighting variations.

The secondary option was to create widgets located by the design element to help guide the user through the VIE. To ensure users are able to locate the widget menu, a tracking arrow would prompt users in the correct direction. However, it was concluded that, through the perspective of the users, it would shift the purpose of the experiment from understanding the design changes to a sequential progression through the space.

In review of the design element: Lighting Intensity, it was found that the initial decision to have 3 options 1. Low, 2. Medium, 3. High; each with associated Kelvin levels was unrealistic. Considering this, the lighting intensity widget slide was changed from three options to a slider that increases/decreases when the slider is shifted along its axis.

5. Concluding Comments

This paper reports on the development process of a VR experiment which was devised to help the design participation experience of a non-design-expert end-user stakeholder group. The literature was used to designate the areas which could have been addressed and benefitted from the development of the VR experiment for design collaboration. While there were other potential design areas or variables, they were not deemed directly relevant, hence excluded. This was because they were pertaining to other different design decision levels which require more specialized expert decisions, are bound to meet other technical requirements or supposed to fulfill regulatory or obligatory requirements. The use of UE for development of the VIE in this study, although more challenging compared to some off-the-shelf VR solutions, was proved beneficial as it offered a higher level of flexibility and allowed for customization of the VIE to the specific research design in this study. Some of the preferences highlighted by the participants conform with the findings of the literature review although sometimes with a different level of priority or importance, while some others showed a different pattern to the contrary of the findings of the literature review. This could have been due to the direct or indirect implications of the COVID restrictions or due to specific participant samples used in this study. This is very hard, if possible, at all, to substantiate at this stage. Practical steps were taken in the development of the VR experiment to ensure that the UX would be as intuitive and smooth as possible. However, this was not reviewed, tested or fed back by the participants in this research due to COVID access restriction and was hence considered as future research. This was developed chiefly based on previous experience of the team in development of VR experiments using game engines and supported by the various resources provided by developer communities and evidenced in previous research.

6. Future Research

Future research includes, but is not limited to, testing the experiment with a focus group of teaching staff and collecting feedback to improve the application with respect to its construct, system hierarchy and the graphic/visual appearance. This can also potentially help develop the application further in some of the areas already covered and/or add some other design features that may have been overlooked. Building upon the findings of this research, a more comprehensive VR experiment can be developed to include other teaching facilities in a typical school such as computer labs, science labs, libraries, multi-functional spaces, and staff rooms. In case the developed application is applied to a broader range of stakeholders (both teaching staff and pupils), the collected data can be used to feed into a (semi-) automated self-enhancing design engine using principles of machine learning (ML) to improve the participatory design experience of teaching staff. To facilitate this, scripting may be required to enable data capture and extraction to feed the data into subsequent research.

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ID 58

The Last Planner System®: State of the Art

Kiruthika Murugaiyan[1], Wassim Al Balkhy[1*], Zoubeir Lafhaj[1], Fabien Font[2]

[1] Centrale Lille, 59650 Villeneuve-d'Ascq, France
[2] Teamoty – Groupe IMMA, 75015 Paris, France
wassim.albalkhy@gmail.com

Abstract

Lean construction is an evolving philosophy introduced in the construction industry with the aim of delivering the project with maximum value, continuous flow, and improved reliability. Last Planner System® (LPS) is an important key lean technique, which increases the reliability of planning and reduces the variation at the construction site. LPS is an example of a production planning and control system that has been successfully implemented and applied to complex construction projects to improve workflow reliability, production performance and to promote production control by engaging all members of the project team. An extensive literature review was carried out to understand the origin, principles, planning stages, effectiveness, benefits, and barriers in implementing the Last Planner System in the construction industry. Finally, the areas that need further research are highlighted and the need for incorporating LPS is emphasized.

Keywords

Construction Planning, Lean Construction, Last Planner System®, Productivity, Look Ahead Schedule, Barriers, Benefits

1. INTRODUCTION

Poor project management is one of the main reasons for the delay in construction projects (Alsehaimi and Koskela, 2008). Planning and reducing delays are the most efficient ways to increase the productivity of any project. Lean Production was developed by the Toyota production system in the 1950s led by Engineer Ohno who was committed to eliminating waste (Dakhli et Lafhaj, 2018). The core concept behind Lean Production is to enable the flow of value by creating work steps while eliminating non-value steps. Lean production ideas were first formulated through the TFV (Transformation-Flow-Value) theory of production (Abdelhamid et Salem, 2005, Dakhli and Lafhaj, 2018). In Lean, planning and control are considered to be complementary and dynamic processes throughout the entire project (Alsehaimi et al. 2009). Lean-based tools have emerged and have been successfully implemented in construction projects with the focus on increasing value for customers and making profits (Salem et al. 2005). Poor performance in the construction industry is mainly because of uncertainty and variability in the workflow (Aziz R and Hafez, 2013). LPS is an important key lean technique that increases the reliability of planning and reduces the variation at the construction site (Ballard and Howell, 2003, Bertelsen, 2004). According to the Lean Construction Institute, the companies using the LPS have been able to deliver the project on time and at budget under stress-free production planning and control processes (Abdelhamid and Salem, 2005). This literature review aims to provide a synthesis of the origin, principles, benefits, and barriers in implementing LPS. An extensive literature review of studies published from 1992 to 2022 was done to identify the existing benefits and barriers which can be used by future researchers to propose potential solutions. This paper is organized into 4 sections. Section 2 deals with the Methodology; Section 3 describes the origin of the Last Planner System, Principles, Planning stages, Applications of the Last Planner System, Benefits and Barriers in implementing LPS; Section 4 presents the conclusion and future research direction.

2. METHODOLOGY

A critical and comprehensive analysis of the current knowledge on the Last Planner System is provided in this narrative literature review. The literature review analysis is very important to cover the state-of-the-art progress about the studied topic and cover its different aspects. During the conduction of this study, the authors found six previous articles that were conducted to review the related literature about LPS (Desarrollo, 2019; Kortenko et al., 2019; Babalola et al, 2020; Yu et al, 2020; Schimanski, 2020; Sbiti et al, 2021). Even though all of these works were very important, none of these articles covered the same objectives this study does. In addition, most of the previous work aimed to link LPS with other topics such as Building Information Modeling (BIM), design management, and other lean tools.

To achieve the objectives of the study, the study used a search in the title of the articles published on Google Scholar between the years 1992 and 2022. The selection of the year 1992 was because it was the year that witnessed the first work that aimed to present the concepts of lean to the construction industry by Koskela (1992). The search included: ((last planner) AND (origins OR benefits OR barriers OR principles OR applications OR levels)). The inclusion was for the articles that were written only in English. The total number of selected articles was 50.

3. RESULTS

3.1 ORIGIN OF THE LAST PLANNER SYSTEM

Construction projects require planning and control throughout the life of a project. Glenn Ballard and Greg Howell have been involved in the process of developing LPS since 1992 (Kalsaas et al. 2009; Ballard and Tommelein, 2012; Daniel et al. 2015, Dakhli and Lafhaj, 2022). LPS is a system for production planning and control method adapted from the manufacturing industry to improve the predictability and reliability of the production process (Mossman 2012; Mejia et al. 2016). The Last Planner is a holistic approach which means that every part of it is necessary for lean project planning and execution. Last Planner breaks down larger tasks into specific work assignments, which are then assigned to individual teams to be completed in the specified time frame (Santos and Tokede, 2016). Initially, LPS was developed to increase the quality of assignments in the Weekly Work Plan (WWP) and then extended to design from construction. During the process of development, the focus was shifted from increasing productivity to improving the reliability of workflow (Ballard, 2000). Over the years, LPS has been implemented in many countries demonstrating its effectiveness in different work cultures (Alarcon et al, 2005; Viana et al. 2010; Daniel et al. 2015). According to the website of Lean Construction Institute, the Last Planner System is defined as: "*The collaborative planning system which integrates should, can, will, and did planning and perform constraint analysis, and weekly plans based on commitments and reliable promises and learning from measuring Plan Percent Complete and analyzing variance*".

LPS is a planning and control technique, which increases the productivity of the project by applying these three principles: (1) By coordinating the last planners through regular meetings, (2) Through commitment and responsibility of these last planners (Hamzeh et al, 2009 and Seppanen, 2010) and (3) By the representation of the obtained results using Percent Plan Complete (PPC). The primary goal of LPS is to improve the workflow by eliminating waste and to complete the work as and when promised. It replaces unrealistic planning with collaborative planning by evaluating the worker's performance and potential in completing the assigned work in planned time. Production unit control and workflow control are the two important components of the system. At the production level, the key performance dimension of the planning system is the output quality, that is the quality of plans made by the last planner system. Production processes can be grouped into three different categories: 1) Conversion of inputs to outputs, 2) Flow of materials and information through time and 3) Value generation for customers. (Ballard, 2000). According to Koskela (1992), the following are the principles for a production control system that also holds good for the Last Planner System: The work can be started only when all the resources required for the completion of the work are available. This principle is also called Complete Kit by Ronen. a) Assignments should be monitored and measured using PPC, which is the percentage of several completed planned activities divided by the total number of planned activities. b) Identification and removal of causes for non-realization which helps in continuous improvement. c) A buffer of tasks has to be maintained so that if the assigned tasks become impossible to execute, then the workers can shift to another task. d) It also helps to avoid production loss and decrease productivity. e) Look ahead Planning is suggested so that the prerequisites of the forthcoming assignments can be made ready in advance.

In general, push and pull are the two ways by which workflow can be regulated in production control. Traditionally construction schedule follows a push system. In the push system, the materials and information are released according to the preassigned due dates or target completion dates whereas in the pull system the materials and information are released according to the work progress. Resources are released into the production process only if the process can do that work (Ballard, 2000). In the Look Ahead process, assignments are made ready using pull techniques. Therefore, LPS is a type of pull system. Reliability greater than the supplier lead time is required for the pull system to be effective. The Last Planner System pulls activities by reverse phase scheduling through resource optimization and proper team planning. This tool is similar to the Kanban system and production leveling tools in Lean manufacturing (Salem et al. 2005).

3.2 PRINCIPLES OF THE LAST PLANNER SYSTEM

The five important principles of the Last Planner System are 1) Detailed planning of the work as the start date of the work approaches; 2) Collaborative planning with those members who will execute the work; 3) Identification and removal of constraints of the planned work; 4) Make a reliable plan and promises and learn from variance; 5) Elimination of waste and continuous improvement based on previous learnings to avoid reoccurrence of failure (Daniel et al, 2015). The last Planner System helps to maintain a reliable workflow. In weekly meetings of push planning the work that SHOULD be done is planned; whereas, in pull planning, the work that CAN and WILL be done is planned and considered (Dakhli and Lafhaj, 2018). Last Planner transforms what SHOULD be done into what CAN be done (Stratton et al, 2010). LPS consists of five levels of planning processes: Master planning, Phase planning, lookahead planning, Weekly work planning, and learning (Ballard 2000; Ballard and Howell 2003; Daniel et al. 2019; Mossman 2012).

Master Scheduling: It is the general long-term plan which is driven by the project objective and design criteria. Aligning the team and the key milestones are set within the master schedule. It also identifies the time required for the completion of each activity. The Work Breakdown Structure of the project is recognized in this phase. It defines some top-level tasks of work breakdown structure based on initial scope, time, and budget. During this phase, execution strategies are developed and the feasibility of completing the work within the given time is analyzed and demonstrated. It forms the basis of Phase planning (Daniel et al, 2015).

Phase Scheduling / Collaborative planning / Reverse phase scheduling: This phase provides a more reliable and detailed work plan and objectives that could be deliberated as targets. This phase includes strategic planning of work segments which involves pulling the schedule backward to avoid mistakes later. It also helps in providing a detailed weekly work plan (Seppanen et al, 2010).

Look Ahead Planning / Make work ready planning: Look Ahead a Schedule is a tool for workflow control. It is in the mid-level of the planning hierarchy, in between front-end planning and detailed planning. It involves mapping the resources with workflow and making the task ready so that they can be completed at the right time and also ensures production proceeds at the optimum level (Ballard, 2000). The objectives of the look-ahead schedule include identifying and eliminating the constraints and also reducing uncertainty (Daniel E, 2017). Look Ahead Plan helps to start the activities on time and allows only the activities with available prerequisites to be started (Ballard, 2000). Look Ahead acts as a forecast of activities to be performed in the next 3 to 12 weeks and makes the schedule of the assignment for the following weeks (Santos and Tokede, 2016).

Weekly work planning / Commitment planning: In this phase, specific resource planning and assignment has to be made for the successful completion of the work. It is carried out every seven days in the presence of the last planners. It includes planning each day's work and sequencing next week's work to create a reliable workflow plan. The tasks planned during the previous week are reviewed to create a plan for the week ahead. Only the tasks which meet the four production criteria are allowed into the Weekly Work Plan. The production criteria are 1) well defined and detailed task breakdown 2) the task that can be done 3) the tasks that are sequenced 4) properly sized task. The tasks which do not meet these criteria are called workable backlogs. They are retained and not allowed into the WWP. (Daniel et al. 2015).

The key metrics used in LPS implementation are Percentage Plan Complete (PPC), Reasons for Non-Completion (RNC), Task Made Ready (TMR), and Task Anticipated (TA). Root causes of variance are analyzed and continuous improvement is made in this phase which contributes to the minimization of the problem in long term. Last Planner System uses lean construction techniques such as Just in Time delivery, Value Stream Mapping, Pull planning, etc. The general implemented components of LPS include Weekly Work Plan (WWP), Percentage Plan Completed (PPC) (Daniel et al. 2015; Hamzeh et al. 2015), Reasons for Non-Completion (RNC), Look ahead and Daily Huddle meeting. Extensive quantitative research has been done by Daniel et al (2015) on LPS implementation based on 57 IGLC reports from 16 countries. According to the research, PPC, WWP, RNC and Look ahead are the most commonly used components (Daniel et al, 2015, Hua and Schwartz, 2021).

One way of developing the involvement and communication among laborers is through visualizing the required information at the workplace. Increased visualization is an effective way of communicating the key information related to safety, schedule, and quality to the workers. Workers can be certain of elements such as workflow, performance targets, and specific required actions. Setting up instructions for material and equipment storage, reduces waste, such as the time for searching and transportation. These plans can then be displayed which is a form of visual management and referred to convey the performance standard (Mastroianni, 2003,).

3.3 APPLICATIONS OF THE LAST PLANNER SYSTEM

Planning is a key element for successful production generating high profit (Friblick 2009). Applying LPS in the design stage helped in identifying the conditions of satisfaction of the customers at an early stage. It gave a clear picture to the design team, of where to focus on the design. The inputs from the construction team to the design team helped in eliminating inefficient design which would have led to rework in the future. (Miles 1998). Still, there are some questions regarding the implementation and effect of LPS in the design stage. Hamzeh et al.2009 researched the application of LPS in the design stage during the construction of Cathedral Hill Hospital, California. Few adjustments and modifications have been made to introduce LPS in the design stage. Ballard emphasized the three factors which differentiate production control during design, 1. Increased uncertainty decreases the ability to foresee the tasks in the future 2. Effect of increased speed of execution and constraint removal to make tasks ready for execution 3. Interdependencies between tasks in design accelerate the complexity of work (Hamzeh et al 2009). The applications of LPS in various projects are tabulated below in Table 1.

Table 1: Applications of the Last Planner System

Project	Outcome after implementing the LPS	Methodology	Reference
Small high-tech project	Increase in PPC to 75%, the design was completed one week earlier than expected and design costs were reduced by 7%	Implementation of LPS in design and construction stage	Miles 1998
Construction of library in Campinas, Brazil	Completion of project on time, decrease in cost by 42%.	Weekly preparation of medium-term schedule, Detailed weekly work plan (daily plan).	Conte 1998
CCSR Project – Laboratory building for Stanford University	Active involvement of team members	Implementation of LPS, constraint analysis, identifying the readiness of assignments and taking actions to make them ready, and measuring PPC	Ballard 2000
Next stage (Amphitheatres in US cities)	LPS was 44% more effective than a traditional management practice	Implementation of LPS in the Design and construction stage	
Pacific Contracting	Achieved average PPC level of 76%	Implementation of LPS by specialty contractor, First Run Studies	
Old Chemistry Building Renovation, Linbeck Construction	Achieved PPC level of 85%	Implementation of LPS	
Zeneca, Barnes Construction	Achieved PPC near 100%	Implementation of LPS, constraint analysis and make ready	
77 construction projects in Chile	Increase in PPC from 63% to 71% in 3 years.	The first group involved a basic level of implementation with importance on WWP and an informal Look Ahead Plan. In the second group, emphasis was given to formal look ahead planning, workable backlog, and learning.	Alarcon et al. 2005
Construction projects in Sweden	Decrease in time spent on working with non-value-added activities. Labor efficiency increased up to 8.7%	Implementation of Last Planner System	Friblick 2009

Cathedral Hill Hospital, California	Increased communication among designers and team members and owners had an important role in LPS implementation	Implementation of LPS in the design process	Hamzeh et al. 2009
Two Construction projects in Saudi Arabia	Increase in PPC from 69% in the first week to 86% in last week in the first project and 56% to 82% in the second project.	Implemented in four phases. PPC measures and reasons for non-completion were analyzed.	Alsehaimi et al. 2009
Seven construction projects in Mexico	Gives a better understanding of program control, coordination of team members, Better visualization, and clear vision	Training and Implementation of LPS, analysis of critical points, and effective measures to improve implementation	Cerveró-Romero et al. 2013
Construction of 1534 apartments in Fortaleza, Brazil	PPC level of 70% to 80% was achieved	Training and Implementation of LPS and Visual management for one year	Barbosa G et al. 2013
Construction site in South Western China	Challenges in implementing LPS are the exclusion of foremen in the planning process, lack of updates on planned information, and lack of involvement and cooperation among stakeholders	Implementation of LPS of production control, identify constraints, and measure PPC	Huang H 2015

3.4 BENEFITS OF IMPLEMENTING THE LAST PLANNER SYSTEM

The benefits of the LPS across several countries around the world can be realized from the outcomes of the projects where it has been implemented (Ballard and Howell, 2003). Successful implementation of the LPS can result in smooth workflow, reliable work plan, increase in productivity, improved communication, cost minimization, reduced delivery time, and better participation among team members and subcontractors (Ballard 2000; Fiallo and Revelo, 2002; Koskenvesa and Koskela, 2005; Kim and Yang, 2005; Fernandez-Solis et al. 2012, Albalkhy and Sweis, 2019). Proper implementation of the LPS can also improve safety in the construction site. Based on the literature review, the various benefits of implementing LPS are listed in Table 2 (Ballard 2000; Formoso and Moura 2009; Hamzeh 2011and Fernandez-Solis et al. 2012).

Table 2: Benefits of the LPS implementation

Benefits	Fernandez-Solis et al (2012)	Viana et al (2010)	Alarcon et al (2002)	Fiallo et al (2002)	Mejia Plata et al (2016)	Johansen et al (2003)
Increased reliability in planning	✓	✓				✓
Improvement in project delivery	✓	✓	✓	✓	✓	✓
Better Team communication	✓	✓				
Expanding knowledge and learning among team members	✓	✓	✓			
Improvement in supply chain integration	✓		✓			
Better construction management practices	✓	✓				
Increase in quality of work	✓					

3.5 BARRIERS IN IMPLEMENTING THE LAST PLANNER SYSTEM

According to Leong and Tilley (2008), not identifying the factors that influence the successful implementation of the LPS may lead to the inability of the organization to understand the efforts which should be improved, where these efforts should be focused, or what effort is required to attain the better results. Studies have reported that organizational resistance followed by a negative attitude towards the new system (Albalkhy et al, 2021), lack of management support and the lack of exposure to the benefits and need to adopt the LPS, and difficulties in understanding its concepts to be significant barriers to the successful implementation of LPS (Daniel E I 2017; Ryan et al. 2019). Other factors include the use of incompatible procurement strategies and focus on cost (Conte 1998; Johansen and Porter, 2003), less integration of the supply chain and subcontractors (Ayalew et al, 2016), culture, and structural problems within the organization (Johansen and Porter 2003). Based on the literature review, the various barriers to the implementation of the LPS are shown in Table 3.

Table 3: Barriers in implementing the LPS

Barriers	Fernandez-Solis et al 2012	Viana et al .2010	Alarcon et al 2002	Koskenve-sa and Koskela 2005	Mejia Plata et al 2016	Ballard 2000	Alsehai-mi et al 2009	Garza and Leong 2000
Organisational resistance to change	✓	✓	✓	✓	✓		✓	✓
Lack of experience and training	✓	✓	✓		✓	✓		
Lack of time to implement		✓	✓					
Late or partial LPS implementation	✓		✓	✓			✓	
Lack of support from stakeholders	✓				✓	✓		✓
Misinterpretation of PPC indicator	✓		✓					✓
Poor use of information obtained from LPS implementation	✓	✓				✓		
Lack of leadership and commitment from management to implement LPS	✓		✓	✓		✓	✓	✓
Lack of collaboration among team members	✓							
Lack of understanding of LPS among human capital						✓		
Lengthy procedure to get approval from top management and client							✓	
Contract issues						✓		✓

4. CONCLUSION

Implementing lean and LPS in construction projects significantly improves the efficiency and productivity of the construction industry. Introducing LPS in the construction industry has several benefits such as increased process transparency, reduced project variability, and balance flow improvement. LPS is a dynamic process that has constantly evolved over the last 25 years. At present, research and studies have been conducted to integrate LPS with other systems such as BIM, Location-Based Management System, Takt Planning, etc. (Daniel et al, 2015). To bring out the developmental change in the field of construction, acceptance of lean tools and LPS is mandatory. In this paper, the evolution of LPS and the impact of adopting LPS in the construction industry are explained. The barriers in implementing LPS have been discussed and the need for implementing LPS in the construction industry has been emphasized. An efficient look ahead planning and constraint removal before and during execution can have a great impact on reliability measured by PPC and the entire project duration (Hamzeh et al, 2016). By implementing LPS, construction companies can have a better understanding of waste that is generated which can lead to improved efficiency in construction activities.

4.1 CONTRIBUTION OF THE STUDY AND FUTURE DIRECTIONS

The current study aims to contribute to the existing efforts made to disseminate the practices and culture of lean in the construction industry by providing a summary of the origin, principles, application, benefits, and barriers of lean construction in general and LPS in particular. This summary is useful for researchers and academics to present new directions for future research. It also serves as a reference for practitioners who are aiming at improving the levels of lean adoption in their projects.

Future research can be conducted on construction organizations that have implemented the LPS concept by observing their practices on-site and by developing the adaptations to be made in LPS. A qualitative research approach is suggested to investigate the nature of the significant barriers identified and to propose strategies for overcoming barriers to implement the LPS. This paper also proposes that practitioners focus on the interaction between LPS and BIM for further research

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Energy Performance: Effects of Air Distribution Systems and Building Envelope Design on Indoor Air Quality and Energy Efficiency

First Author (Na Han)[1], Second Author (Shinming Shyu)[2], Third Author (Suleiman Ashur)[3]

Eastern Michigan University, Ypsilanti, MI 48197, USA
nhan1@emich.edu

Abstract
Building design and systems are essential for indoor air quality and energy efficiency. This research emphasized enhanced building envelope design, which was related to measuring the exterior walls with a thermal resistance (R-value), the windows with window-to-wall ratio, and the rate of solar heat gain coefficient values based on building codes and standards. In addition, emphasis was placed on advanced air distribution systems by comparing traditional and advanced air-handling unit systems. The systems were related to outdoor air airflow with ventilation requirements based on building codes and standards that include the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 62.1; ASHRAE 90.1; the U.S. Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) v4; and the International Energy Conservation Code (IECC). This research found significant improvements from manipulated building envelope and air system treatments. Total energy consumption was decreased, and indoor air quality was improved when building conditions were improved with an envelope design and building system changes.

Keywords
Building Envelope Design, Air Distribution Systems, Indoor Air Quality Factors, Energy Efficiency Factors, Building codes, ASHRAE 62.1—Ventilation for Acceptable Indoor Air Quality, ASHRAE 90.1—Energy Standard for Buildings, USGBC LEED v4, IECC.

1. Introduction

Introduction and Background

Increasing consideration of climate change and limited natural resource problems have emphasized the need for sustainable building design and systems because of the considerable impact that buildings have on society, the environment, community, and the economy (USGBC, 2013). Based on an energy review report, around 40% of the total energy consumed annually in the United States was consumed by buildings (USGBC, 2013). Also, based on the U.S. Energy Information Administration (EIA)'s report, it was estimated that the major source of energy consumption is electricity (EIA, 2020). Generally, buildings consumed electricity to operate systems such as heating, ventilation, and air-conditioning (HVAC).

According to the U.S. Environmental Protection Agency (EPA)'s report, almost 30% of new or renovated buildings have experienced indoor air quality problems (EPA, 1991). The leading causes were inadequate ventilation and indoor/outdoor chemical pollutants. Indeed, indoor air problems contributed to building-associated illnesses, such as sick building syndrome (SBS), building-related illness (BRI), and multiple chemical sensitivity (EPA, 2020 a). As occupants spend more of their time indoors, they are likely to suffer from more health problems.

Multiple research outcomes and records provided evidence that building systems and designs caused indoor air problems that impact human health and that a significant amount of energy is required to operate air systems. Other research indicates that building systems and designs were directly related to both indoor air quality and energy efficiency because of buildings' energy (thermal/heat) performance and energy demand/supply. In the energy performance process, air contains energy (thermal/heat) in the forms of temperature and humidity (Tao & Janis, 2001).

For these reasons, this research determined that sustainable applications to building systems and designs are critical for improving both indoor air quality and energy efficiency. The problem to be studied in this research was to identify different factors of traditional and advanced air distribution systems and building envelope design methods for indoor air quality and energy efficiency. This research used a building energy design and energy performance simulation software program (Carrier Hourly Analysis Program [HAP] 5.11) for manipulating variables to find their effects.

Statement of the Problem

Facing the challenges of energy efficiency and indoor environmental health, building research professionals were prompted to formulate solutions to meet needs. This research study was based on the fact that the effects of advanced air distribution systems and enhanced building envelope design on indoor air quality and energy performance had not been well addressed.

Hypotheses

Both active and passive building envelope designs and systems contribute to indoor environmental quality and energy efficiency. Factors of advanced air distribution systems and enhanced building envelope design methods might affect the indoor air quality and energy efficiency in educational buildings.

Based on an understanding of the research problem and related literature, this research investigates concisely phrased hypotheses. The study attempted to address the following research hypotheses:

- Hypothesis 01: Factors of advanced air distribution systems, outdoor air (OA) intake, and variable air volume (VAV) will be able to improve indoor air quality (i.e., reduce CO2 level) and reduce energy consumption.
  - Hypothesis 01.a: OA-intake and VAV will be able to improve indoor air quality by 30% or more based on LEED v4 or meet ASHRAE 62.1—Table 6-1 "Minimum Ventilation Rates on Breathing Zone."
  - Hypothesis 01.b: OA-intake and VAV will be able to reduce energy consumption by 15% or more to meet ASHRAE 90.1.
- Hypothesis 02: Factors of enhanced building envelope design, R-value, solar heat gain coefficient (SHGC), and window-to-wall ratio (WWR) will improve indoor air quality and energy efficiency.
  - Hypothesis 02.a: Enhanced building envelope design will improve indoor air quality by 5% or more based on building envelope infiltration and 20% based on passive ventilation to meet ASHRAE 62.1- OA Ventilation Data.
  - Hypothesis 02.b: Enhanced building envelope design will improve energy efficiency by 40–50% or more to meet ASHRAE 90.1 based on 50% Advanced Energy Design Guide.

Research Questions

Based on an understanding of the research problem and related literature, this research investigates concisely phrased research questions (see Figure 1). The study attempted to address the following research questions:

- Research Question 01: To what extent will air distribution systems affect indoor air quality and energy efficiency?
  - Research Question 01.a: What is the impact of constant air volume (CAV) on indoor air quality and energy efficiency?
  - Research Question 01.b: What is the impact of variable air volume (VAV) on indoor air quality and energy efficiency?
- Research Question 2: To what extent will building envelope design factors affect indoor air quality and energy efficiency?

- Research Question 02.a: What is the impact of R-value on indoor air quality and energy efficiency?
- Research Question 02.b: What is the impact of SHGC on indoor air quality and energy efficiency?
- Research Question 02.c: What is the impact of WWR on indoor air quality and energy efficiency?

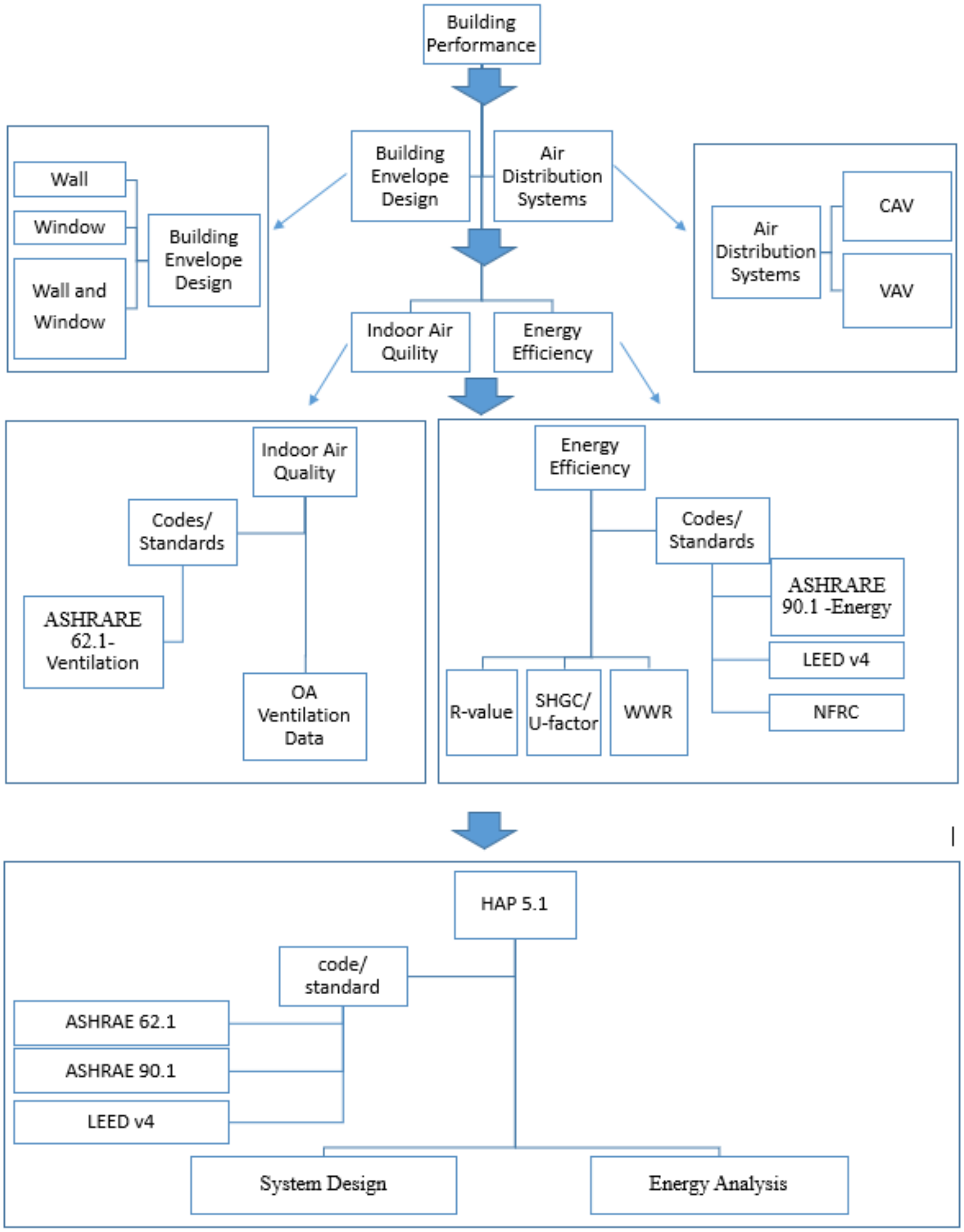

Fig. 26. Research map/framework.

Significance of the Study

The quality of indoor building environments has a significant impact on human health. This is because the average American spends approximately 90% of their time indoors, based on a survey by the EPA. Many indoor environmental factors, such as temperature and humidity, collectively shape indoor environmental quality, which in turn moderates the productivity of building users.

Thermal performance is related to a human factor that describes the state of mind that expresses satisfaction with the surrounding environment. Thermal performance refers to several conditions in which most people feel comfortable (Healey & Webster-Mannison, 2012). The body loses heat by conduction, convection, radiation, and evaporation of heat flow in indoor environments (Binggeli, 2010). The human body produces heat depending on activity level and expels heat according to the surrounding environmental conditions. Three main factors affect thermal performance, and they should be controlled to keep a healthy balance for occupants in an indoor environment.

This research also explains buildings' air distribution systems and envelope methods that can bring about the treatment of heat/thermal transfer, infiltration, and moisture control. Indeed, they improve indoor energy performance. Through building envelopes, heat transfers and solar energy enters buildings to provide acceptable thermal performance conditions for its occupants (Zemella & Faraguna, 2014).

Building systems operate heating, ventilation, and air conditioning (HVAC) systems. Specifically, an air distribution system monitors, measures, and controls outside air and the ventilation system for an optimal indoor environment. The building envelope defines the boundaries of the built environment, which functions to protect users from adverse natural elements, house various activities, and provide comfort and security.

For these reasons, this study planned to investigate the effects of advanced air distribution systems for indoor environmental quality and energy efficiency of buildings. In addition, this research focused on building envelope designs for their indoor environmental quality and energy performance. First of all, this research emphasized enhanced building envelope design, which is related to a measure of the exterior walls with a thermal resistance (R-value), the windows with the WWR, and the rate of SHGC values based on building codes and standards.

Then, it also emphasized advanced air distribution systems by comparing traditional and advanced systems. The systems were related to OA airflow with ventilation requirements based on building codes and standards: ASHRAE, and LEED. The codes and standards used in this research are specified below:

- ANSI/ASHRAE/IES 90.1—Energy Standard for Buildings Except Low-Rise Residential Buildings
- ANSI/ASHRAE 62.1—Ventilation for Acceptable Indoor Air Quality
- ANSI/ASHRAE/IES 169—Climate Data for Building Design Standards

Purpose of the Research

This research aimed to approach integrated building design and systems regarding the sustainable building. This research studied air distribution systems and building design, which determined building performances regarding indoor air quality and energy efficiency. Indeed, the stated objectives of the research were to examine combinations of building design methods and building systems, and determine their impacts on indoor air quality and energy efficiency.

For these reasons, this proposed study investigated the relationships between building design, air distribution systems, and the indoor environmental quality of buildings. It used building codes, standards, and guidelines for buildings' performance of airflow and energy. This research also used related data sets of building performance as a baseline, which was compared with current requirements for building system and design methods, such as CO2 monitoring systems, outside-air intake systems, and automatic ventilation systems. The systems were specified in building codes and related industry standards, including International Mechanical Code (IMC), IECC, and ASHRAE 62.1-Ventilation standard.

This research intended to introduce the factors of building envelope design and air distribution systems affecting building performance of heat and airflow. It also investigated building behavior and performance of heat flow and airflow in response to surrounding climate changes. This research understood factors of heat gain/loss, which were directly related to heat flow and airflow of energy performance with building design and system methods for discovering indoor air quality and energy efficiency.

To address building envelope design, this research discovered building performance in response to envelope design methods through wall, window, and door designs, knowing that the envelope design was directly related to building tightness and air ventilation. This research intended to describe thermal transfer, infiltration, and moisture control concerning building technology and science in building design for indoor air quality.

Besides, building tightness and air ventilation with air distribution control systems led to high energy performance and indoor air quality. The treatments of building envelope design methods contributed to human health issues of indoor contaminations in the building environment.

Overall human health was related to indoor air temperature, air humidity, and air speed, which affected indoor air quality by controlling air distribution systems. In addition, the study dealt with the symptoms of BRI and SBS, which resulted in decreased productivity/academic performance, increased absenteeism/sick days/health costs, restricted activity, and health issues.

For these reasons, it was critical to address building design and its impact on building tight and air ventilation control with air distributions systems for improving human health issues. Living and working building environments should be considered because buildings' human health issues, such as BRI and SBS, had adverse effects on occupants in the indoor environment of buildings (Bonda & Sosnowchik, 2007).

Providing healthy indoor environment quality was a significant design matter because it also related to social and economic issues. Therefore, the present research intended to study the ways in which the factors of building envelope design affect the energy performance of building designs.

The research goal was to determine a building's airflow and energy efficiency performance by using Carrier HAP software for testing. The major points explained in this research were air distribution system types and building envelope design methods, indoor air quality factors, and energy efficiency factors in buildings based on building codes/standards/reference guide ASHRAE and LEED v4.

As a result, this research determined that the enhanced advanced air distribution systems and building envelope design methods can affect indoor air quality and energy efficiency in buildings. This research explained that considering building design and the system is important because it adjusts heat flow with airflow through air distributions systems and the building envelope. Moreover, this research demonstrated that controlled heat flow with airflow through air distribution systems and building envelopes could reduce energy consumption and improve the indoor air quality of spaces in buildings.

2. Settings or Methods or Materials and Methods

Research Design and Methodology

Research Design

This research designed and used methodology for an experimental study. It explored/discovered the effects of air distribution systems and building envelope design methods on building performance: indoor air quality and energy efficiency in buildings.

Research Type

The type of research was an experimental study. It took an existing setting and used software programs to make incremental environmental factor adjustments to seek an optimum condition for indoor air quality and energy efficiency. Exploring the combination of factors and their various levels helped inform designers and builders about structural changes needed to address new and renovation construction that could ultimately affect climate change.

This research used experimental analysis to explore modifications to the building air system and envelope design methods by developing whole building simulation models that estimate indoor air quality and energy efficiency.

Research Population, Sample, And Subjects

The samples were classrooms and office areas within Sill Hall, an educational building at Eastern Michigan University. In addition, architectural drawings of the building were created by using the software programs Auto CAD and Revit.

Data Instrumentation(s)

The instrumentation of this experimental research was Carrier, eDesign Suite Software, Hourly Analysis Program (HAP version 5.1). The software enabled the design and analyze building air distribution systems

(HVAC systems) and building design methods (wall and window) by calculating energy peak load, sizing HVAC systems, and modeling energy performance.

Data Collection

The data collection explored the effects of advanced air distribution systems and enhanced building envelope design on indoor air quality and energy efficiency in educational buildings. This research used the software HAP 5.1 to run multiple energy design simulations for testing building performance: air distribution systems and their energy used in representative classrooms and office areas. It manipulated independent variables (i.e., air distribution systems and building envelope design methods) with middle variables (CAV, VAV, R-value, SHGC, WWR) of representative areas (classrooms and offices) based on the climate zone map. (Michigan is located in Zone 5, defined by ASHRAE and IECC.)

For collecting data, this research checked the existing conditions of building systems and building design methods of representative areas.

Data Collection Procedure

During the summer and fall semesters in 2019, this experimental research made a practical software setting of HAP 5.11 in Room 213, Roosevelt Hall, Eastern Michigan University. Then this research was conducted for testing variables and collecting data results.

After testing all treatments separately, this research tested treatment with the selected sample areas (total five times) for generating energy simulation data. Experimental treatments for the energy simulations were air distribution systems and building envelope design treatments. Experimental test procedures for the energy simulation were: CAV with existing conditions (TCAV-0), CAV with treatment 01 (TCAV-01), CAV with treatment 02 (TCAV-02), VAV with treatment 01 (TVAV-01), and VAV with treatment 02 (TVAV-02). The detailed experimental research procedure is listed below (see Figure 2):

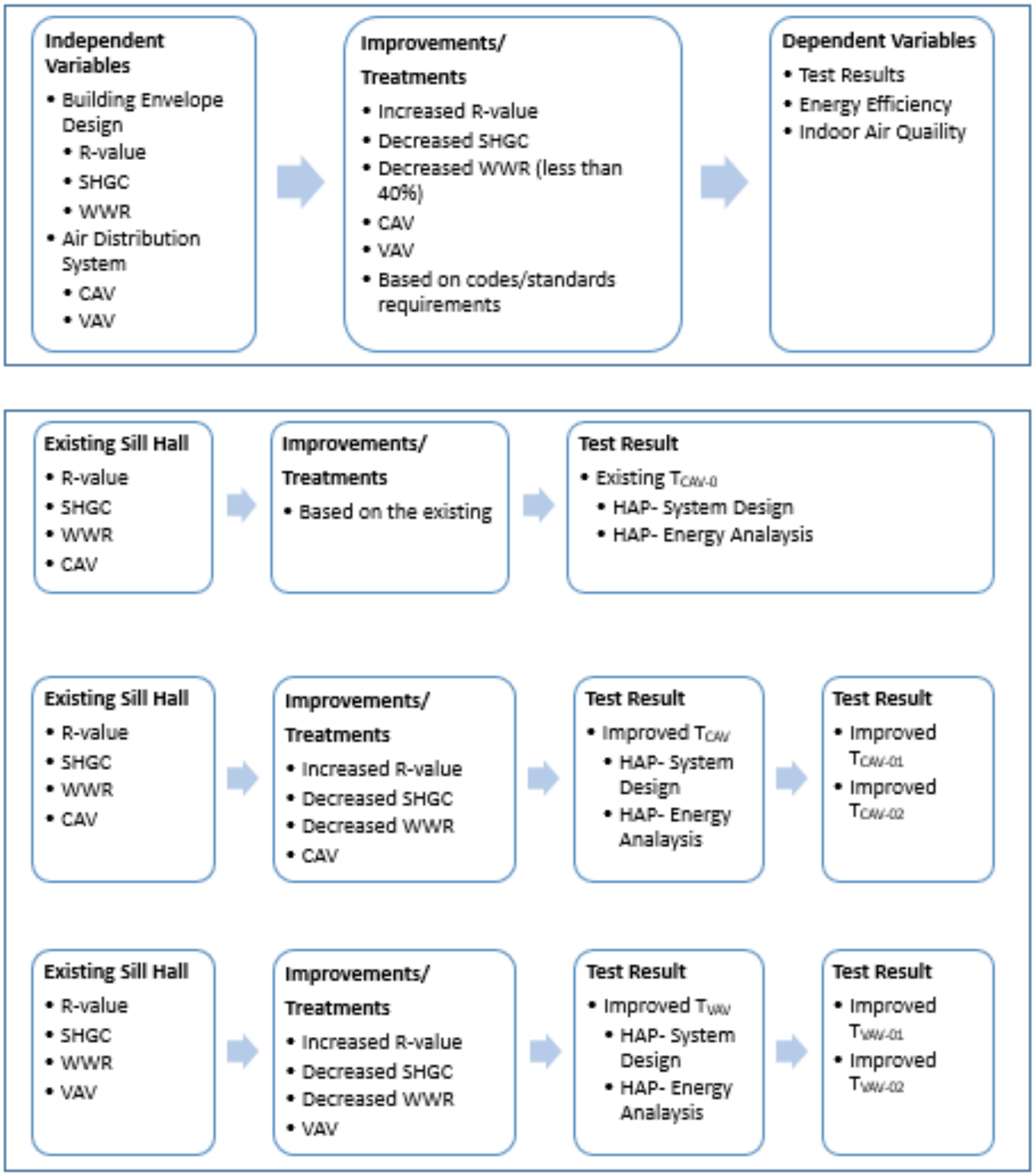

Fig. 27. Experimental research test procedure.

This research design explored the effects of building envelope design and air distribution systems on a building's energy performance. This research type was an experimental study. Its research sample was classrooms and office areas within Sill Hall at Eastern Michigan University. The data were collected by using data instruments Carrier's eDesign Suite Software Hourly Analysis Program (HAP version 5.1).

3. Results

Data Analysis and Findings

Data Results and Data Analysis

For the data procedure based on this research problems, the study gathered input content to enter data into software HAP 5.11 and to generate energy design simulation results (findings) for this experimental research. The tables and figures of data and results were examined and explained. Input data included settings for the weather conditions, wall constructions, window constructions, space sizes, and air system types for the sample. Then, output data results noted the impact of differing envelope designs and energy systems' airflow and energy usage for the air distribution system.

Input data.

Input data results were gathered, and the data were entered into HAP 5.11. Input data settings explained the weather, walls, windows, spaces, and air systems of the selected sample (classrooms and office areas within Sill Hall). The input data properties described problems of this research: types of air distribution systems and building envelope design methods that influenced the energy design analysis (HVAC systems design and energy usage for HVAC systems) in this research design.

Output data.

This experimental research generated energy design simulation reports (results) from the input data (weather, air systems, wall, window, and space) of the selected sample using HAP 5.11.

Output data reports analyzed the air distribution systems' design and building envelope design methods (regarding indoor air quality) and energy usage for air distribution systems (regarding energy efficiency) and for the input data (air systems, walls, and windows) of the sample classrooms and office areas within Sill Hall. The output data results addressed the research questions and hypotheses as well as the ways in which gathered input data settings influenced the healthy indoor environment and energy usage.

The energy design simulation reports presented air distribution system and building envelope design methods (regarding heat flow and airflow) and energy usage (regarding building loads): design load and system-psychrometrics. The results demonstrated the impact of input data on output data: the ways in which gathered input data settings improved indoor air quality by designing methods of air distribution systems/ventilation and energy efficiency by designing methods of building envelope design with air distribution system/ventilation.

In the sample spaces of the building, heat flow and airflow were addressed by modeling elements of loads: spaces of project, group of spaces (zones) sharing the same thermostat, air systems providing conditioned air to zones of a building, and plants providing cooling/heating to air systems. The software estimated the operating energy of the building.

The input data reports used independent variables, and the output data reports were dependent variables. Based on the output data reports, findings were compared to discover differences.

Address heat flow and airflow. This research demonstrated the ways in which air distribution systems and building envelope methods addressed heat flow and airflow for designing ventilation, heating, and cooling loads: the amount of energy to be added/removed to keep an acceptable range of temperature. The reports included calculated design loads for four (4) building areas.

For analyzing the results of energy efficiency (see Figure 3), this research identified result values of design loads with the following steps:

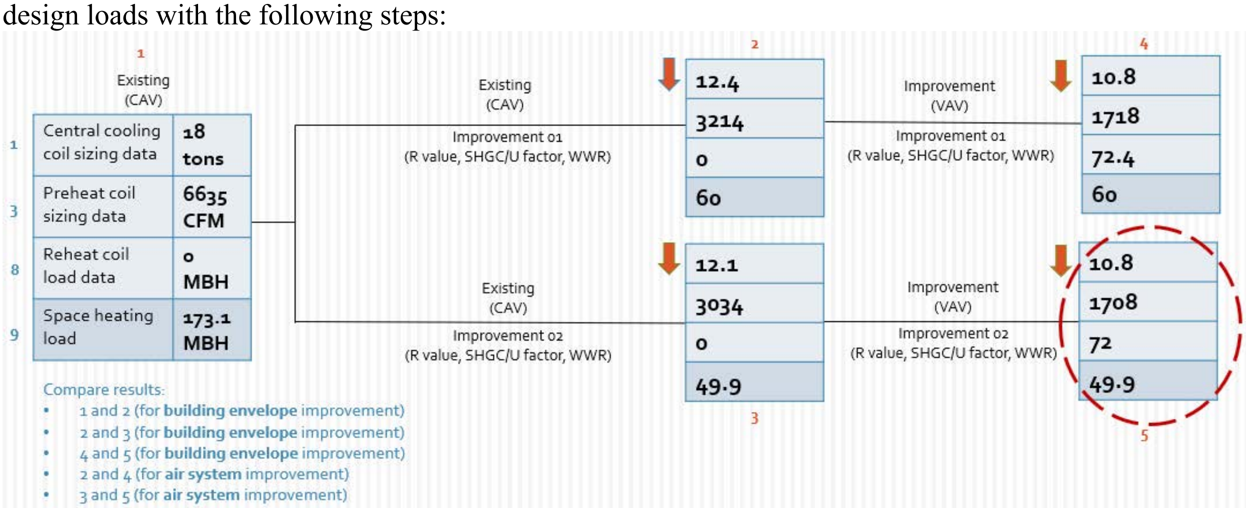

Fig. 28. Identified result values of design loads with steps.

For analyzing the results of indoor air quality (see Figure 4), this research identified result values of design loads with the following steps:

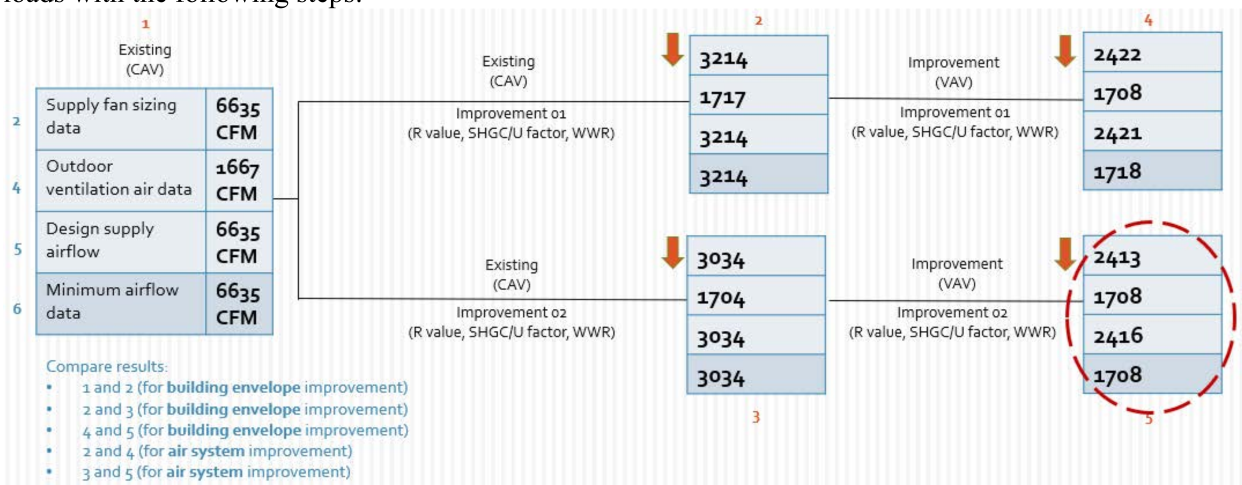

Fig. 29. Identifies result values of design loads with steps.

Address airflow with air-water mixtures. This research demonstrated the ways in which air distribution systems and building envelopes addressed airflow with air-water mixtures for designing ventilation, heating, and cooling loads: the amount of air to be added/removed to keep an acceptable range of airflow. The reports included calculated airflow with system-psychometrics for four areas in the building. The calculated values of airflow (CO2 level, airflow, latent heat/sensible cool) of system- psychrometrics' components for the sample are listed below and shown on the psychrometric charts.

For analyzing the results of indoor air quality (see Figure 5), this research identified result values of system-psychrometrics' components with the following steps:

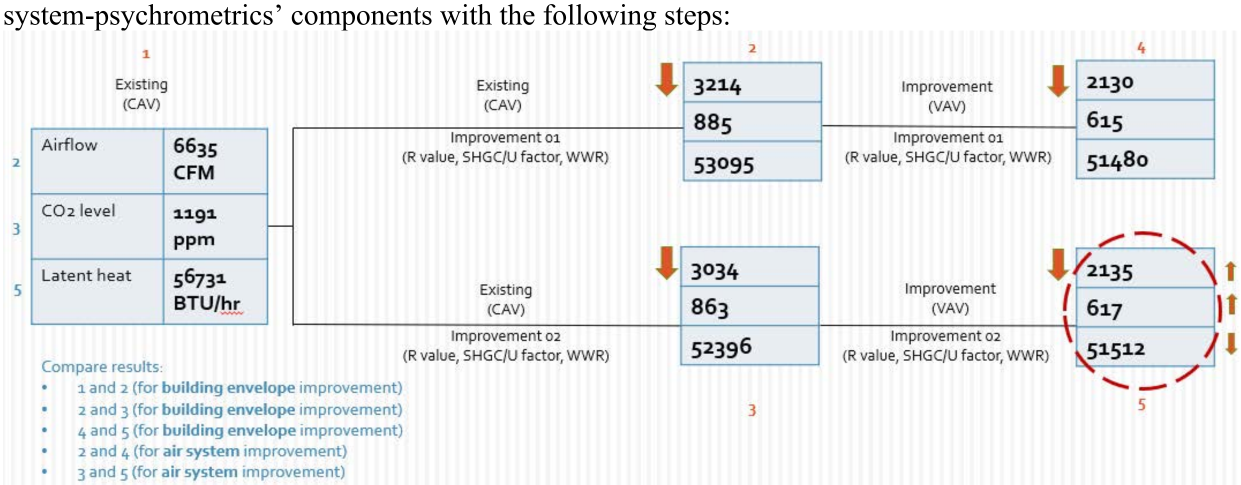

Fig. 30. Identified result values of system-psychrometrics' components with steps.

The results showed significant outcomes when comparing air systems (CAV and VAV) due to manipulated treatments of building envelope treatment for increased R values and decreased SHGC/U factors, and increased/decreased WWR for test results 01 and 02, 03 and 04, and 04 and 05.

When building conditions were modified with building envelope treatment 02 (increasing R value from 4.67 to 25, decreasing SHGC/U factor from 0.60 to 0.38, and modifying WWR from 16/16/32/48% to 35%) and air system treatment (VAV), the total energy consumption was decreased, and indoor air quality was improved.

Result values of the amount of energy usage were decreased. Result values of the amount of airflow to maintain adequate ventilation and indoor air quality were decreased. Result values of system psychrometrics components were airflow sizing, CO2 level, and latent heat/sensible cooling. The values of the amount of airflow and water vapor of air to maintain adequate ventilation and indoor air quality decreased. Moreover, result values of psychrometric charts were different in graphic slopes of points; improved results were steeper than the previous results. Slopes of points of results were steeper than the previous result; the less sensible heat/latent cool and latent heat/sensible cool loads existed. Airflow was circulated well in less sensible heat/latent cool and latent heat/sensible cool loads because the air was cooled and dehumidified. Points moved both horizontally and vertically: the air was mixed in an increased warm temperature and humidification; the air was changed to an increased cool temperature and dehumidification; the air was supplied to spaces in an increased cool temperature and dehumidification; and the air was returned to cooling/heating systems to manage temperature and humidity. The improved results—a range of mixed, cooled, supplied, returned air temperature and humidity—were wider than the previous results. Properly managing different conditions of various spaces depended on the demands of those spaces to maintain adequate indoor air quality. According to ASHRAE 55, cool temperatures from 72 to 80 and dry relative humidity of 30–60 will create a comfortable indoor zone; a slightly cooler temperature will be acceptable in spaces for indoor quality and energy efficiency (Tao & Janis, 2001). Under the proper cooling conditions, lower supply airflow speed was identified in this study, and reduced or lower airflow was required to maintain good air quality by supplying fresh air and managing temperature and humidity. The experiment showed these significant changes in both building envelope and air distribution system treatments, which can be connected to occupant safety and health.

After analyzing data results, this research verified the proposed hypotheses that factors of enhanced and advanced building envelope designs and air distribution systems contributed to indoor environmental quality and energy efficiency in buildings.

4. Discussion/Limitations/Delimitations of the Study

Limitations of this study might affect the findings and outcomes. Using available lab instruments, this research focused on outdoor air intake to ensure that carbon dioxide (CO2) and relative humidity levels followed building code requirements and ASHRAE 62.1. Other indoor air quality issues of cost and chemical analysis of volatile organic compounds (VOCs), dust, and mold were considered for future research.

Moreover, the results related to possible future research questions and hypotheses by modifying treatment values and expanding the range of independent variables. In addition, this research indicated that further research should include indoor spaces as a whole building simulation, energy recovery systems regarding advanced air system, window treatments on the interior or exterior, and commissioning processes after applying improved building system and design methods for indoor air quality and energy efficiency.

5. Conclusions

Findings

This experimental research study used air distribution system/ventilation rates for identifying indoor air quality. The research also used air in heating and cooling rates to determine energy efficiency. Air distribution systems and the modified properties of walls and windows were examined to check the ways in which they provide healthy indoor air quality and save energy usage in buildings. For the study building, examined data involved different types of air distribution, increased R-value for insulation, decreased SHGC/U-factor for thermal comfort, and increased/decreased WWR for the building envelope.

For Hypothesis 01 regarding indoor quality, this research demonstrated treatment when fan size decreased airflow supply and reached minimum airflow. Also, this research showed that CO2 levels and airflow sizing went down, and different values of psychrometric chart points' slopes were steeper.

For Hypothesis 02 regarding energy efficiency, this research showed that efficiency improved when values of central cooling coil sizing data, supply fan sizing data, preheat coil sizing data, design supply airflow, minimum airflow data, reheat coil load data, space load, and airflow data decreased. The results of this research provided systematic testing and validation of air distribution systems and building design methods that can be used to impact building indoor air quality and energy efficiency.

Recommendations

This research considered heat flow and airflow of building design and system and the ways in which it caused healthy indoor air quality and energy efficiency in buildings. Indoor air quality treatments and reduced energy usage can be impacted by applying building design methods and air distribution system modifications for any building type.

This research aimed to apply sustainable strategies to air systems and building envelope design for improving indoor air quality and reducing energy usage. The research results encouraged sustainable strategies of air distribution systems and building envelope design by providing monitored changes in energy usage (building loads) and indoor air quality (airflow rate) of the test (sample building).

This experimental research verified the proposed hypotheses and research questions, proving that factors of enhanced and advanced building envelope designs and air distribution systems contributed to indoor environmental quality and energy efficiency in buildings.

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Investigating Design and Deployment of Eco-Feedback Dashboards

Keegan Loftin[1], Keith Rahn[2], and Kevin L. Hitchcock[3]

[1, 2, 3] Auburn University, Auburn, AL 36849
klh0097@auburn.edu

Abstract
This pilot study investigates the design and deployment of an eco-feedback dashboard, use of an eco-feedback dashboard as an educational tool, and the perceived influence of the dashboard on building occupants' behavior. A preliminary survey measured each participant's prior knowledge on sustainability, LEED, personal environmental behavior, and their personal understanding to how a building consumes energy and water and results showed that most participants considered themselves environmentally friendly (79%) and were familiar with sustainability regarding building operation (93%). A postliminary survey after deployment of the eco-feedback showed that all participants (100%) believed that the eco-feedback dashboard helped them learn more about energy consumption but only sixty-three percent (63%) of participants thought the dashboard influenced their behavior to be more environmentally friendly. Findings suggest that eco-feedback dashboards can help building occupants understand energy usage in building operation, but may not increase environmentally-friendly behavior, particularly within a population that has environmental awareness and understanding of energy use in building operation.

Key Words
Eco-feedback dashboard, LEED, sustainability, occupancy behavior, energy consumption

1. Introduction

Operating and maintaining buildings consume around one-third of total energy use, making them a prime target for the application of energy-efficiency measures. Studies have suggested that occupant behavior can have a substantial impact on building energy consumption, which have the potential to reduce US emissions by 7.4% with little or no impact on household well-being. Significant investments have already been made in sensing infrastructures that can provide relevant consumption data, while less attention has gone toward making energy information comprehensible, attractive, and relevant to the building occupants (Paone and Bacher, 2018).

An eco-feedback dashboard (EFD) provides building occupants with information regarding actual building energy consumption. EFDs operate on the premise that building occupants are largely unaware of how much energy is used on a day-to-day basis, and once occupants become aware of their actual consumption, they will take steps to decrease consumption. While numerous factors are associated with the effectiveness and implementation of an EFD, the system's interface design is a key factor in achieving substantial energy reduction. However, research suggests an overall lack of understanding as to which design components are driving the consumption reductions, and which are not. Therefore, which eco-feedback design components are driving resource reduction is crucial to develop interface systems that achieve long-term substantial and sustainable reductions in the built environment (Jain et al., 2012, 2013). Froelich et al. (2010) conducted a meta-analytical study that examined over 100 EFDs and developed design guidelines for EFD interface design, feedback frequency, and information visualization. Since then, Karjalainen (2011) has extended upon this study through the utilization of a rapid prototyping methodology and user surveying to further understand the different user preferences in regard to eco-feedback design components.

This research aims to investigate eco-feedback dashboard design and placement and building occupants' behavior influences on overall electricity and water consumption in a LEED Gold certified building and assessing visual dashboard methods to proactively influence building occupants' perception of energy and water consumption through the implementation of an EFD.

The objectives and questions driving this research are:

- Evaluate design, information display and interface on an EFD deployed in a building. What engages the user, how do they interact with the system and what information does the user want in an EFD?
- Determine if EFD's influence user behavior and their understanding of building resource consumption (participant reported).
- Determine if an EFD change Building user behavior regarding building resource consumption and if that change in behavior is reflected in the resource consumption data. This was a preliminary goal for additional research.

2. Methodology

This research study was conducted on the campus of Auburn University in Auburn, Alabama, USA during the Summer 2021 through the utilization of a mixed-methods approach. The building in this study is the Gorrie Center Building (GCB), a LEED Gold Certified building that houses the McWhorter School of Building Science, was completed in 2006, is 36,997 gross square feet and provides classrooms, offices, an auditorium and a demo lab for students. The participants were faculty, staff, students and other users of the GCB during the study. Both quantitative and qualitative data were obtained and analyzed through user surveying before and after the implementation of an eco-feedback dashboard (EFD) in the GCB . Research participants were recruited based on their involvement with the GCB in summer 2021. The EFD was displayed on four different TV stands located in various parts of the Building. Anyone within the XX was able to interact with the EFD. The dashboard ran continuously throughout the research period and building occupants were free to observe the display at any time but did not have any ability to influence the active display as the display did not include any interactive features. Only information and data and obtained from the participants completing the pre- and post-surveys were used for this research.

Three weeks after the implementation of the EFD, the postliminary survey was then sent out to the same participant pool within the Building. The postliminary survey sought to validate the effectiveness of the EFD to engage, interact, and educate building occupants on their direct energy and water consumption.

For this study's framework, design interventions included eco-feedback, behavior steering, and persuasive technology. The influential attributes being communicated through these design interventions included attitudes, social attributes, and affection. These attributes may be derived from knowledge, beliefs, subjective values, emotions, etc. Understanding consumer behavior changes and their attributes are imperative for eco-feedback research for they encourage the enhancement or restriction of pro-environmental behavior (Kuo et al., 2018).

2.1 Data Collection Method

1. A preliminary short survey questionnaire to determine participant's current environmental knowledge and behavior surrounding LEED.
2. An EFD was introduced and installed within a common area of the building to encourage user participation and to test influencing ability.
3. A follow-up survey was conducted investigating any change in pro-environmental behavior and eco-feedback design elements that may need to altering for future research.

2.2 Pre-liminary Survey

The preliminary survey consisted of a total of 18 questions. The survey obtained each participant's prior knowledge on sustainability, LEED, personal environmental behavior, understanding of why some people might not participate in pro-environmental behavior, and their understanding of how the building consumes energy and water within a given timeframe. The survey also focused on understanding where the dashboards should be located in the GCB, what information should be displayed on them, and which graphs are easier to comprehend than others.

2.3 Implementation of the EFD

The EFD was streamed through (3) 55” Samsung Smart TVs and (1) 75” Samsung Smart TV. The web-based software will be accessed using (4) Azulle Byte 3 Mini Desktop PCs, which are mounted on the back of each monitor and connected via HDMI cable. The EFD was displayed on four different mobile TV stands throughout the Building (Figure 1).

Fig 1. Eco-feedback dashboard deployed in main foyer at main (front) entrance of the XXXXXX XXXXXX

The visual dashboard (Figure 2) transitioned through eleven different display slides displaying the following information:

1. The Building’s real-time electricity, water, chilled water, and hot water consumption data.
2. A historical comparison graph illustrating last period's consumption data compared to current, real-time consumption data.
3. Relevant weather information for the location of the building.

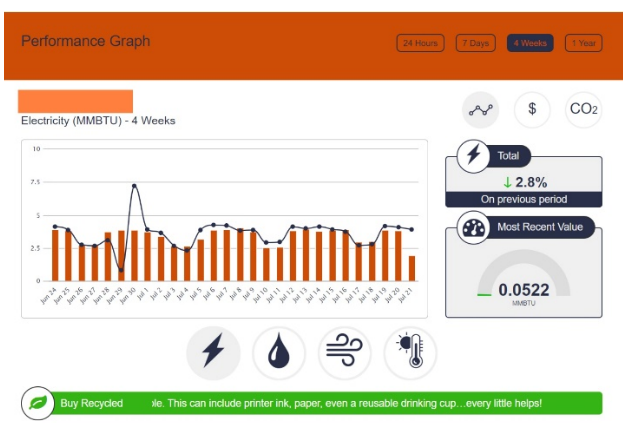

Fig. 2. One of eleven displays looped (30 secs ea.) on dashboard

2.4 Postliminary Survey

The postliminary survey consisted of a total of 12 questions, 3 of which being the screening process. The postliminary survey design intent was to provide feedback and validation to just how effective the EFD was and to understand how often the occupants engaged and interacted with it. The survey asked questions, such as: how often each participant viewed the dashboard system in a given period, where was the dashboard located when they viewed it the most and did the dashboard system assist in further educating them on how the Gorrie Center Building consumes energy and water. Additional questions asked how the dashboard's design could be changed/altered to attract more viewers and to propose the best location to permanently install an EFD in the building.

3. Results

The preliminary and postliminary survey responses were analyzed and measured through the use of a nominal scale, assigning numbers to all possible answers without any rank or priority. Participant demographics are shown in Table 1 and select results of the preliminary and postliminary survey are shown in Tables 2 and 3.

Table 30. Survey Participants

Preliminary				Postliminary			
Male/Female	9	5		Male/Female	9	2	
Faculty/Staff/Student	4	3	7	Faculty/Staff/Student	3	1	7
Grad/Undergrad/Other	3	4	0	Grad/Undergrad/Other	3	4	0

Table 2. Preliminary Survey Results

Do you consider yourself to be environmentally friendly?	Very	Somewhat	Not so much	Not at all
	5	6	2	1
How familiar are you with the term sustainability in regard to a building's operating system?	Very Familiar	Somewhat Familiar	I've Heard of it	Not Familiar
	6	7	1	0
How familiar are you with how much energy the building consumes during a 5 day week?	Very Familiar	Somewhat Familiar	I've Heard of it	Not Familiar
	0	3	2	9

Table 3. Postliminary Survey Results

How many times a day did you view the eco-feedback dashboard?	0	1-3	4-7	7-10	More than 10
	0	7	3	0	1
Did the eco-feedback dashboard help you learn more about the building's energy consumption?	Very	Somewhat	Not So Much	Not at all	
	5	6	0	0	
Was the information on the eco-feedback dashboard easy to understand and comprehend?	Very	Somewhat	Not so much	Not at all	
	4	7	0	0	
Did the eco-feedback dashboard influence you to be more environmentally friendly?	Very	Somewhat	Not so much	Not at all	
	2	5	3	1	

4. Discussion

The study participants appeared fairly knowledgeable in sustainability and resource consumption. Study participants found the display of the eco-feedback dashboard somewhat easy to understand but predominately commented that the graphics needed to be easier to understand. Participants overwhelmingly responded that providing graphics that were easier to comprehend would attract more viewers to the EFD. This is consistent with what was observed during EFD deployment. Two weeks into the dashboard deployment and after receiving multiple questions regarding how to read and interpret the information on the dashboard, the researchers posted an instructional guide (Figure 3) to assist viewers. The participants reported that their overall understanding of building resource consumption increased while the dashboards were in place. General recommendations for dashboard placement include at elevator landings, student lounges, and other areas that did not impede traffic, such as in hallways. It was observed that building users would touch the dashboard screen, thinking it was touchscreen. The screen was quickly covered in fingerprints as a result. Future deployments could use trackball, touchpad or touchscreen components.

Fig 3. Posted instructions for eco-feedback dashboard

The participants reported that their understanding of building resources and sustainability issues increased as a result of the dashboards. Given the results between the preliminary and postliminary surveys, this strongly suggests that users believe the EFD is educative. Participants also believe that the EFD influenced their behavior regarding resource consumption. Perhaps they were intrigued with the new technology or perhaps they were drawn to its novelty, but either way, the deployment of the EFD did appear to increase awareness around sustainability, building resources and personal consumption. Researchers had access to all consumption data for the period of the study, 1 year prior to study and the after conclusion of study. The EFD's were only deployed for 9 weeks, during Summer semester when enrollment and building use is low. This was further exacerbated by building use limitations created by the COVID-19 global pandemic. Building use the previous year was at record lows due to the pandemic and comparative data is questionable. Researchers further observed that post-occupancy adaptations to building systems design functionality had taken place, bringing to question design-intent versus user-need and how that will be evaluated in future studies.

5. Conclusion

The objective of this research was to assess visual dashboard methods to proactively influence building occupants' perception of energy and water consumption via the implementation of an EFD. The results obtained from both the preliminary and postliminary survey validates the presumption that an EFD installed within the Gorrie Center Building in summer 2021 could both educate and engage building occupants in understanding their energy and water consumption. Although it's proven the EFD attracted and engaged the occupants within the building to some extent, more data is needed to conclude that it is influencing their actual consumption behavior. Therefore, a need for a more developed graphical visualization design is needed to attract, engage, and influence building occupants on energy and water consumption; thus, encouraging overall building consumption savings more proactively.

To further validate and improve upon this research study, there are multiple avenues in which research can be focused. The EFD's design must first be revised to display more comprehendible graphs and tables for the occupants within the building. Furthering the updated design of the dashboard system, future research should develop a historic baseline consumption graph for the building. After the development of the baseline, researchers can then deploy the revised EFDs and compare the real-time consumption data to the baseline to validate any major changes in building consumption. Through the installation of electrical and HVAC sensors in each classroom and water sensors to each bathroom, researchers can integrate the real-time data obtained from these sensors into an interactive, color-schematic BIM Model highlighting each room's consumption data. Adding this kind of in-depth information to an EFD allows building occupants to further understand which rooms within the building may be responsible for the greatest energy consumption and learn ways to further reduce them.

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ID 61

An Investigation on the Impact of 4D BIM on Construction Scheduling

Sanjeev Adhikari, Ph.D.[1], Salman Azhar, Ph.D.[2], Pavankumar Meadati, Ph.D.[3] and Nader Alaeddin[4]

[134] Kennesaw State University, 830 Polytechnic Lane Marietta, GA 30060
[2] Auburn University, 216 M. Miller Gorrie Center, Auburn, AL
sadhika3@kennesaw.edu

Abstract
This research aims to investigate the impact of 4D BIM on construction scheduling and whether using 4D BIM reduces construction delays or not? Multi-dimensional Building Information Modeling (BIM nD) integrates different project applications with BIM, such as scheduling and estimation. 4D BIM is the process of linking the project schedule with the 3D model to generate relevant data for constructability analysis, safety planning, and building assembly. The methodology used in this paper consists of a comprehensive literature review on 4D BIM and then comparing the results with the data collected from a survey distributed to AEC industry professionals. Based on the findings, 4D BIM is improving project performance, enhancing decision making, and helping achieve on-time delivery. The main challenges are related to software interoperability issues and manually linking scheduling activities into model components. The three top barriers from survey results are (i) lack of training, (ii) high implementation cost, and (iii) software/hardware issues. Future research may focus on automating the 4D BIM process of linking scheduling activities into the model components. Another important research topic is the return on investment analysis for 4D BIM implementation on project objectives.

Keywords
Building Information Modeling, Scheduling, BIM, 4D, Construction

1. Introduction and Background

Building Information Modeling (BIM) is widely known for integrating all the construction project information across different stakeholders (Azhar, 2011). BIM 3D visualizes the building adding the elevation as a third dimension, known as the z-axis. However, BIM 3D includes spatial dimensions as 3D CAD and all the geometric and functional properties of the objects in the building model (Ding, Zhou, & Akinci, 2014). There have been additional dimensions associated with BIM 3D in recent years, such as time and cost. The fourth dimension of BIM (BIM 4D) is integrating the project Scheduling into the 3D model of the project (Gledson, 2016). This research aims to investigate the effect of 4D BIM on construction Scheduling and whether using 4D BIM reduces construction delays or not. The aim is divided into four objectives (i) investigate the status of 4D BIM adoption in the construction industry, (ii) discover benefits of 4D BIM for construction contractors, (iii) explore the status of software interoperability and the method of integrating the Scheduling into the 3D model, and (iv) identify the challenges and barriers of utilizing 4D BIM in construction delays.

The author believes, from his experience working in construction in Oil & Gas projects, when 4D BIM is implemented effectively in construction projects, huge benefits can be yielded for project stakeholders. Potential benefits are the simulation of the project timeline, better trades coordination, clearer data for project stakeholders, and improved decision making. For example, there will be a positive influence on management decisions, emphasizing critical path activities on a weekly basis and improved procurement of materials on site. The main advantage of 4D BIM is seeing the Scheduling timeline associated in the 3D model. Every project stakeholder can easily understand the project Scheduling status and where the focus should be in the coming weeks. The project stakeholder should not have an engineering background or technical experience when looking at 4D BIM timelines compared to Gantt charts for large construction projects. This is in addition to better site coordination between different trades and improved clash detection; thus, reducing change orders and improving As-build drawings.

A literature review is done addressing all these concerns and challenges in implementing 4D BIM in the industry. In addition, data about 4D BIM from a survey distributed to industry professionals will be utilized and compared with literature review results.

2. Research Method

As mentioned, the first step used in the methodology of this paper involves a literature review of 4D BIM implementation. The author started searching the Associated School of Construction (ASC) proceedings from 2005 to 2020. As mentioned in table 1, different search terms have been used to cover all the published papers related to BIM 4D. For example, the keyword "schedule" was used for scheduling to cover the papers talking about schedule or scheduling.

Table 31. Key terms used for search in ASC proceedings.

No.	Keyword used	Research Area	Papers Published
1	Building Information Modeling, Building Information Modelling, BIM	BIM	70
2	Schedul, Scheduling, Schedule	Scheduling	44
3	BIM 4D	BIM 4D	1
4	Building Information Modeling and Scheduling	BIM 4D	0

Then, the author expanded the search to other scientific databases, i.e., Scopus, Web of Science, and Google Scholar. The same keywords were used, focusing on "BIM 4D" and "construction schedule". Since many papers are available about 4D BIM in these databases, different filters were used, such as within the last five years and most cited. After reading abstracts and some of the papers, the author finalized the search into 12 papers that match the most with the objectives of this research (see references list).

In addition to the literature review, information from industry professionals is extremely important as they are on the front line for BIM implementation. They can provide valuable information about the current barriers and challenges for executing BIM 4D. A survey was designed to collect as much data as possible from the industry professionals. The survey is divided into different sections, facilitating the survey flow using the blocks feature in Qualtrics software and software for designing and distributing surveys. The first section includes the consent question and the general information of the respondent's company, such as type of business, geographic location, company size, and company revenue. Also, it includes general questions about BIM, such as whether the company uses BIM or not, software usage, duration of using BIM, and frequency of using BIM. After that, the survey will start asking questions about each dimension of BIM. Starting with BIM 3D until the last dimension used, depending on the respondent's answer of how many dimensions the company uses. Each BIM dimension section in the survey contains main questions and matrix questions. In this paper, the focus will be only on the section results of the 4D BIM questionnaire. The main questions will ask about the software used and if the company uses BIM until the end of the project. The matrix questions are multiple-choice questions. They are the same set of questions for each BIM dimension which are six questions (i) Is 4D BIM regularly used at your company (meetings, preparation of reports, presentations for client...)? (ii) Is 4D BIM helpful in company meetings? (iii) Do you think 4D BIM has a significant influence on project management decisions? (iv) Your familiarity with 4D BIM Application (v) On the scale of 1 (lowest) – 5 (highest), please rate your competency of using 4D BIM Modeling and (vi) Please list the barriers in using 4D BIM (check all that apply).

Survey distribution started on November 18, 2020, by posting the survey link on LinkedIn weekly until January 30, 2021. The authors chose the largest five BIM groups on LinkedIn as the targeted audience. Additionally, the survey link was distributed for the Industry Advisory Board of Construction Management department members in Kennesaw State University. Furthermore, the authors distributed the link to their contacts in the BIM industry. A total of 67 survey responses was received by the end of January 2021. After asking the question of using BIM, 11 responses were incomplete, which means they started the survey but did not complete it. So, Qualtrics will save their partial answer, and thus these responses were omitted from the data analysis for this paper. Another 12 responses who answered "No" for using BIM were excluded from this research. Eight responses from the remaining 44 responses were excluded because the responses do not have recorded data. Incomplete response is one of the limitations of this survey, where almost half of the responses were excluded because of partial information. Hence, as shown in Figure 1, a final of 36 responses with recorded data was analyzed and studied for this paper in the data analysis section below. Most of the complete responses came from the contacts of the writers and not from LinkedIn groups. This indicates the importance of a targeted audience when distributing long surveys and the limitation of the survey as a research method.

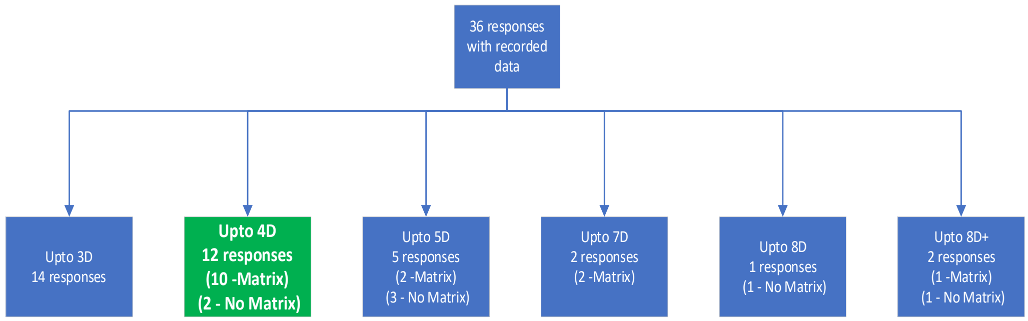

Fig. 1. Survey flow chart

3. Data Analysis and Results

The first objective is to investigate the status of 4D BIM adoption in the construction industry. (M.L.A.E. Borges, 2018) did a systematic mapping study of the current research in scientific paper format published from 2006 to 2016 about BIM 4D. (M.L.A.E. Borges, 2018) found the number of studies on 4D BIM has been increasing over the years where 51 articles out of 148 articles discuss the implementation of 4D BIM (about 32%). Most of the studies are case studies that indicate the current development, improvement, and implementation of 4D BIM among academic professionals as well as industry professionals (M.L.A.E. Borges, 2018). Nevertheless, 4D BIM is still not widely used by small-size companies in the construction industry (Sediqi, 2018).

Alternatively, figure 1 shows the number of survey respondents using each BIM dimension. The data is collected from two questions. The first question asks if the company utilizes more than BIM 3D, where 14 respondents answered “No”. Thus, there are 14 survey respondents out of 36 who use BIM 3D only. It means their companies do not use more than BIM 3D. The second question asks, “Up to how many dimensions is your company currently using?” where the respondent can choose only one answer from the choices (4D, 5D, 6D, 7D, 8D, or 8D+). Therefore, the data was analyzed from another perspective where the actual number of companies using BIM 3D is 36 (all the respondents) and not only the 14 companies who use BIM up to 3D. The number of companies that used 4D (12 respondents), 5D (5 respondents), 7D (2 respondents), 8D (1 respondent), and 8D+ (2 respondents) have been added to the 14 companies who answered “No” to the first question. Because when the respondents answered up to 4D, for example, it means they used 3D in addition to 4D and not only 4D.

For BIM 4D, 22 survey respondents out of 36 use 4D BIM (61% of total survey responses). This indicates 4D BIM adoption is increasing among Architecture Engineering and Construction (AEC) industry stakeholders. It can be concluded that as the dimensions of BIM are increasing, the number of companies using them is decreasing. 4D BIM implementation is the highest dimension used with the 3D model.

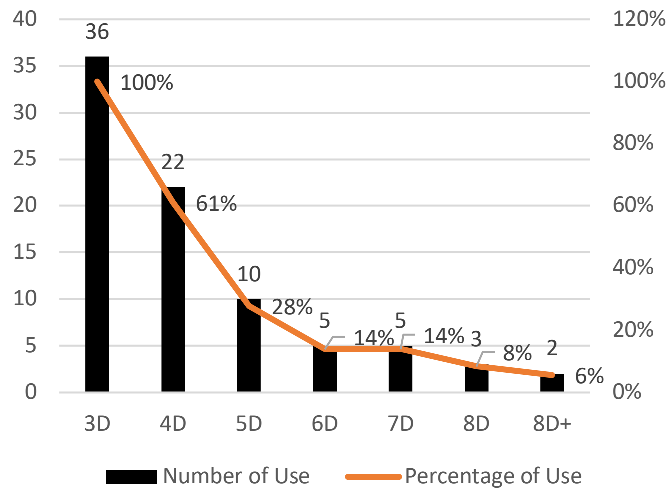

Fig. 2. Count of survey responses for using each BIM nD

The second objective is to discover the benefits of 4D BIM for construction contractors. (Martins, Evangelista, Hammad, Tam, & Haddad, 2020) found the following benefits of 4D BIM in their case study in Brazil (i) better representation of the construction project, (ii) evaluating different methods of construction, (iii) better communication among project stakeholders, (iv) improved project decisions, (v) valuation of resources of each construction activity, and (vi) visual preparation for site logistics and installation. These benefits will lead to achieving project objectives efficiently, such as finishing projects on time and within budget (Martins et al., 2020). In a different perspective for 4D BIM implementation, a case study of a megaproject in Australia was analyzed to assess the effect of 4D BIM visualization models on the communication of risk information (Datta, Ninan, & Sankaran, 2020). The authors discovered 4D BIM assisted in reducing different risks such as safety risk, interface risk, and program risk (Datta et al., 2020). (Hergunsel, 2011) found that 4D BIM can be very useful for updating progress on the project Scheduling as well as for monitoring and closing punch-lists. (Romigh, Kim, & Sattineni, 2017) did qualitative research about the importance of using 4D BIM on construction sites by interviewing construction superintendents. The results showed a strong requirement from superintendents to use 4D BIM as a tool on site to improve communication with different project stakeholders during the project execution phase (Romigh et al., 2017). 4D BIM is expected to improve site operations in the construction industry by enhancing construction planning and sequence of work (Romigh et al., 2017).

Similarly, twelve survey respondents out of thirteen believed that 4D BIM is useful in company meetings (see figure 3). These results from the survey show the value of 4D BIM in the construction industry.

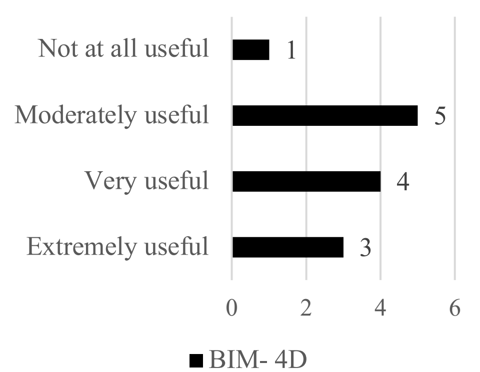

Fig. 3. Count of survey responses for using each BIM nD

The third objective is to explore the status of software interoperability and the method of integrating the Scheduling into the 3D model. Figure 4 presents the data collected from the survey when asking about software usage for BIM 4D. The survey results show Navisworks, BIM 360, and Synchro are the most used software for BIM 4D. Navisworks is the highest software being used in the industry (17 survey respondents out of 22; percentage of 77%). BIM 360 and Synchro come in second and third places, respectively (8 responses for BIM 360 and 7 responses for Synchro). This software is frequently found in case studies, discussed in this paper, from the literature review. In the case study in Brazil, (Martins et al., 2020) investigated the interoperability of Revit, Tally, Navisworks, and Green Building Studio. Although there is effectiveness of 4D BIM using Navisworks and BIM-Revit, there are some constraints found such as (i) massive use of separate software, (ii) software flaws carried out through project, and (iii) possible rise in project costs (Martins et al., 2020). When (Zhang & Laddipeerla, 2018) simulated two models for a bridge and an apartment and during importation, they found that IFC-based interoperability can be reached by using distinct architecture, engineering, and construction (AEC) objects. Although there is a lot of improvement in creating 4D BIM simulations with different commercial platforms (Navisworks, Synchro, and Navigator), going back from 4D simulations to Industry Foundation Classes (IFC) models is still missing (Zhang & Laddipeerla, 2018). Likewise, (Hergunsel, 2011) observed the availability of some challenges in 4D BIM simulation, such as using different platforms and interoperability of BIM tools.

Two main articles address auto-linking Scheduling to the BIM model and thus automation of BIM 4D. In the first study, (Taiebat & Ku, 2010) suggests a data model approach to auto-generate construction plans based on project stakeholder criteria. (Taiebat & Ku, 2010) believe when you use parametric and object-oriented modeling concepts, it will reduce the planner's work and let the planner achieve more accurate results. In the second study, (Elghaish & Abrishami, 2020) did an extensive literature review and found research gaps in integrating the Scheduling into the 3D model. Then, (Elghaish & Abrishami, 2020) did an exploratory case study to find a workable solution for automating the 4D BIM process. (Elghaish & Abrishami, 2020) propose a planning library similar to structural and architectural design libraries to help automate the 4D BIM process. In conclusion, (Elghaish & Abrishami, 2020) found the results presented a cost saving of 22.86 percent when automating BIM 4D.

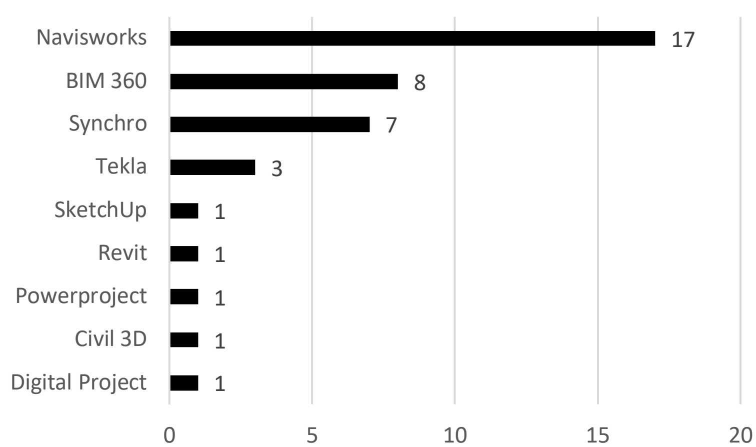

Fig. 4. Software usage for BIM 4D

The fourth objective is to identify the challenges and barriers of utilizing 4D BIM in construction delays. Even though a lot of challenges for 4D BIM can be identified from the literature review, the focus in this paper will be on the barriers from the survey results. In their case study, (Martins et al., 2020) identified different challenges for 4D BIM implementation, such as (i) use of different software, (ii) diverse scopes of construction projects, (iii) increase in cost, and (iv) training of project professionals. (Romigh et al., 2017) recognized the hardship of learning the current software in the market as the main barrier for utilizing 4D BIM on-site.

As per survey results and as shown in figure 5, lack of training is the highest barrier for 4D BIM (7 out of 15 responses: 47%). (Martins et al., 2020) also found the training of project stakeholders is difficult and expensive because of extensive use of multiple software for 4D BIM implementation.

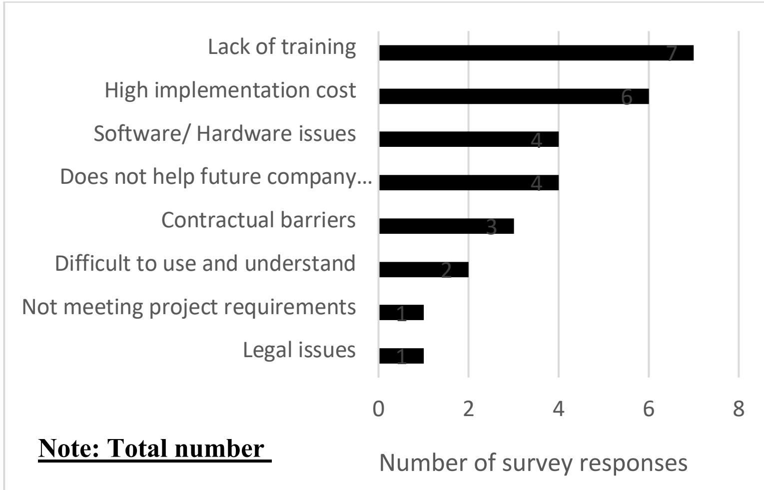

Fig. 5. 4D BIM barriers

Thirty-two percent (32%) of survey respondents (7 out of 22 respondents) are not using 4D BIM till the end of the project. After asking the following survey question about the reasons for not using 4D BIM till the end of the project, five responses were collected from the survey, as shown in table 2. The author grouped the reasons into two categories. The first category of reasons falls into barriers for not using 4D BIM till the end of the project. Time constraint appeared twice as a barrier; however, after reading response 1 in table 2, the survey respondent talks about the time required for linking Scheduling activities to the model components. Again, this validates the importance of automating the 4D BIM process, as discussed in the third objective, to save time. The second category falls into BIM usage for the beginning of the project only without any barrier.

Table 2. Reasons for not using 4D BIM till the end of the project

No	Response	Type
1	Time constraints of adding individual Scheduling activities to model components. Construction Scheduling has 1000+ activities with 25,000+ model components create a barrier to fully updating without hiring specific roles to maintain the 4D model. The simple analysis is competed on the front end of a job to prepare for site logistics	Barrier
2	Company policy	Barrier
3	Time	Barrier
4	Just for Construction Simulation in Tender Phase	Usage only at the beginning of the project
5	Linking Scheduling to models and updating them automatically	Usage only at the beginning of project

Future research may focus on feasibility studies and analysis of the return of investment on project objectives for implementing 4D BIM in construction projects. After the above data analysis, future research may focus on automating the 4D BIM process of linking Scheduling activities into the model components. Another important research topic is comparing similar projects with the only difference is using 4D BIM effectively. The results from such research will uncover whether using 4D BIM has a positive outcome on project objectives such as time, cost, and quality or not. Additionally, a return-on-investment analysis will motivate the construction industry to embrace 4D BIM in more projects and revoke the current barriers for 4D BIM execution.

4. Discussion, Limitations, and Future Studies

From a research perspective, the topic of 4D BIM has been vigorously investigated to determine its applications in construction planning, scheduling, constructability analysis, and control of production. However, our survey results reveal that its actual implementation in the construction firms is merely limited to the development of visualizations for owners and/or marketing purposes, with very few firms exploiting its full potential. Though the survey results provided several reasons for its implementation, more systematic research is needed to investigate these underlying reasons further and develop strategies and best practices to encourage construction firms to move beyond 3D BIM. The authors plan to continue this study. More data will be collected to develop a framework for 4D BIM implementation in construction firms to improve project performance and productivity.

5. Conclusions

The 4D BIM is a current topic of interest for both academic and industry professionals. Despite the availability of many case studies, the question of whether 4D BIM reduces construction delays could not explicitly be found. However, based on findings, 4D BIM improves project performance, enhances decision-making, and achieves on-time delivery. Another benefit is better planning and preparation of work and thus an increase in the workers' productivity. Additionally, visual preparation for site logistics and installation will reduce costs by procuring materials in advance and delivering them just in time.

Moreover, clearer communication among project stakeholders is one of the important advantages of 4D BIM, where technical experience is not required for understanding construction Scheduling. The main challenges from the literature review are related to software interoperability issues and manually linking Scheduling activities into model components. The three top barriers from survey results, related to software issues as well, are (i) lack of training, (ii) high implementation cost, and (iii) software/hardware issues. Though a lot of improvement has happened in the last decade for 4D BIM software, more improvement is required in this aspect. For example, Autodesk has Revit to develop BIM 3D, link Microsoft Project Scheduling into Navisworks with BIM 3D, and thus build a simulation of BIM 4D. Using different software increases implementation costs and requires the training of project personnel for using the software. Furthermore, manually linking Scheduling activities into model components requires a lot of time and personnel. Finding a solution to automate the 4D BIM process with minimum software usage can lead to huge rewards in the construction industry.

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ID 62

Indoor Localization and Tracking of Building Components and Fixtures Using Ultra-Wide Band

Jyoti Singh, Ph.D., Post-Doc and Chimay J. Anumba, Ph.D., DSC., Dean and Professor
University of Florida, Gainesville, Florida
Jyoti.singh@ufl.edu

Abstract

Modern buildings create vast amounts of data throughout their lifecycle. Carefully managing the data makes it more valuable. This data is contained in static printed materials or documents. These documents quickly become outdated, and all too often much valuable time is lost tracking down the relevant information. It is important to associate project information with specific elements in each location for future reference. Location based real-time information sharing is key to productivity for an organization. Position coordinates may be used to link important information with the given location and effectively connect data using indoor localization technology. This paper explores use of indoor positioning technologies for organizing and accessing information in construction industry using content analysis. Ultra-wideband (UWB) is a most promising technique that has proven effective in indoor localization. In addition, the research reviewed past five years papers to understand the application of UWB in various stages of construction. The research then studied potential stages where adoption of UWB can be an imminent research area to revolutionized information sharing in construction. The research found that no research has been focused on using UWB during the commissioning stage of construction, which is one of the important stages requiring real-time information sharing.

Keywords

Indoor Localization, Ultra-wideband (UWB), Digital Information Sharing, Content Analysis, Construction Stages

1. Introduction

A large amount of data is associated with a building's lifecycle - from preliminary planning of a building to the demolition stage. The data associated with a building needs to be carefully managed so that it can be used at a later stage when needed. Much of this data is contained in steady materials or documents. The construction industry still relies on and gets hindered by paper-based static materials and processes such as, plans and drawings, blueprints, manuals, supply chain orders, etc., (Lerkenfeld 2017). Additionally, paper-based static information sharing makes it difficult to capture and analyze data, leading to loss of important and relevant information. Moreover, construction transitioning to digital information delivery, with paper-based documents being phased out, as information storage and retrieval is burdensome. Therefore, it is important to automate the tracking of necessary information associated with relevant elements in a specific location for future follow up.

The construction industry is learning the importance of real-time and digital information sharing. To reduce the costs associated with untimely information sharing, timely access to the data and information is crucial. Thus, real-time information sharing process is a requisite in construction industry. Efficient transfer and extraction of information is important and the location associated with each information is also necessary. Thus, location based real-time information tracking and sharing are crucial for construction productivity and efficient flow of information through different stages of the project delivery process. Position coordinates may be used to link necessary information with a given location and efficiently connect data using indoor positioning technology. The technology can help to ensure smooth workflow to share information in real time within and between different users (Lerkenfeld 2017).

Indoor positioning technology is a system that continuously and in real-time determines the position of a person or an object in an indoor environment (Alarifi et al., 2016). Indoor positioning applications may require different quality attributes such as location accuracy, line of sight (LOS) condition, hardware, etc., and thus should be carefully selected to meet the requirements of the application. Indoor location-based services are an important application of indoor computing. Accurate position coordinates are a critical requirement for indoor positioning techniques. This paper reviews the use of indoor positioning technologies for organizing and accessing real-time information in the construction process. The research reviews and studies literature over the past five years to comprehend the application of the most promising indoor positioning technologies at various stages of construction. In addition, it explores emerging new application areas related to stages in construction that require automation of real-time information sharing using indoor positioning technologies. The research adopts content analysis as the primary methodology to review indoor positioning technologies and their applications. This involved investigating research papers and articles with the following keywords: indoor positioning technology; features of UWB; application of UWB; and stages of construction.

2. Indoor Positioning Technologies

A large variety of techniques and devices are used to provide indoor positioning in the built environment. The top 10 indoor positioning technologies are briefly introduced below (Li et al., 2020).

Wi-Fi is the most widely used indoor positioning technology, due to its paramount existence Due to high availability of wireless application arrangement, Wi-Fi systems do not require new hardware equipment. The precision of the systems is moderate, but power consumption is high (Zhao et al., 2014).

Bluetooth Low Energy (BLE) is common short-range wireless communication technology and is based on standard Bluetooth. BLE and Wi-Fi use the same carrier frequency (2.4GHz) but BLE has much lower power consumption (Alarifi et al., 2016; Li et al., 2020). BLE systems perform better than Wi-Fi systems by 27%, but accuracy is still low compared to other communication technologies.

Radio Frequency Identification (RFID) is another short-range communication technology. RFID systems offer moderate to high accuracy depending on line of sight (LOS) condition (Yang et al., 2014). The cost and power consumption of RFID ranges from low to moderate based on system design and tags used (Li et al., 2020).

Zigbee is designed to be used in small personal area networks (Alarifi et al., 2016). It is secure technology for short-range communication with low data rate, low power, and low cost (Zheng and Lee, 2004). Zigbee has a moderate performance at the sub-meter (1mm to 1m) level only.

Indoor Global Navigation Satellite Systems (GNSS) depend on radio frequency (RF) waves to carry signals. The main benefit of indoor GNSS systems is that the targets can use smartphones to seamlessly position themselves indoors. However, signals cannot penetrate other floors in buildings (Rizos et al., 2010). Indoor GNSS systems with high number of repeaters offers accuracy and precision at sub-meter level with longer response times *(Jardak and Samama, 2009).*

Ultrasound can achieve very high positioning accuracy and precision at the sub-millimeter (<1mm) level when noise interference is less (Medina et al., 2013). One limitation of ultrasound systems is that signals cannot penetrate walls and has a low coverage.

Range Imaging is evolving technology in metrology and navigation sector. This is device-free communication technology which does not require receiver on the positioning targets (Li et al., 2020). Range imaging provide 6D object pose estimation (3D position and 3D orientation). One limitations of range imaging systems are strict requirement of line of sight (LOS) conditions. (*Brscic et al., 2013).*

Geomagnetic Waves for indoor positioning have emerged in recent years. Geomagnetic waves exist everywhere in the environment but establishing accurate and precise indoor positioning systems based on geomagnetic waves is very challenging, due to low visibility (Shu et al., 2015). Additionally, geomagnetic waves can vary both horizontally and vertically (Li et al., 2020).

Image Processing is an emerging technology. Image processing systems uses computer vision techniques and visible light cameras developed on smartphones and other cameras (Werner et al., 2011; Song et al., 2011; Alarifi et al., 2016). These system offers moderate accuracy at sub-meter level in static environment with little noise interference (Kawaji et al., 2010). The system requires line of sight (LOS) condition for image processing for better precision (Li et al., 2020).

Ultra-wideband (UWB) is a short-range wireless communication protocol that uses radio frequency (RF) waves to enable devices to 'talk' to each other and provide a simple example (e.g., tap free mobile payment, asset tracking, building access control, ticket validation). UWB transmitters transmit high data while consuming small energy (Svalastog, 2007). UWB offers short pulse radio frequency (RF) waveforms and large bandwidth (Shen et al. 2008), which results in fine time resolution, good potential for application in localization and positioning, and better immunity to multipath effects (Jiang et al., 2011). The low frequency of UWB signals permits the pulses to effectively transmit through various obstacles as experienced by other wireless modalities. Based on various researchers, UWB systems is most suitable and foremost technologies among other indoor positing technologies in terms of large data transmission, accuracy, and precision with minimized error to sub-centimeters (1cm to 1mm) level, even under strong noise interference (Ghavami et al., 2006; Liu et al., 2007; Svalastog, 2007; Cheng, 2012; Shahi et al., 2012; Segura et al., 2012). Given its potential advantages over other indoor positioning technologies, this paper explores how best to leverage UWB technologies to improve the different construction processes by providing real-time access to component-level information.

3. Key Features of Ultra-Wideband

UWB has various important features that are explored and studied in the literature on different industry sectors. Alarifi et al., (2016) performed SWOT analysis for evaluating UWB technology and summarizing its key features in terms of strengths, weakness, opportunities, and threats. Some of the key features of UWB are summarized in Table 1 (Hämäläinen et al., 1999; Miller, 2003; Aiello and Batra, 2006; Otis and Rabaey, 2007*; Ubisense, 2009;* Porcino and Hirt, 2011; Savioli et al., 2012; Alarifi et al., 2016).

Table 1: Key features of UWB

Strength	Weakness	Opportunities	Threats
• License free • Large bandwidth • Short pulses • Low power consumption • Less interference with other systems • Effective multipath resolution • High data rate transmission • Acquire high level processing • Carrierless transmission • Opposition to Jamming	• Potential interference with systems operating on same spectrum • Long time to synchronize	• Tracking system • Indoor navigation • Localization and positioning system	• Commercially expensive • Not totally immune to multipath • Design and implementation may be challenging

4. Applications and Uses of Ultra-Wideband in Construction

UWB technology is most promising for indoor positioning and localization applications (Alarifi et al., 2016). Due to the increase in demand, researchers have begun to explore new opportunities to leverage. UWB technology is becoming more widely used in the construction industry. In recent years, a significant amount of research effort and application of UWB has been carried out to enhance the efficiency of construction (Jiang et al., 2011). UWB has been applied to various stages in construction for precision positioning and localization both for research and industry purposes.

This paper reviewed research papers over the past five years on the application of UWB in five main stages of the construction process (feasibility, design, construction, commissioning, operation and maintenance (O&M)) (Table 2). During the construction stage, UWB has been primaily adopted and in various ways, such as construction resource position and tracking (Li et al., 2021; Zhang and Liu, 2020, Siddiqui et al., 2019, etc.), site supervision (Wei et al., 2021, Norrdine et al., 2020, Shen and Zhang, 2020, etc.), and safety management (Pittokopiti and Grammenos, 2019; Rodriguez et al., 2019). During O&M, UWB can be used for operation and maintenance planning (Hou et al., 2020), non-destructive testing (Kim et al., 2017), detection of corrosion condition of concrete and other building materials (Nishimoto et al., 2019;), electrical application control (Fiawoyife and Louis, 2018). In design stage, UWB is applied in indoor scanning (Chen et al., 2019), if required during design planning based on existing situation of project, e.g., renovation project. Limited research has been focused on using UWB during the feasibility and commissioning stage of construction (Table 2).

UWB has many potential applications to be researched. Following the review of research papers, this research mapped the key features of UWB application with the requirements of the different stages in construction, to highlight the potential benefits UWB can provide to various stages of construction (Table 3). After mapping, it was found that UWB has considerable potential in the three project lifecycle stages – construction, commissioning, O&M and less potential in the design and feasibility stages (Table 2). There are various research papers on the application of UWB at the construction and O&M stages. However, there is nothing on the commissioning stage, despite the potential benefits of UWB application at this stage (Table 2). Commissioning process documents the performance standards of the various building systems and verifies that designed and constructed work meets design standards ((WBDG, 2016). UWB can be helpful at commissioning stage by tagging performance information with the specific location of the building elements and systems obviating the need to rummage through design and construction documents, drawings, equipment manuals, technical specifications, and handover notes.

Table 2: Papers on UWB application at various stages of construction

	Stages in Construction				
	Feasibility	Design	Construction	Commissioning	O & M
UWB		Chen et al., 2019	Arabshahi et al., 2021; Zhao et al., 2021; Wei et al., 2021; Li et al., 2021; Dérobert et al, 2021; Norrdine et al., 2020; Li et al., 2020; Norrdine and Motzko, 2020; Jie et al., 2020; Zhang and Liu, 2020; Ansaripour et al., 2020; Moselhi et al., 2020; Shen and Zhang, 2020; Umer and Siddiqui, 2020; Wen et al., 2020; Zhnag et al., 2020; Siddiqui et al., 2019; Pittokopiti and Grammenos, 2019; Rodriguez et al., 2019; Jin et al., 2019		Hou et al., 2020; Nishimoto et al., 2019; Fiawoyife and Louis, 2018; Kim et al., 2017

Table 3: Potential uses of UWB at various stages of construction

	Stages in Construction				
	Feasibility	Design	Construction	Commissioning	O & M
Use of UWB	X	XX	XXX	XXX	XXX

X – Least use; XX – Average use; XXX – Highest use

5. Discussion

The construction industry should revolutionize how building information is accessed and create efficient information retrieval mechanisms for the construction workforce. UWB is a well-suited technique that has proven effective in indoor positioning and tracking. UWB-based technology can be used for organizing and accessing information as part of the commissioning of a building by providing a simple, intuitive, and inexpensive solution to easily access accurate building information, when and where necessary. Adoption of UWB for location based real-time information sharing at the commissioning stage of construction is crucial and is an important application area for the future. The acquisition and transmission of data during commissioning is time-consuming, monotonous and requires a huge human effort when done using conventional approaches. Use of UWB at commissioning stage in building enables the use of real-time location services, direction of interest and a smart device to allow easy access to actionable data created during the lifecycle of a project. This approach should organize content according to location coordinates to help track referential information as per associated location coordinates in a time-efficient manner thereby, facilitating better coordination and communication between owner and teams during project handover and commissioning. UWB provides wireless coordinates that are associated with physical locations for high tech location and direction. As a user moves around a building site, different information or functionality can be made available using an augmented reality or 2D interface on a standard smart device. New information or functionality can be made available based on the user's context (e.g., new location and new direction of interest). Reference manuals, how to videos, part ordering, e-commerce, design plans, as-built records, manuals, or any other desired digital capability, can all be available via a simple point and touch interface.

6. Conclusions

Indoor positioning technology has changed significantly in different industry sectors with the rapid development of wireless positioning and tracking technologies. Ultra-wide band is a fast, secure, short range, low power radio protocol used to determine location with accuracy unmatched by any other wireless technology. UWB provides accurate positioning throughout buildings in various fields and facilitate better decision making due to its distinctive technical features. This study reviewed indoor positioning technologies and found UWB the most favourable for organizing and accessing real-time information in construction. Content analysis was adopted to review papers on indoor positioning technologies for real-time information sharing over the past five years. It also explored papers on the application of UWB at various stages of the project delivery process. In addition, the research also explored potential application areas for UWB application. It can be concluded that there is considerable potential in leveraging UWB technology to facilitate efficient information flow at the commissioning stage of a project - especially between geographically distributed team members and without the need for a huge IT infrastructure.

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Supply Chain Management in Construction: State of The Art

Kiruthika Murugaiyan[1], Wassim Al Balkhy[1*], Zoubeir Lafhaj[1], Fabien Font[2]

[1] Centrale Lille, 59650 Villeneuve-d'Ascq, France
[2] Teamoty – Groupe IMMA, 75015 Paris, France
wassim.albalkhy@gmail.com

Abstract
Supply Chain Management is a concept originally developed in the manufacturing industry and later implemented in the construction industry to reduce cost, on-time delivery, and better productivity. An extensive review of the literature published from 1982 to 2021 on the origin, types, and role of Supply Chain Management is discussed in this paper. Literature from the area of the supply chain in the construction industry was studied and a brief background on how Supply Chain Management can be diffused into the construction industry and the impact of Machine Learning in better decision making in Supply Chain Management are explained. This paper aims to review the existing literature and provide the synthesis and suggestions for future works. Further work on analyzing the compatibility of Supply Chain Management with the current strategies and its role in achieving sustainability in the construction sector can be carried out.

Keywords
Supply Chain Management, Construction Planning, Implementation, Project Management, Decision making

1. INTRODUCTION
The supply chain in construction is complex because of the high level of sub-contracting and projects of varying sizes and complexity. Since the 1990s supply chain management has emerged as an innovative concept and as a solution for the problems in the construction industry. Quality and profit can be increased in a systematic way using Supply Chain Management (SCM). The need to decrease cost and improve quality, productivity, and expansion in the economic weight of the supply chain calls for discussion about SCM (El Moussaoui et al, 2021). Along with the development of lean techniques in the construction industry, there has been development and research in SCM simultaneously. According to Vrijhoef and Koskela (2000), even in a normal situation, a large quantity of waste is generated in the construction supply chain and these wastes are mainly generated because of obsolete and myopic control of the construction supply chain. SCM in the construction sector can result in better integration among different parties and waste reduction. This paper includes a literature review about the trends of SCM in the construction industry. An extensive literature review has been done to understand the importance of SCM in improving companies' performance. Although the literature recommends that the generic supply chains must be simple and linear, the reality is different in the construction industry where a multitude of construction supply chains and markets are integrated to deliver the solution to the ultimate customer. Integration between vendors, designers, contractors, sub-contractors, and site team is essential to improve the project performance, reduce waste, and deliver the projects on or before the project completion time.

1.1 ORIGIN OF SUPPLY CHAIN MANAGEMENT
SCM is a concept that was originally developed in the manufacturing industry. The term Supply Chain appeared for the first time in literature in 1982 (Olivier and Webber, 1982). The initial steps of SCM can be seen as Just in Time delivery system in Toyota Production System. The generic configuration and understanding of the Supply Chain in Manufacturing are shown in Fig 1. The main aim of this concept was to decrease inventories drastically and to synchronize the supplier's interaction with the production line. After its appearance in the automotive industry, SCM has gained an independent status in industrial management theory and scientific research (Bechtel and Jayaram, 1997). Western contributors like Burbridge and Forrester played an important role in understanding the supply chain in manufacturing (Towill,1996). Though the development and application of SCM in the manufacturing industry have

been successful and achieved the expected outcome, its application in the construction industry has some problems because of the complex nature of the construction sector (Christopher, 1992). The expected outcomes include cost reduction, on-time delivery, improvement in productivity, value creation, and higher customer satisfaction. The major differences between supply chain in the manufacturing and construction industry are that most of the projects are unique, the equipment and methods of production vary from project to project.

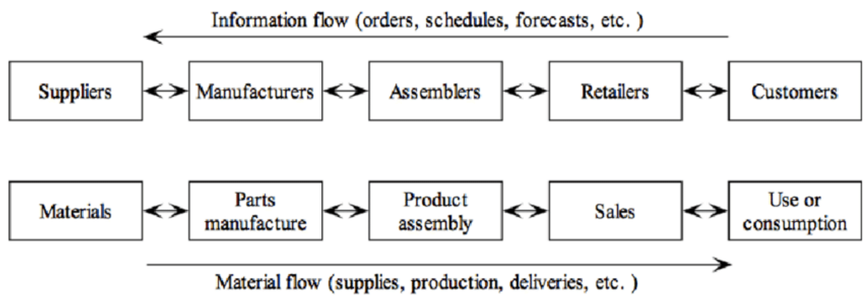

Fig 1: Generic configuration and understanding of Supply Chain in Manufacturing [Vrijhoef and Koskela (2000)]

This paper is divided into 4 sections. Section 2 describes the methodology of the paper; Section 3 describes the concept of Supply Chain Management and its subsection describes the types of Supply chain, differences between the traditional way of managing supply chain and SCM, Evolution of Supply chain in the construction industry, the role of SCM in construction and Machine learning in Supply chain management; and Section 4 presents the conclusion and direction for future research.

2. METHODOLOGY

A narrative literature review involves a comprehensive and critical analysis of the existing knowledge on a particular topic. It forms an essential part of the research process and helps in identifying the trends in the studies to identify gaps and future research. The analysis of the literature was based on reviewing the published articles on Google Scholar between 1982 and 2022 and selecting those that included the studied objectives in the title or the abstract only (e.g. the concept, types, differences between traditional and SCM, and the evolution of SCM). The search included "construction supply chain management" as a keyword and only the articles written in English were included in the search.

Accordingly, 40 articles were selected to synthesize the concept, types, and role of SCM and to understand how to apply and integrate Supply Chain Management in the construction sector to address the issues of productivity and efficiency.

3. CONCEPT OF SUPPLY CHAIN MANAGEMENT

The supply chain has been defined as 'the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services in the hands of the ultimate customer' (Christopher, 1992; Vrijhoef and Koskela 2000). In 1994, The International Centre for Competitive Excellence defined Supply Chain Management as the integration of business processes from end-user through original suppliers that provide products, services, and information that add value for clients (Cooper et al,1997). The general idea of SCM is to identify the interdependency in the supply chain and to enhance control and configuration based on the integration of business processes. It can also be defined as facilities involved in raw material procurement and transforming them into intermediate and final products (Lee et al, 1995). SCM aims to harmonize the requirements of the clients with material and information flow till a balance between client satisfaction and the cost is reached (Papadopoulos et al, 2016, El Moussaoui et al, 2021). Effective supplier management strategy is essential for end customers to maximize the business value of procured products and services (Cox and Ireland, 2001, Font and Grua, 2018). Another important factor is the type of firm selected to deliver solutions. A proper understanding of the relationship between clients, consultants, contractors, and subcontractors in terms of collaboration and integration is essential. The investigation of procurement approaches between 1960 and 2000 in the construction industry is summarized in Fig 2. In the early nineteenth century, the traditional single-stage approach to procurement dominated the construction clients (Saad et al, 2002; Butkovic et al, 2016). This approach is identified by short-term and adverse relationships. Alternative procurement routes such as 'two-stage competitive tendering', 'Design and

Build', 'Management Contracting' and 'Construction Management' represent some differences in relationships, roles, and power between the consultants, contractors, and sub-contractors. These alternate approaches to procurement resulted in great potential for better collaboration and integration.

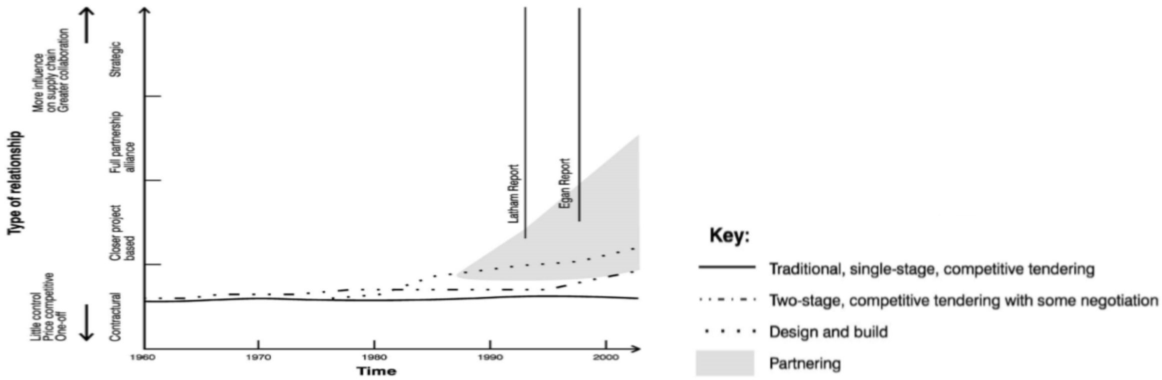

Fig 2: Relationships in the construction industry (Saad et al, 2002)

3.1 TYPES OF SUPPLY CHAIN

There are three types of the supply chain in construction (Butkovic et al, 2016).

- Primary supply chain which delivers material for incorporation into the final construction product.
- Support chain which provides equipment and material to facilitate construction.
- The supply chain which involves the supply of labor.

Fig 3 illustrates that the supply chain is simple but the reality is quite different.

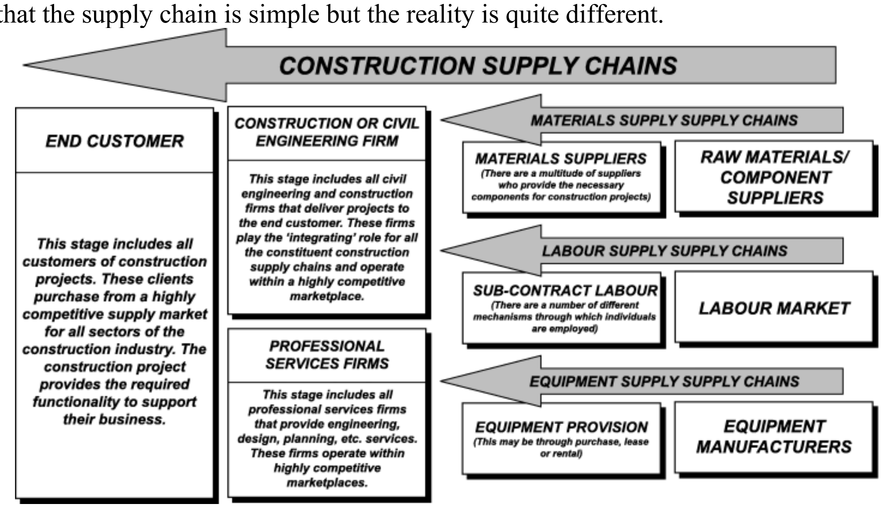

Fig 3: The myriad of the construction supply chain (Cox et al, 2001)

In a construction process, the end customer selects and appoints the construction firm or professional, and the construction firm plays the major integrating role within the generic supply chain. However, the construction industry involves a high degree of sub-contracting and main contractors engage third parties that can be integrated within the solution. Sub-contracting adds to the problem related to adversarial because of another party involved in the supply chain to earn margins to the detriment of other firms (Cox and Ireland, 2001).

3.2 TRADITIONAL SUPPLY CHAIN VS SCM

The traditional way of managing the supply chain was largely based on the transformation view of production while SCM is based on the flow view of production. Independent control of each production stage is suggested by the transformation view whereas SCM concentrates on control of the total flow of production (Koskela, 1992). The differences between traditional management and supply chain management concerning different elements such as Inventory Management system, cost approach, etc. are explained in Fig 4 below.

Element	**Traditional Management**	**Supply Chain Management**
Inventory Management Approach	Independent efforts	Joint reduction of channel inventories
Total cost approach	Minimize firm costs	Channel -wide cost efficiencies
Time horizon	Short term	Long term
Amount of information sharing and monitoring	Limited to needs of current transaction	As required for planning and monitoring processes
Amount of coordination of multiple levels in the channel	Single contact for the transaction between channel pairs	Multiple contacts between levels in firms and levels of channel
Joint planning	Transaction - based	On going
Compatibility of corporate philosophies	Not relevant	Compatibility at least for key relationships
Breadth of supplier base	Large to increase competition and spread risks	Small to increase coordination
Channel leadership	Not needed	Needed for coordination focus
Amount of sharing risks and rewards	Each on its own	Risks and rewards shared over the long term
Speed of operations, information and inventory levels	"Warehouse" orientation (storage, safety stock) interrupted by barriers to flows; localized to channel pairs	"Distribution center" orientation (inventory velocity) interconnecting flows; JIT, quick response across the channel

Fig 4: Differences between the traditional way of managing supply chain and SCM (Cooper and Ellram, 1993)

3.3 EVOLUTION OF SUPPLY CHAIN IN CONSTRUCTION INDUSTRY

The evolution of the supply chain in the construction industry is slower than in the general industry. The techniques like inventory management, production, and planning control were applied to improve the performance of construction projects (Fig 5). At present, the focus is shifted towards strategies and techniques such as Material Requirement Planning (MRP), Enterprise Resource Planning (ERP), Business Process Re-engineering (BPR), Computer-Aided Design (CAD), and optimization techniques (Xue et al, 2005; Vaidyanathan 2009).

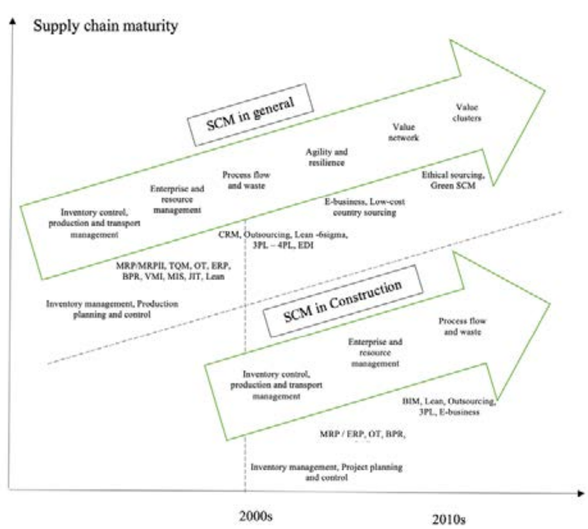

Fig 5: Evolution of supply chain in general and in the construction industry (Le Phuoc Luong et al, 2018)

3.4 THE ROLE OF SCM IN CONSTRUCTION

In the manufacturing system, multiple products pass through the factory whereas a construction factory revolves around a single product. The construction supply chain is represented by uncertainty, fragmentation (Studer et al, 2021), instability, unpredictability, and separation between the design and construction phases. Construction projects involve creating a new prototype or product every time with little or minor repetition. Therefore, it involves making to order supply chain where each project requires a new product or prototype. According to Vrijhoef and Koskela

(2000), SCM has four major roles in the construction industry which is represented in Fig 6. Firstly, the emphasis should be on the effect of the supply chain on the site activities. The aim is to reduce the cost and time duration of site activities. The primary concern should be to ensure labor and material flow to the site to prevent workflow disruption which can be achieved by focusing on the relationship between contractors and direct suppliers. Secondly, the focus must be on the supply chain itself, with the aim of cost reduction specifically those related to logistics, inventory, and lead time. Thirdly the focus is on transferring activities to earlier stages of the supply chain from the site to reduce total cost and duration. Fourthly the emphasis should be on integrated management, supply chain improvement, and site production. All four roles of SCM are applied simultaneously to increase the efficiency of the supply chain.

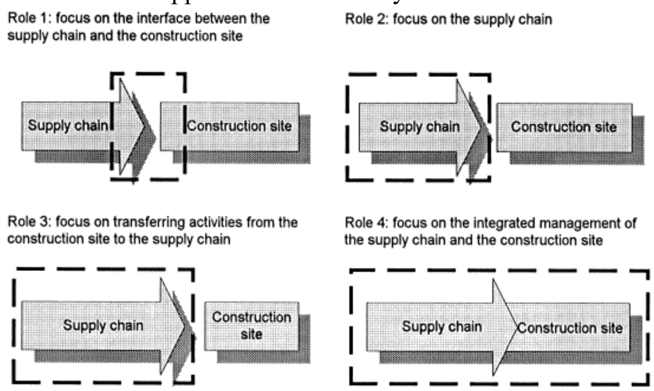

Fig 6: The roles of supply chain management in construction (Vrijhoef and Koskela, 2000)

Decision-making plays a significant role in the construction supply chain. During the first phase, the general contractor provides feedback to the designer. The owner plays a vital role in managing the general contractor's plan in terms of cost, time, and quality. The separation of design and construction, lack of communication between different disciplines, and lack of strategies to share risk results in inefficient construction planning and design (Xue et al, 2005; Vaidyanathan 2009). Advanced technologies such as cloud-enabled BIM help in better and transparent communication among clients, designers, and contractors (Papadonikolaki et al. 2015; Dave et al, 2016, Dakhli and Lafhaj, 2017). During the second phase, the general contractor concentrates on decisions of partnership building, selecting suppliers, production planning, and material purchase as shown in fig 7. In the third phase general contractor is responsible for decisions related to onsite operations. IT-based planning and logistics-based planning are recommended to reduce the uncertainty in on-site construction operations (Dakhli and Lafhaj, 2022).

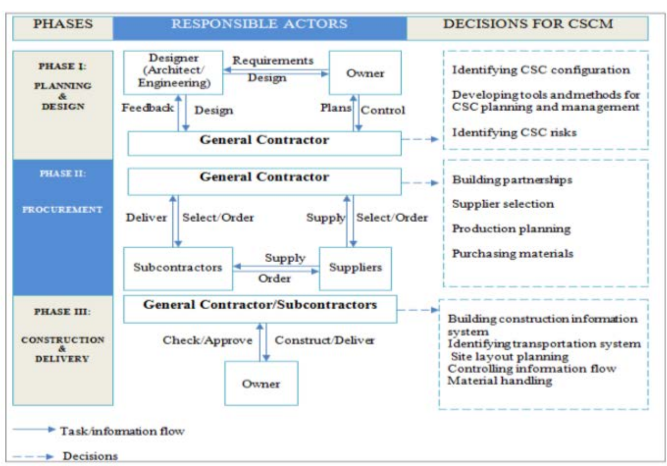

Fig 7: Focused decision on each phase of a construction project (Le Phuoc Luong et al, 2018)

3.5 MACHINE LEARNING IN SUPPLY CHAIN MANAGEMENT

The main aim of the supply chain is to satisfy customer demand and minimize the cost. But uncertainty in demand and supply risk results in the bullwhip effect. To overcome these obstacles Machine Learning algorithms can be used for better decision making and predictions (Bousqaoui et al, 2018).

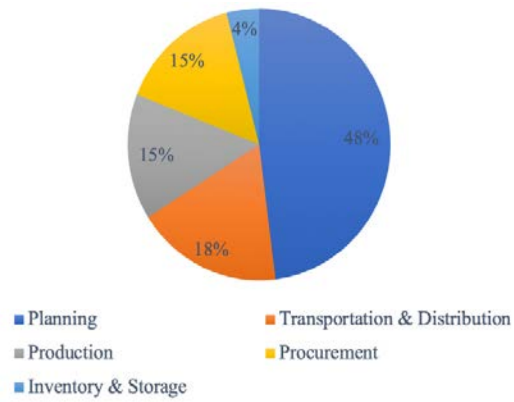

Fig 8: Machine Learning Algorithms applied in each area of the supply chain (source: Bousqaoui et al, 2018)

According to Fig 8, most of the Machine Learning application is during the planning stage, in which the most important is selection of suppliers and Just in Time (Wild, 2018; Hoppe, 2019). The next important area of application in the supply chain is the transportation and distribution area, which mainly includes the vehicle routing problem. The goal is to find the best possible vehicle route to deliver the products to the respective production facility or customer. According to the study conducted by Becker et al, 2016, it has been revealed that the performance of neural network models is 48% more than that of standard optimization heuristics. The third most important field is the production process. Better calculation and prediction of lead time and manufacturing time before the production stage can avoid delays in customer delivery. The model created on the influence of the algorithm indicated a good performance when employed to predict the manufacturing time of new batches. The industries which used Machine Learning to organize their supply chain activities had shown better results in logistics and demand forecasting (Hoppe, 2019).

4. CONCLUSION

This paper focuses on providing an overview of the context of supply chain studies within the construction sector. The interface between site activities and the supply chain has to be developed and improved. Logistics is the main focus of SCM in construction (Wegelius-Lehtonen and Pahkala, 1998). To improve the total flow of material, the focus has to be on suppliers' and contractors' cooperation. An extensive cost and time analysis are vital for supply chain development and improvement. For overall improvement, the trade-off between inventory, transportation, and production costs should be considered. Uncertainty in the supply chain and varying site conditions have an impact on productivity and supply chain performance (O'Brien, 1995). On-site, activities can be transferred into offsite activities by remodeling the supply chain. For instance, prefabrication can be regarded as means of eliminating on-site activities from the total production chain. For the integration of supply chain and construction site, alternatives like open building and sequential procedure have been recommended. (Bobroff and Campagnac, 1987). Efforts from the professionals, contractors, subcontractors, and other parties involved are necessary for the effective adoption of SCM in construction projects. Proper application of SCM in the construction sector helps the project managers in strategic planning to achieve a partnership with different parties and to improve efficiency in operational construction.

The current study covers the trends of the supply chain management and concludes that the use of digitization and the practices of industry 4.0 might present many solutions to improve the SCM in construction projects as they are helpful to trace and improve the flow of the materials, achieve better visibility for the chain, improve the collaborative work between the partners, and support the delivery processes and site works.

4.1 CONTRIBUTION OF THE STUDY AND FUTURE DIRECTIONS

The current study aims to contribute to the existing efforts made regarding the support of improving practices of construction supply chain management. This summary is useful for researchers and academics to present new directions for future research. It also serves as a reference for practitioners who are working to improve the practices of supply chain management in their projects.

Detailed studies on strategies and methods to improve construction supply chain management have to be done. Further research can be carried out to analyze the compatibility of Supply Chain Management strategies with existing strategies and the role of Supply Chain Management in achieving sustainability in the construction sector and research has to be conducted to fill the knowledge gap.

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Introducing Construction 4.0 into Construction Management Curricula

Mandisa Khesa and John Smallwood

Nelson Mandela University, Port Elizabeth, PO Box 77000, 6031, South Africa
john.smallwood@mandela.ac.za

Abstract
The rise of the Fourth Industrial revolution has forced many, if not all industries to embrace the transformation and adopt its concepts and technologies. Innovation that resulted from Industry 4.0 technologies gave rise to Construction 4.0, and the construction industry is adopting these Construction 4.0 technologies, as they are extremely beneficial. The adoption of Construction 4.0 has created a skills gap as the current and future workforce does not have the necessary skills for a Construction 4.0 environment. A quantitative study was conducted among recent construction management graduates of Nelson Mandela University between 2019 to 2021, to determine how Construction 4.0 can be integrated into the construction management curricula. The findings indicate the construction industry is slow to adopt Industry 4.0 concepts and technologies and it faces challenges in terms of increasing Construction 4.0 awareness; the current skills gap needs to be addressed and qualifications need to be restructured to include digital skills, and more digital training programmes need to be adopted on site. Conclusions include that universities and the construction industry both need to make progress in terms of adopting Industry 4.0 concepts and technologies so that they are current and can fully embrace the new innovations and trends that will be beneficial to them. Recommendations include: the relevant Construction 4.0 technologies need to be introduced into construction management curricula; students should develop the related skills, and vacation work should be a requirement, which will enable students to apply what they learn in the lecture environment in the workplace.

Keywords
Construction Management, Curricula, Industry 4.0.

1. Introduction
Construction Management curricula have played a vital role in the success of construction professionals in the construction industry, as they provide a foundation, providing graduates with the knowledge and skills that they will need in the workplace.

Industry is continuously evolving, and new information and technologies are discovered every day, but unlike other industries, the construction industry is the slowest to adjust. For example, the construction industry is historically reported as the second lowest sector to have adopted information technology (Perera et al., 2020).

The 4th industrial revolution (Industry 4.0) follows three previous industrial revolutions, namely Industry 1.0 (water and steam power), Industry 2.0 (electricity), and Industry 3.0 (internet, electronic devices). According to Perera et al. (2020) "Industry 4.0 is characterised by the seamless integration of cyber-physical environments propelled by an array of technologies that enable the development of a digital and automated industry as well as the digitisation of the value chain."

Construction 4.0 has been described as the digitalisation of the construction industry, introducing building information modelling (BIM), autonomous construction, advanced building materials such as nanomaterials, augmented and virtual reality, and more. Osunsanmi, Aigbavboa and Oke (2018) propose that construction professionals should adopt Industry 4.0 to improve the overall performance of the industry in South Africa.

Innovation generates new opportunities that allow for improvements within the construction industry. Becker et al. (2011) suggest that for construction professionals to benefit from innovative technologies and emerging business environments, they must both recognise opportunities and possess the prerequisite education and training needed to capitalise thereon. Therefore, Construction Management curricula must be current in terms of what is happening in the industry, to prepare students for the industry.

Given the abovementioned, the aim of the study was to evolve a framework for digitalisation of construction management curricula, the objectives being to:

- determine the degree of adoption and experience of Industry 4.0 technologies in construction;
- determine the digital skills construction managers will require in the future;
- determine the incidence of vacation work during graduates' studies;
- identify which modules need attention, and
- identify which Industry 4.0 technologies can be integrated into such modules.

2. Review of the literature

2.1 Industry 4.0

According to Dima (2021), "Industry 4.0 originated in 2011 from a project in the high-tech strategy of the German government that promoted computerisation of manufacturing." It is in that same year that the term Industry 4.0 was introduced publicly.

Carvalho and Cazarini (2020) refer to Industry 4.0 as an industrial model that characterises the Fourth Industrial Revolution. The advanced manufacturing model is represented by intelligent, virtual, and digital performance in large scale industries and emerges as a disruption to the previous three industrial revolutions. The focus of Industry 4.0 on interconnectivity through the Internet of Things (IoT), machine learning, and the processing of real-time data.

Phuyal, Bista and Bista (2020) state that this industrial revolution connects IoT and the industrial internet to manufacturing systems to interact with the machines to enable sharing of their information, and to make intelligent decisions based on the systems' algorithms.

Zhang and Yang (2020) cited by Phuyal, Bista and Bista (2020) opine that Industry 4.0 includes artificial intelligence, automated robots, flexible manufacturing automation systems, additive manufacturing, and augmented reality.

2.2 Students', graduates', and professionals' knowledge regarding Industry 4.0

Industry 4.0 is not a new concept, but most people in different parts of the world are still not aware of it and its significance.

A review of accredited programmes in the United States of America determined that construction management students receive little exposure to the vast amount of mobile technologies used in the industry (Radden, Collins and Kim, 2017). In a similar vein, a study conducted by Osunsanmi, Aigbavboa and Oke (2018) in South Africa determined that construction professionals have a low level of awareness with respect to Construction 4.0 principles.

One of the challenges that Construction 4.0 is facing is increasing awareness thereof. The construction industry needs to clearly communicate the benefits of Construction 4.0 technologies to migrate its workforce into the future and ensure that everyone adapts and improves together (Go Construct, 2022).

2.3 Work experience and vacation work

Neill and Mulholland (2003) suggest that traditional educational programmes are failing to address the needs of both students and industry and contend that students should develop competencies and the aptitude for construction through undertaking work in a real economic setting.

Vacation work refers to work undertaken by students during vacations, and Mthunjwa (2022) cites the following as the benefits of vacation work: students can establish whether their career field of choice is the right one by undergoing real-time work experience, which may further solidify their choice of study, and the opportunity for new experiences and encounters. Industry 4.0 technologies being an example of the latter.

2.4 Adopting Industry 4.0

Although the construction industry is one of the slowest industries to adopt to Industry 4.0 concepts, globally, many firms have initiated the transition. According to Phuyal, Bista and Bista (2020), migrating to Industry 4.0 is a gradual process and takes time to upgrade operations from the existing system. Physical infrastructure, adoption of new technologies, familiarity therewith, and the availability of technical expertise are necessary for such upgrades.

The World Economic Forum (2018) contends that for the construction industry to remain relevant in a Construction 4.0 environment, firms should: attract new talent and develop capacity in terms of the required skills; integrate and collaborate across the construction industry's value chain; adopt advanced technologies at scale, and maximise the use of data and digital models throughout processes.

2.5 Industry 4.0 skills

The workforce skills needed in the construction industry are evolving due to Industry 4.0. According to Emerald Publishing (2022), Construction 4.0 emerged as a concept to drive improvement of the overall quality of the workforce capacity involving professional, technical vocational, and education and training addressing skills, competency, and competence.

Autodesk and Chartered Institute of Building (2018) state that the current skills gap is a pressing issue that must be addressed, and that there is a need to evolve qualifications, courses, and apprenticeship programmes to include digital skills and introduce more digital training programmes on site.

2.5 Integrating Industry 4.0 into Construction Management curricula

Integrating Industry 4.0, or rather its technology into construction management curricula is not a new idea. According to the Construction Industry Training Board (CITB) (2018), Dudley College of Technology has built a Centre for Advanced Building Technologies. The curriculum focuses on using digital technologies delivering learning across disciplines such as building services engineering, civil engineering, construction, design and BIM, and environmental technologies.

Abbas, Din and Farooqui (2016) contend that the onus is on universities to introduce IT tools into construction management curricula, and that one such tool that appears promising is BIM.

3. Research

3.1 Research Method and Sample Stratum

The study entailed a self-administered online questionnaire survey. The sample strata for the research study were limited to Nelson Mandela University BSc (Honours) (Construction Management) Alumni from 2019 to 2021. The questionnaire consisted of twenty-seven questions; thirteen closed ended question, and eight of the close ended questions were Likert scale type questions, four were open-ended questions, four multiple choice questions and six were demographics related. The responses to the open-ended questions are not reported on. 19 Responses were included in the analysis of the data, which entailed the computation of frequencies, and a measure of central tendency in the form of a mean score (MS), which equates to a response rate of 45.2 %.

3.2 Results

Table 1 indicates the degree of familiarity which respondents have regarding Industry 4.0 concepts and technologies, and a MS ranging between 1.00 and 5.00. It is notable that both MSs are above the midpoint of 3.00, which indicates that respondents are moderately familiar to extremely familiar with Industry 4.0 concepts and technologies. Both MSs are > 3.40 to ≤ 4.20, which indicates that the respondents' self-rating of their familiarity of Industry 4.0 and its technologies is between familiar to more than familiar / more than familiar.

Table 1. Respondents' self-rating of their familiarity of Industry 4.0 and its technologies

Aspect	Response (%)						MS	Rank
	Unsure	Not at all familiar …Extremely familiar						
		1	2	3	4	5		
Industry 4.0 concepts	0.0	5.3	0.0	10.5	52.6	31.6	4.05	1
Industry 4.0 technologies	5.3	0.0	5.3	31.6	36.8	21.1	3.63	2

Respondents were required to indicate their level of exposure to Industry 4.0 technologies on a scale of not at all exposed to extremely exposed. The resultant MS of 2.63 is > 2.60 to ≤ 3.40, which indicates that respondents maintain their level of exposure to Industry 4.0 technologies is between less than exposed to exposed / exposed.

In terms of Industry 4.0 technologies respondents were exposed to in university, BIM (30.2%) predominates, followed jointly by drones and site automation (14.0%), and then jointly by the IoT and prefabrication and digital fabrication (11.6%) (Table 2). It is notable that three further technologies were identified by less than 10% of respondents.

Table 2. Industry 4.0 technologies respondents were exposed to in university

Technology	Yes (%)
BIM	30.2
Drones	14.0
Site automation	14.0
IoT	11.6
Prefabrication and digital fabrication	11.6
Social and mobile computing	9.3
Augmented / Virtual reality	7.0
Other: Construction cost and planning software	2.3
Collision of the digital & physical world	0.0
Machine learning and artificial intelligence	0.0

Table 3 indicates the relevance of Industry 4.0 concepts and technologies to construction management undergraduate and postgraduate qualifications in terms of percentage responses to a scale of 1 (not at all relevant) to 5 (extremely relevant), and a MS ranging between 1.00 and 5.00. It is notable that both MSs are > 4.20 ≤ 5.00, which indicates that the relevance of Industry 4.0 concepts and technologies to construction management undergraduate and postgraduate qualifications is between more than relevant to extremely relevant / extremely relevant.

Table 3. Respondents' rating of the relevance of Industry 4.0 concepts and technologies to construction management undergraduate and postgraduate qualifications

Qualification	Response (%)						MS	Rank
	Unsure	Not at all relevant …Extremely relevant						
		1	2	3	4	5		
Undergraduate	0.0	0.0	0.0	10.5	42.1	47.4	4.37	1
Postgraduate	0.0	5.0	0.0	5.0	45.0	45.0	4.25	2

57.9% of respondents participated in vacation work during their time of study, and 42.1% did not. The mean period of such work is 2.97 months.

Respondents were required to indicate the importance of vacation work for students on a scale of 1 (not at all important) to 5 (extremely important). The resultant MS of 4.79 is > 4.20 to ≤ 5.00, which indicates that respondents maintain vacation work is between more than important to extremely / extremely important.

In terms of the frequency at which respondents encountered Industry 4.0 technologies during vacation work on a scale of never to every time, the resultant MS of 2.00 is > 1.80 ≤ 2.60, which indicates that respondents never to rarely / rarely encountered Industry 4.0 technologies during vacation work.

Respondents were required to indicate the frequency at which they engage in personal reading on a scale of never to constantly. The resultant MS of 3.16 is > 2.60 ≤ 3.40, which indicates that respondents rarely to sometimes / sometimes engage in personal reading to remain abreast of recent news and technologies relevant to their field of study / career path.

Furthermore, in terms of a related issue, respondents were required to indicate the construction related magazines and newsletters they subscribe to (Table 4). Only three magazines and newsletters were subscribed to by more than 20.0% of respondents, and four by more that 10.0% of respondents. Construction Manager, BIM plus, and Construction news predominate. The Construction Manager is the Chartered Institute of Building's (CIOB's) online newsletter, and it should be noted that Construction Management students are encouraged to join the CIOB. The South African Council for the Project and Construction Management Professions (SACPCMP) is the statutory council responsible for accrediting Construction Management programmes, and they publish their magazine ShapeShifter quarterly.

Table 4. Construction-related magazines and newsletters respondents subscribe to

Technology	Yes (%)
Construction Manager	25.0
BIM plus	21.4
Construction news	21.4
Construction News Magazine	14.3
Global Construction Review	7.1
Construction Insight Magazine	3.6
Residential Contractor Magazine	3.6
ShapeShifter	3.6
Buildingtalk	0.0
The Construction Index	0.0

47.4% of respondents are registered with the SACPCMP, 42.1% are not registered. The remaining 10.5% of the respondents include those who have applied for registration and are awaiting feedback and registered with the South African Council for the Property Valuers Professionals.

52.6% of respondents are members of the CIOB, and 47.4% are not members. Zero respondents are members of the Association of Construction Project Managers (ACPM).

In terms of the readiness of respondents' workplaces for the adoption of Industry 4.0 on a scale of 1 (not at all ready) to 5 (extremely ready), the resultant MS of 2.62 is > 2.60 to ≤ 3.40, which indicates that their workplaces are between less than ready to ready / ready for the adoption of Industry 4.0.

Respondents were required to indicate the extent to which their workplaces have adopted Industry 4.0 on a scale of not at all, pre-adoption, adoption, and post-adoption. The resultant MS of 1.56 is > 1.00 ≤ 1.75, which indicates the extent to which their workplaces have adopted Industry 4.0 is between not at all to pre-adoption.

Table 5 indicates the extent to which professionals need to acquire knowledge / skills to be successful in an Industry 4.0 workplace according to the respondents. It is notable that no knowledge / skill attracted more than 14.0% response, and that the general level of response is very low.

Table 5. Extent to which professionals need to acquire knowledge and skills to be successful in an Industry 4.0 workplace

Knowledge / Skill	Yes (%)
Problem solving	14.0
Computer programming, design, and knowledge of software tools	13.1
Data analytics	13.1
Digital competence	13.1
Information processing	12.2
Online communication	10.3
Decision making	9.4
Cyber security	7.5
Human machine communication	7.5

Table 6 indicates the Industry 4.0 technologies respondents have used in their workplace. It is notable that 8 / 19 (42.1%) responded 'none', 1 / 19 (5.3%) 'N/A', and 1 / 19 (5.3%) 'not sure'. 9 / 19 (47.4%) of the respondents have used Industry 4.0 technologies such as Additive Manufacturing, BIM, Drones, IoT, GPS land surveying tool, laser measuring devices, and prefabrication.

Table 6. Industry 4.0 technologies respondents have used in their workplace

R No.	Industry 4.0 technology
1	None
2	BIM
3	None
4	None
5	IoT
6	Not sure
7	Drone
8	GPS land surveying tool
9	Drones and laser measuring devices

10	None
11	N/A
12	None
13	Additive Manufacturing
14	Drones for mapping and surveying
15	None
16	None
17	Prefabrication and drones
18	IoT
19	None

15.8% of the respondents indicated that they had undergone Industry 4.0 related training in their workplace, and 84.2% had not. Respondent No. 5 cited 'BIM', No. 8 cited 'Using GPS Land surveying instruments', and No. 18 cited 'employee training and IoT privacy policy', and 'uniform cyber security standards and guidelines'.

Table 7 indicates the various Industry 4.0 skills and technologies respondents advocate that should be integrated into construction management curricula. 57. 9% opine that BIM should be integrated into construction management curricula, followed by drone technology (26.3%).

Other skills and technologies with a response of less than 20% include IoT, digitisation, VR, AR, site automation, machine learning, quality assurance technology, big data, additive manufacturing, autonomous vehicles, robotics, cloud computing, AutoCAD, Cyber security, AI, 3D Printing, along with data analytics, critical thinking and analysis, coding, online communication, computer programming and in-depth lessons on Microsoft Project, and in-depth lessons on quantity surveying software.

Table 7. Industry 4.0 skills and technologies which should be integrated into construction management curricula

R No.	Industry 4.0 technology / skill
1	BIM, IoT, site automation, drones, and 3D printing
2	BIM, IoT, and drone technology
3	Digitisation
4	BIM
5	BIM, VR, and drones
6	Site automation, and machine learning
7	Critical thinking and analysis
8	Quality assurance technology operated by internal management officer
9	BIM, IoT, and coding
10	Online communication, data analysis, IoT, and big data
11	Drones and computer programming
12	Drone technology and BIM
13	Additive Manufacturing
14	BIM
15	BIM
16	Drones and autonomous vehicles, AR, BIM, cloud computing, and robotics
17	BIM, AutoCAD, in depth lessons on Microsoft Project, and in-depth lessons on Quantity Surveying Software
18	Cyber security, AI, AR, and data analytics
19	BIM

Table 8 indicates the extent to which modules require the integration of Industry 4.0. Construction Management attracted the highest level of response (16.0%), followed by Project Management at 14.0%, Building Science (Environment and Services, Materials and Methods, and Structures) at 12.0%, Professional Practice for Construction Management, Production Analysis and Construction Surveying at 8%, and Basic Surveying and Computing Fundamentals with the lowest rating of 5 %.

Table 8. Extent to which modules require the integration of Industry 4.0

Technology	Yes (%)
Construction Management	16.0
Project Management	14.0

Building Science (Environment and Services)	12.0
Building Science (Structures)	12.0
Building Science (Materials and Methods)	12.0
Professional Practice for Construction Management	8.0
Production Analysis	8.0
Construction Surveying	8.0
Basic Surveying	5.0
Computing Fundamentals	5.0

4. Discussion

The respondents'self-rating of their familiarity of Industry 4.0 and its technologies is between familiar to more than familiar / more than familiar (MSs are > 3.40 to ≤ 4.20), despite maintaining their level of exposure to Industry 4.0 technologies is between less than exposed to exposed / exposed (MS is > 2.60 to ≤ 3.40). The latter is reinforced by the exposure of respondents to Industry 4.0 technologies in university, in which case BIM (30.2%) predominates, followed jointly by drones and site automation (14.0%), and then jointly by the IoT and prefabrication and digital fabrication (11.6%). It is notable that three further technologies were identified by less than 10% of respondents, and a further two by zero respondents. Effectively, the respondents indicated that their workplaces are between less than ready to ready / ready (MS is > 2.60 to ≤ 3.40) for the adoption of Industry 4.0. The latter finding is reinforced by the extent to which the respondents' workplaces have adopted Industry 4.0, which is between not at all to pre-adoption (MS is > 1.00 ≤ 1.75). Furthermore, 15.8% of respondents indicated that they had undergone Industry 4.0-related training in their workplace, 42.1% of the respondents indicated that they had not used any Industry 4.0 technologies in their workplace,

The respondents' rating of the relevance of Industry 4.0 concepts and technologies to construction management undergraduate and postgraduate qualifications, which is between more than relevant to extremely relevant / extremely relevant (MSs are > 4.20 ≤ 5.00) indicates awareness on the part of the respondents with respect to the role of Industry 4.0 in construction.

A notable finding arising from the study is that although respondents maintain vacation work is between more than important to extremely / extremely important (MS is > 4.20 to ≤ 5.00), only 57.9% responded that they participated in vacation work during their studies, the mean period being 2.97 months. It appears that the transition from students to graduates engendered a realisation on their part of the importance of vacation work. The vacation work-related findings are further reinforced by the finding that respondents rarely to sometimes / sometimes (MS is > 2.60 ≤ 3.40) engage in personal reading to remain abreast of recent news and technologies relevant to their field of study / career path. The latter finding is further reinforced by the findings that only three magazines and newsletters were subscribed to by > 20.0% ≤ 25.0% of respondents, and four by > 10.0% ≤ 25.0% of respondents. Vacation work and university studies are mutually reinforcing, as vacation work enables students to relate their university studies to their pending vocation, and vacation work assists their university studies in terms of understanding the theory and the development of skills in the university environment.

47.4% of respondents are registered with the SACPCMP, and 52.6% of respondents are members of the CIOB, which in general indicates a low level of commitment to professionalism.

In terms of integrating Industry 4.0 skills and technologies into construction management curricula, 57. 9% opine that BIM should be, followed by drone technology (26.3%). It is notable that the other skills and technologies were identified by less than 20% of respondents. Furthermore, in terms of the extent to which ten modules require the integration of Industry 4.0, Construction Management attracted the highest level of response (16.0%), followed by Project Management (14.0%), and each of the three Building Science modules Environment and Services, Structures, and Materials and Methods (12.0). The remaining five modules were identified by between 8.0% and 5.0%.

5. Conclusions

Graduates are aware and have been somewhat exposed to Industry 4.0, but they do not have much knowledge with respect to it, and how beneficial it could be to them as professionals, and their workplace.

Although the construction industry might be somewhat ready for Industry 4.0, it has not really made any drastic changes with regards to adopting Industry 4.0 technologies.

BIM is one of the construction Industry 4.0 technologies which graduates are more familiar with, and it is also being integrated into Construction Management curricula more than other technologies.

Universities need to integrate the range of Industry 4.0 technologies into their curricula, and the construction industry needs to make progress in terms of adopting Industry 4.0 concepts and technologies so that they can benefit from such adoption.

6. Recommendations

Innovative ways need to be evolved in terms of increasing the level of awareness regarding Industry 4.0 in both universities and the construction industry. The Construction Industry Development Board, statutory councils, and professional and employer associations have a major role to play, and should provide guidelines for the industry.

Construction Management curricula need to be restructured and integrated with the relevant construction Industry 4.0 skills and technologies.

Vacation work should be a requirement, or universities should introduce a work experience programme in partnership with the construction industry, which will enable students to apply what they learn in the lecture environment at work and experience the workplace environment.

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Exploring the Challenges of Attaining the Required Competencies for Sustainable Construction Projects: A Case of Built Environment Professionals in South Africa

Bontle Beauty Chabaesele[1] and Justus Ngala Agumba[2]

[1] Tshwane University of Technology, Pretoria, Gauteng, South Africa
[2] Tshwane University of Technology, Pretoria, Gauteng, South Africa
bontlebeauty@gmail.com

Abstract
The purpose of this study was to explore the challenges that the built environment professionals encounter in pursuit of attaining the required competencies to enable them to successfully execute sustainable construction projects (SCPs) in the South African construction industry. The dearth of research in this area motivated the researchers to explore the aim of this study. Evidence in the previous literature suggest the focus has been on the challenges encountered in the construction industry in adopting sustainable construction methods, of which lack of competencies for SCPs has been a key factor. To achieve the purpose of this study, constructivism philosophy was adopted and data was collected using semi-structured interviews with 21 built environment professionals, who were purposively sampled. Atlas.ti version 7 was used to organize the data and interpret the themes and the sub-themes. Data saturation was achieved after the 21st interview was analyzed. The findings on the challenges encountered by the built environment professionals in acquiring the competencies for sustainable construction projects were: limited awareness of the required competencies, lack of finance, lack of training/education, no or little experience (technical skills) and corruption. The recommendations to the construction industry are that: awareness of the competencies required should be improved, financial support is required, motivate their professionals to go for training and improve their technical skills. Furthermore, any form of corruption relating to who should be upskilled regarding sustainable construction projects should be avoided entirely in the construction industry. These recommendations will ensure to some extent that the professionals' competencies are improved in order for them to deliver SCPs satisfactorily to the clients.

Keywords:
Built environment, challenges, construction, competencies, professionals, sustainable.

1. Introduction

Construction industry is an important sector that plays a vital role in a nation's economic growth. The construction industry is known as an investment-oriented sector, which receives immense attention from the government. The industry is responsible for sustainable development of facilities such as healthcare, education facilities, workplaces i.e. offices, homes, shopping centres, transport and, religious and recreational facilities. According to Berk & Bicen (2017) the importance of the construction industry renders the prosperity of any nation. Seely (2016) further asserted that this sector creates numerous job opportunities for unskilled, semi-skilled, and skilled workforce. To support the aforementioned assertions. In South Africa StatsSA, (2021) indicated that the construction industry employed around 476 185 persons in the formal sector at the end of second quarter of 2021. Furthermore, the construction industry contributed R83 billion towards the country's gross domestic product (GDP) (Construction Industry Development Board, (CIDB, 2021).

Despite the importance of construction industry in the economy of South Africa, it is faced with numerous challenges. Renault, Agumba & Ansary (2018) indicated one of the challenges was poor delivery of construction projects. Which according to Agumba & Haupt (2018) was caused by poor health and safety performance. Apart from the poor performance, the construction activities affect the environment throughout the life cycle of the development, (Ametepey et al., 2015). It can be inferred that the construction industry wreaks havoc on the delicate environment due to its negative effects. Buildings account for around 40 percent of the total carbon dioxide (CO_2) emissions (de Lassio et al., 2016). In addition, the impacts of construction activities across the globe accounts for 25 percent of water use, 30 percent of raw materials use, and 42 percent of total energy consumption, 25 percent of waste generation, 25 percent of timber and 70 percent of electricity consumption (Serpell et al., 2013; Zolfani et al., 2018; Holowka, 2007). As a result, it is clear that steps must be taken to ensure the built environment and construction activities are more sustainable, bearing in mind the three pillars of sustainable development. To embrace the three pillars of sustainable development in the life cycle of a construction project i.e. economic, social and environmental the construction industry professionals must be competent. However, previous studies of, Ametepey et al., (2015), Häkkinen & Belloni (2011) and Aghimien et al.,, (2018) have indicated the challenges that are experienced in the adoption of sustainable construction practices of which one of the factors according to Aghimien et al., (2018) is the lack of competencies of the workers involved in SCPs. Few of the previous studies have tried to identify some of the challenges inhibiting the acquiring of the required SCPs competencies. The identified challenges were lack of training (Higham & Thomson, 2015; Idris et al., 2015). Expensive training and lack of time for training, (Bwanga, 2020) Furthermore, Greenblat (2008) indicated a deficient education and training system was also an obstacle. Furthermore, these challenges were generic and not tailored for specific stakeholders in the construction industry. Therefore, the dearth of research to identify the challenges the built environment professionals' encounter in attaining competencies to enable them to execute sustainable construction projects successfully is evident.

This study is therefore aimed at exploring the challenges experienced by the built environment professionals in South Africa in attaining the required competencies for sustainable construction projects (SCPs).

2. Materials and Methods

Constructivist philosophy was adopted for this research to determine the purpose of the study. The essence of a constructive philosophy of research is to develop theories rather than testing them. The aim of this study was to identify the challenges faced by built environment professionals in attaining the required competencies for SCPs in South Africa. Purposive sampling method which is a non-probability method was used to sample the respondents. In order for the respondents to be included in the study a number of factors were considered: The respondents were supposed to chiefly undertake their work/business in Gauteng and North-West provinces of South Africa, they should have experience in SCPs and registered with a recognized profession council/body in South Africa. In order to achieve credible sample size for semi-structured interviews a minimum sample size of between 5 and 25 is required according (Saunders et al., 2016). This is also supported in the study by Tshele & Agumba, (2014).

Therefore, a total number of 21 built environment professionals participated in the interviews, in which semi-structured interview was used and the interviews were recorded. The interviews took approximately 30mins. The interviews were conducted telephonically due to the lockdown rules and regulation. The data was managed using the Atlas.ti version 7. The thematic analysis was done to attain the themes and sub-themes of the challenges experienced. The data saturation was attained after the 21 interviews were analyzed. The trustworthiness i.e. validity and reliability of the research was achieved by ensuring it was credible, dependable, transferable, hence conforming that the study achieved the requirements that is was credible, dependable and transferable.

3. Results

3.1 Socio-demographics data of the respondents

Table 1 shows the socio-demographic characteristics of the participants. Fifteen (71.4%) of the participants have a BSc Degree as their highest academic qualification, five (23.8%) have a Master's degree while only one (4.8%) participant had a diploma. Nine of these degrees include engineering, five from project and construction management, four quantity surveying, three from architecture. Seven (33%) of the study participants were registered with the Engineering Council of South Africa (ECSA); seven (33%) with the South African Council for the Project and Construction Management Professions (SACPCMP), two (9.5%) with South African Council of Architectural Profession (SACAP), one (4.8%) with the South African Council for the Landscape Architectural Professions (SACLAP) and four (19%) with The South African Council for the Quantity Surveying Profession (SACQSP). Seventeen (81%) of participants have over ten years of experience in the construction industry, while three (14.3%) participants have more than ten years of experience in sustainable construction projects. Only five (23.8%) participants have been involved in over ten sustainable development projects while others have been involved in less than ten of such projects. Concerning the size of company worked for, fourteen (66.7%) participants work for small companies, two (9.5%) work for medium sized companies while 5 (23.8%) identified working with big companies.

Table1. Socio-demographic characteristics of the participants

Participants' Characteristics		N=21 (100%)
Highest Academic Qualification	Diploma	1 (4.8)
	BSc	15 (71.4)
	MSc	5(23.8)
Professional Council	SACPCMP	7 (33)
	SACQSP	4 (19)
	ECSA	7 (33)
	SACAP	2 (9.5)
	SACLAP	1 (4.8)
Years of Experience in the construction industry	0-10 Years	4 (19)
	More than 10 Years	17 (81)
Years of experience sustainable development projects	0-5 Years	9 (42.9)
	6-10 Years	9 (42.9)
	More than 10 Years	3 (14.3)
Company size participants worked for	Large	5 (23.8)
	Medium	2 (9.5)
	Small	14 (66.7)
Number of sustainable construction projects involved in	1-10	15 (71.4)
	More than 10	5 (23.8)

Source: Field data, 2021

3.2 Results

Figure 1 indicates the main and the sub-themes of challenges that were established from the Atlas.ti version 7. The participants identified the challenges the industry is facing with regards in empowering the professionals in the built environment with knowledge, skills and the good attitude to undertake sustainable construction projects. The challenges identified by the participants are summarized under the following main themes: Limited awareness of sustainable construction projects competencies, lack of training or education on sustainable construction projects, (iii) corruption, and lack of finance.

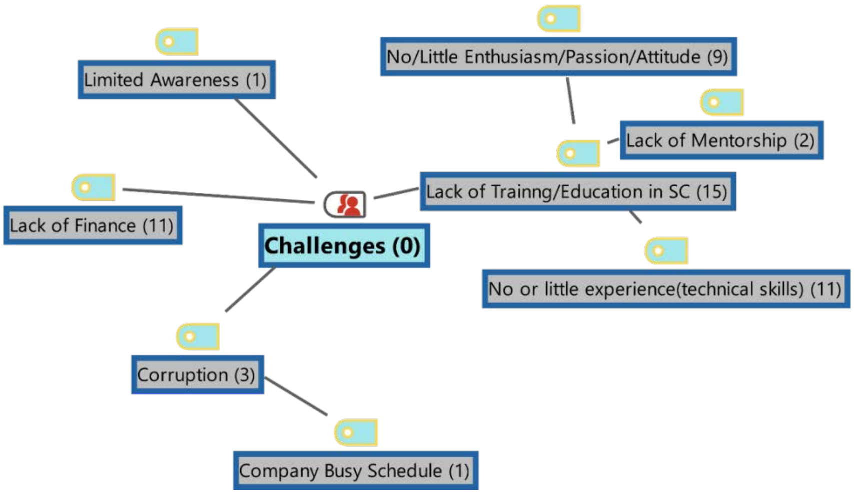

Fig.1 Challenges encountered, Source: Atlas.ti 7

(i) Limited awareness of the competencies required for SCPs

Participants identified that many built professionals do not know about sustainable construction projects and what it entails. Limited awareness of SCPs is a great challenge to undertaking such projects because the knowledge of the concept and process of executing SC projects is missing. One participant said *"...people are not too familiar with sustainability when it comes to these projects, so I'd say it's just a lack of awareness from the teams' perspective, (P21)"*. While discussing on the concept of SCPs, another participant mentioned, *"Not a lot of people really understand the whole concept of sustainable building (P16)*", and that could be with the fact that *"it's still a very new concept, (P14)"*.

(ii) **Lack of training/education to acquire competencies in SCPs**

Participants identified limited training opportunities, highlighting that there are not so many training programs available to the built environment professionals on sustainable construction. One of the participants particularly emphasised that *"There's not a lot of education programs that you can study, ones that focuses on sustainable construction (P4)"*. Lack of good technical trainings available to the professionals is a major challenge in understanding sustainable construction. This was articulated by the participants, one of them said *"We are totally under skilled in this country, in terms of good technical training (P24)"*, a critical point that was rephrased by another participant saying *"Professionals in South Africa find it increasingly difficult to get equipped with knowledge for sustainable construction (P5)"*.

Some of the participants however, highlighted the lack of practical trainings and learning on the job as a setback in the transfer of knowledge from one professional to another. Participants expressed this using different words such as *"Lack of practical training (P20)", "Lack of Mentoring (P2)", and "Lack of apprenticeships (P20)"*; all of these expressing the need for mentoring for the built environment professionals to be adequately equipped for sustainable construction. The following subthemes emanated from described this theme.

No or little experience (technical skills): The lack of highly skilled workers with knowledge of sustainable construction was mentioned by the participants as challenging to the sector. Many of the built environment professionals were reported to *"lack experience (P5)"*. The challenge in the skillset of the professionals made the participants believe that there is *"lack of professionalism (P8)"* and that *"there's not a lot of skills out there when it comes to sustainability P14)"* which results in problems such as having *"...incompetent engineers (P20)"*.

No/ little enthusiasm/ passion/ attitude: While describing the attitude towards sustainable construction projects, the participants strongly emphasised that built environment professionals and organizations have a negative attitude toward it, which is demonstrated by their diminished interests as participants have rightly said- *"Lack of interest (P11)", "the attitude is not right there towards it (P16)"*. This lack of enthusiasm by built environment professionals could be a result of the absence of regulation attached to sustainability of projects as one participant had mentioned - *"it's not normally a requirement that you have all these qualifications….that's why most professional* *team members don't invest a lot of time and money into obtaining these skill sets of sustainability (P21)".* Organizations expressed their negative attitudes by not investing resources to training their staff on it. *"Companies do not have the time and lack of investment in training.*

Lack of mentorship: Participants mentioned a lack of mentorship or coaching from built environment professionals that are competent for SCPs to less experienced professionals as another challenge and further said that this mentorship can be achieved by *"learning from other professionals (P5)* and *"equipping each other internally (P7)"*

(iii) Corruption in providing training on competencies for SCPs

System failure (corruption) is another big issue in the construction sector that discourages professionals from investing in training. *"Corruption is problem….Favoritism, they just take somebody that has political connections and then put them in their system (P10)".*

(iv) Lack of finance for training on competencies for SCPs

The other challenge identified by the participants is the lack of finance. Financing professional trainings are quite expensive. While a participant stated that *"It costs money. It is in general more expensive, (P24)"*, another participant decided to take the challenge to the organizational level saying, *"Lack of money, companies don't want to spend money on training because it is too expensive, (P8)".*

4. Discussion

The results of the socio-economic demographics established that the built environment professionals who were interviewed had the relevant qualification and professional registration in the built environment. Furthermore, they had participated in a number of sustainable construction projects which justifies, that they could identify the challenges inhibiting them from acquiring the required competencies for SCPs execution in South Africa.

Based on the aforementioned sentiments the challenges that were identified by these professionals were: lack of awareness of the competencies required for SCPs. It can be noted that this challenge is critical as lack of awareness of the competencies required could cripple the delivery of any project not to mention SCPs. The finding is in line with previous authors such as William & Dair (2007), who established that the main impediments to the delivery of sustainable structures, are a lack of knowledge, understanding, and information. Furthermore, Whang and Kim (2015) asserted that built environment professionals' awareness of sustainability, as well as their performance, is critical to the successful implementation of SC. Alabi (2012) discovered that construction participants had a limited awareness of the notion of sustainability. Likewise, Aghimien, Aigbavboa, Oke, & Musenga (2018) discovered that the second most important barrier to SC is a lack of sustainability awareness and knowledge. According to Adejumo & Adejumo (2014) sustainability is a problem that affects all aspects of life, and there is a significant need to raise as much awareness about it as possible.

Lack of training/education to acquire competencies on SCPs was also identified as an impediment in acquiring the relevant competencies for SCPs. This was affected by the lack of mentorship in sustainable construction projects, the professionals having, no/ little enthusiasm/ passion/ attitude towards training. To overcome this challenge Osuizugbo et al. (2020) asserted that the government should play a key role in ensuring that sustainable construction is embraced in the construction industry. Bowen et al.'s (2012) finding suggested that professional ethics should be strengthened in course syllabi and reinforced through career development seminars. Therefore, to this challenge career development through seminars is critical. Furthermore, limited to no experience relating to technical skills in SCPs in South Africa also contributed to lack of training/education. In support of the findings of lack of highly qualified skilled workers, Durdyev et al. (2018) said that most construction professionals are ignorant or untrained in SC techniques. The importance of training cannot be understated, Kazaz & Ackara, (2015) suggested that skilled professionals have the greatest influence on labour productivity and are thus considered as a real representation of the performance and success of building operations. Skilled workers in the construction business are mostly tradespeople who have obtained education and training, which adds substantial economic value to the activity at hand (Jarkas et al., 2012).

From the foregoing, training is critical to ensure the professionals become competent in their area of speciality (Oladotun & Edosa, 2017).

Corruption was also identified as an inhibiting factor for acquiring competencies for SCPs. It can be suggested from the sub-theme, when the company undertaking sustainable construction projects are having a busy schedule corruption could inhibit the training of its professionals. Hussein (2005) stated that bribes are given in the construction business to win lucrative contracts and tenders. This can lead to poor performance of delivering construction projects. Finally, the lack of finance for training in SCPs was also established as an impediment to acquiring the required competencies among the built environment professionals in South Africa. It can be suggested that having finance is critical in ensuring the achievement of training or other delivery objectives of a project. To buttress this point Osuizugbo et al. (2020) indicated the importance of financial support to train and educate built environment professionals about SC.

5. Conclusions

In conclusion this research has identified the challenges that the built environment professionals encounter in the endeavor to attain the required competencies for sustainable construction projects. These challenges are: lack of awareness of competencies required for SCPs, corruption in providing training for SCPs, lack of finance and lack of training/education in SCPs. The recommendations to the construction industry in line with these findings are: the awareness of the competencies required for SCPs should be improved within the professional councils, financial support should be provided, the councils should motivate their professionals to go for training and improve their technical skills in SCPs. This can also be achieved using mentorship programs. Furthermore, any form of corruption relating to who should be upskilled regarding sustainable construction projects should be avoided entirely in the construction industry. Finally, a country wide quantitative research is recommended to validate these challenges in order to generalize the findings.

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Offshore Construction Progress Management by Indoor GIS Positioning: Post-COVID-19 New Normal

Kai-Chi Ying[1] ,Chun-Pong Chau[2], Xin Chen[3] and Chuen-Yu Chan[4]

[1] Location Ai Technology Limited, Hong Kong
[2] School of Professional Education and Executive Development, The Hong Kong Polytechnic University – HKCC, Hong Kong
3 Department of Electronic Engineering, The Hong Kong Polytechnic University
4 Maphive Technology Limited, Hong Kong
thomasying@locationaitech.com

Abstract
Travel restrictions have been imposed among countries since the outbreak of the COVID-19 pandemic. Time delays, budget issues, and poor-quality control in construction projects due to the pandemic have severely affected the construction industry. To reduce the influence of the pandemic, the paper introduces an offshore construction site progress management system with a real case study. With the integration of indoor location-based service technology and image processing method, site superintendents (architect, project director, site manager, engineer) can monitor the site progress easily and pinpoint defects for further investigation and measurement. The visualization of site images together with BIM provides a digital twin platform that can help senior management quickly review the site progress, perform quality checks, and resolve discrepancies in early phases. Positioning of workers and equipment with the adoption of digital maps is a further step in sustainable management. The proposed integration provides a new concept for construction site management during a pandemic and supports the post-COVID-19 new normal in the construction industry.

Keywords
Wi-Fi Fingerprint, Indoor Positioning System (IPS), Location Based Service (LBS), offshore management, Geographic Information System (GIS)

1. Introduction
Since COVID-19 emerged at the end of 2019, it has caused immeasurable economic losses and political shock throughout the world, affecting not only the global economy but also the construction sector. Time delays, increased construction costs, limited human resources, supply chain delays, safety considerations, health restrictions, and regulation compliance are not new, but they have become management risks and issues due to the pandemic (Libahim F.S et al., 2020). The construction industry is a labor-intensive industry where numerous people from different sectors work together in a site. Since the pandemic outbreak, the construction environment has changed; everyone needs to maintain a safe distance, wear masks, and follow health restrictions to prevent inflection. Shibanit A et al. (2020) interviewed project managers from the construction industry in the UK and found that delays due to lockdowns, safety measures, and social distancing pose major challenges in construction projects. The majority of participants are unfamiliar with the “new normal” working practices, such as maintaining a safe distance and having only one worker inside a freight elevator at a time. The pandemic has led to time delays, budget issues, and poor quality in construction projects.

A common practice before the pandemic was for project engineers, architects, and senior management to visit and inspect the site progress, monitor project quality in person, and even cross-border business travel, which entailed acceptable traveling time and costs for which they were reimbursed. Since the pandemic, onsite inspections and quality checks have become complicated and costly because of long quarantine requirements, high travel costs, costly PCR tests, travel restrictions, and risk of infection during travel. According to Ogunnusi M. et al. (2020), because of the time and cost issues of quarantine during cross-border travel, site supervision and onsite inspection in foreign countries is not feasible, affecting the quality control, site progress, and management plan. Increasing the use of technological tools, virtual design, and offshore site monitoring and inspection are part of the new normal to tackle and reduce risk and loss due to lockdowns and prepare for the next pandemic.

Building Information Modeling (BIM) provides an efficient platform for design and construction. However, Wang W.S. et al. (2021) explained that it might not draw much attention in China because of its complex application, lack of knowledge, high operation cost in both hardware and software, and incompatibility in all situations. A balance needs to be achieved between complicated BIM application and site monitoring.

During the pandemic, the construction industry faced common problems, such as how to reduce time delays, extra travel costs, quality control, and associated difficulties. These problems have been minimized with the successful application of indoor Location-Based Service (LBS) technology and its related computational services. By integrating indoor Geographic Information System (GIS) and positioning technology, this research introduces a new idea in site progress monitoring and site supervision through a real case study, and it concludes with the adoption of positioning technology to introduce the sustainable management concept.

2. Location Based Service (LBS) application in construction industry

LBS is a combination of wireless communication, Global Positioning System (GPS), and GIS technologies to solve common engineering problems in the construction industry. Material logistic tracking, worker positioning, GPS, and drone application are LBS applications. Land surveying is a key step in construction projects, and accurate setting-out and leveling are basic requirements in traditional construction projects, serving as key elements in the beginning of the construction phase. In modern construction, an as-built survey is conducted in the final phase of the project and input into the BIM for record purposes. The positioning records provide GIS reference for further addition and alteration and renovation works.

With the development of BIM applications, GIS application is not new in the construction industry. Technicians input accurate GIS data such as latitude, longitude, and altitude for every structural element and field information into the BIM platform. 3D walkthrough, animation, sun-path, and integration with the time zone of cities and countries can be easily identified by computer programs (Adb A.M. et al., 2020; Song Y.G. et al., 2017). Such data are then stored in computer software such as BIM for submission and reference.

In the whole project life cycle, GIS helps in accurately pinpointing the point of interest (POI) and integrate it with the BIM. Wu H. et al (2013) applied LBS to establish a collision warning system in a dam construction project, which provided hazard alerts to site workers and guided them to safe assembly points. Erickson and Cerpa (2010) applied BIM in facility management, using sensors and a computer platform to detect the temperature emission of a Heating, Ventilation, and Air Conditioning (HVAC) system in a project, and they recorded a 20% reduction in energy consumption. Antonino M. et al. (2019) integrated an asset information model for facility management with the BIM model by locating sensors in buildings. The sensors provided real-time GIS-based data to the system, and the system activated work orders and tasks to control the HVAC system.

2.1 Geographic information system data capturing

Many products in the market collect accurate GIS data for the construction industry. In traditional land surveys, all kinds of equipment—from station equipment to drones—provide sufficient GIS-based data.

Depending on the requirement of the project and scope of work, different instruments and equipment provide different accurate levels. For example, a high-density 3D scanner can acquire point cloud data of the site, providing a good quality and measurable digital file with GIS data after significant analysis (noise removal and integration). It provides close-to-millimeter accuracy range data but is costly and time consuming, and it requires large data files and expensive software and hardware.

Images captured by a common digital camera or even a smartphone help generate a fairly accurate construction image database with GIS records. When a worker takes site photos by using a smartphone, the images can show the location information, which is acceptable even though the location accuracy may have a more than 5-meter error. This approach is fast and economical, generating small data files and requiring simple software and hardware. Moreover, it is a simpler extraction of GIS reference of the construction site image when compared with professional equipment. The images are then converted into the as-built GIS format and stored in a database. The accuracy range of the positions is not exact but is acceptable.

2.2 Wi-Fi fingerprinting

Commonly adopted positioning methods nowadays include Bluetooth, Wi-Fi, GPS, magnetic field, iBeacon, ultra-wideband (UWB), and radio frequency identification (RFID). People apply different technologies depending on usage, needs, scenario, and site environment. Some technologies have been applied in the construction industry, such as identification of precast element deliveries by using barcode, RFID, or worker/plant positioning in an area by using mobile GPS. Wi-Fi is suitable for indoor scenarios, whereas GPS is good for outdoor positioning.

GPS or the BeiDou navigation satellite system in construction sites is easy to adopt outdoors. However, access point (AP), iBeacon, or Bluetooth adapters are required because GPS does not work well indoors. Woo S.K. et al. (2011) applied Wi-Fi based indoor positioning for location tracking of workers during the construction of the Guangzhou MTR site, achieving an accuracy level within 5 m, thus being feasible for worker, vehicle, or material tracking. The problem is the time and cost of AP installation. Kan C.W. et al. (2020) introduced the iBeacon and Bluetooth system to detect the motion and positioning of mobile cranes on site. This approach also suffers from time and cost (installation and maintenance) issues in maintaining the good operation of the iBeacon.

An installation-free positioning system that uses Wi-Fi signal is ideal because no infrastructure cost involved. Two criteria must be met for installation-free positioning. First, the site should have sufficient Wi-Fi signal for data transfer. Positioning is calculated by using an algorithm based on the captured Wi-Fi signal in the area. One such positioning technology is Wi-Fi fingerprinting. Similar to human fingerprints, the Wi-Fi signal in a 3D space is unique and distinct because the Wi-Fi signal strength varies in different locations. Collecting the Wi-Fi signal at different locations can easily produce the Wi-Fi fingerprint for the site. The Wi-Fi fingerprinting algorithm is one of the widely used methods in indoor positioning systems (Zhao F. et al., 2017).

A strong GPS signal outdoors and a strong Wi-Fi signal indoors are necessary for seamless positioning connection in construction sites; Wi-Fi can be installed easily when building utilities have yet to be installed or when buildings are still in the renovation phase. Otherwise, Wi-Fi AP is recommended to strengthen the Wi-Fi signal of the site (Woo S.K. et al., 2011).

2.3 Digital map

A second prerequisite is a digital map, which can be understood as the latitude, longitude, and altitude of a location. Some examples of outdoor digital maps are Google Maps (https://www.google.com/maps), Baidu Maps (www.baidu.com), Apple Maps (www.apple.com/maps), Bing Maps (www.bing.com/maps), and OpenStreetMap (www.openstreetmap.org) (Xiao Y., 2020). These may include signal maps and visual maps. Apple (www.apple.com/) is one of the first companies to provide the indoor mapping date format (IMDF) for iOS and requires only a Wi-Fi network to help people navigate indoor venues (Apple, 2022). A city-based digital map is necessary for indoor navigation. Artificial intelligence (AI) algorithms are needed to eliminate digital background-noise data and for integration with computer programming (Huang B.Q. et al, 2019). When using smartphones with iOS for positioning, IMDF should be the standard format; no restrictions have been set for Android.

Through the combination of positioning technology and digital map, all POIs and workers' and plants' location can be pinpointed in the digital map. The data can be shown through a backend server or a mobile app through the help of a computing expert. This issue is a research gap in image demonstrating and positioning in construction management because it needs the contribution of different experts, such as civil engineers who have GIS knowledge, electronic engineers, and computing engineers.

3. Digital Twin in Construction management

The adoption of digital technologies is one of the latest trends in the construction industry. A simple shift from traditional paper submission to digital format is a small step for improvement. Digital construction, including digital manufacturing and automotive, needs technologies such as BIM, system integrity, energy reduction, and GIS. Digital twin is a comprehensive life cycle process that helps improve productivity and accuracy according to the Industry 4.0 concept. A collaborative and autonomous system that improves design and construction processes through information technology and engineering system can be achieved (Maskuriy R. et al., 2019). Integration with geo-information and site images can be compared with digital images provided by BIM (Opoku D.G.J. et al.,2021).

3.1 Offsite progress monitoring

Indoor GIS positioning can support the COVID-19 new normal situation to address problems related to travel restrictions, large time and cost requirements, infection risks during travel, offshore site monitoring, and defect inspection. This approach is an efficient arrangement if the site superintendent (project architect, engineers, managers) virtually visits the sites and addresses inquiries through an online system (offshore inspection). Transparency regarding the site progress and quality performance can be efficiently achieved, and the site superintendent can inspect the project and monitor the site progress visually anytime and anywhere.

A powerful cloud platform stores all the images and defect records with GIS tags, which can help the user trace records. It is convenient and environmentally friendly because essential photos and documents are stored in digital format.

3.2 Defect notification

Project superintendents can instruct site staff remotely to do open-up inspection or mark enquiry for verification to clarify discrepancies, thus reducing the overall time, cost, and travel risk. They can mark down defects through the online platform in case of discrepancies or inconsistencies between structural and building elements. The user can achieve synchronized conversion between 360° images and the BIM.

4. Case Study

A case study was performed on a skyscraper tower project in Tianjin, Mainland China. The COVID-19 pandemic has made it difficult for the project teams of a well-known Hong Kong-based Asian developer to inspect the site and monitor the site progress physically for more than a year while the high-rise building was under renovation. The structural part of the project has since been completed, and the building has been renovated. However, renovation and finishing cannot be completed easily because of lockdowns. Moreover, the project teams cannot inspect the site because of travel restrictions and their unwillingness to undergo quarantine. Thus, the overall renovation schedule has been delayed. The developer remedied the situation and ensured continued progress by using a digital twin. The case study facilitated offshore progress monitoring, provided 360° video and BIM synchronization for inspection, provided defect tracking and reporting, enabled the setup of workflow for defect handling, and facilitated the sharing of cloud-based information to stakeholders.

Fig. 1 shows a 360° image and BIM synchronization on the site. The image on the left-hand side was captured by site staff, and the right-hand side is the BIM model. A digital twin synchronization image can be produced by adjusting the alignment and coordination.

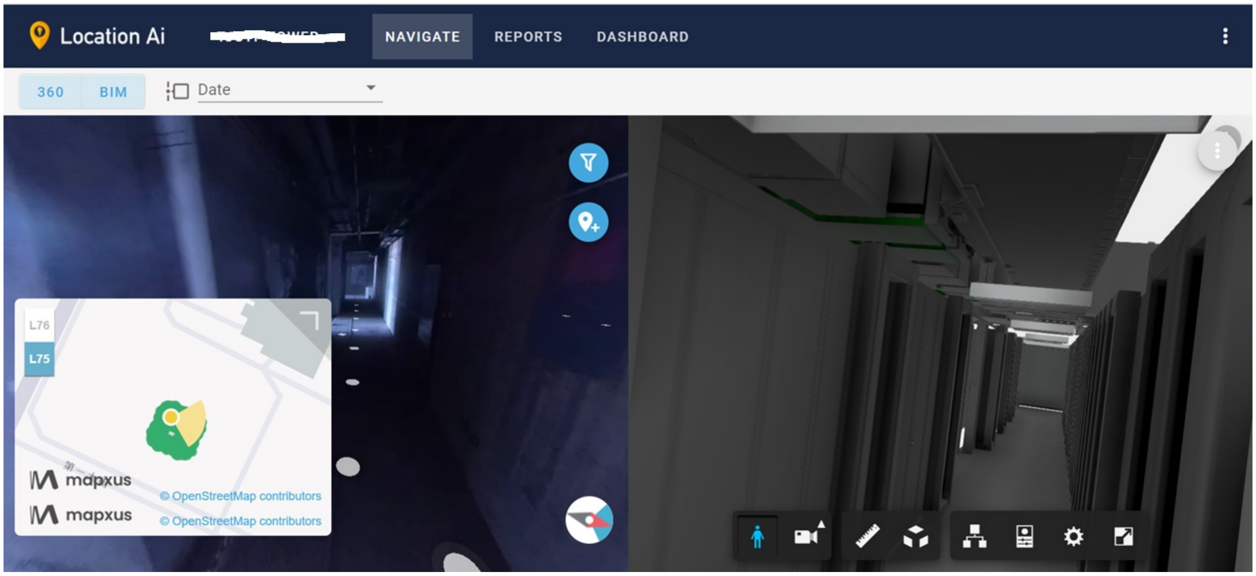

Fig. 1. 360 image and BIM synchronization

4.1 Operation

At the beginning of the project, the developer provided the floor plans of the site for the development of an indoor map and converted into a digital map. Alignment between the BIM model and the digital map was a prime parameter, where sufficient geo-reference points like CGCS2000 (Mainland China standard) or WGS84 (global standard) are required. The site image was captured from June 21 to 22, 2021. Site staff used a household 4K 360° panoramic digital camera for video capturing (Fig. 2). The captured videos were then converted into 360° images and uploaded to the system according to the exact route path. Slight alignment and coordination adjustment were necessary for a good fit. Zou H. et al. (2017) stated that the offline site survey process is time consuming and labor intensive, and that it requires numerous calibration points to ensure localization accuracy. Our successful AI algorithms for integrating the digital maps, 360° images, and BIM synchronization into a system ensure that the data are ready for reviewing and monitoring the project progress. The overall duration of the system deployment was about two weeks, covering digital map preparation, alignment adjustment, image capturing, and post-examination. Table 1 shows the workflow of the Tianjin case study:

Task	**Thing to do**	**Estimated time**
1	Indoor map preparation	2 days
2	360° file first alignment to BIM model	2 days
3	Site image capturing	2 days
4	Route checking before upload	2-3 hour
5	Upload 360° image	4-5 hours
6	360°/ BIM bearing & synchronization	1 weeks
7	Data storage	Immediate
8	Load and view site data	Immediate

Table 1: Workflow of the case study

No requirements are given for the 360° digital camera. A good camera usually provides high sensitivity and low contrast in adverse environments in construction sites, especially in dark indoor sites. In the Tianjin project, the contractor used a household-grade digital camera for video capturing. The resolution of the 4K video is pixels (WxH) 3840 × 1920, 56 Mbps.

Fig. 2. Outlook of the 360° digital camera

4.2 Defect management

The site superintendent can mark discrepancies remotely and notify site staff to verify the issue, and then compare the 360° images with the BIM file in case of discrepancies or to verify the structural or building elements. Then, they can click a “mark request” button when the screen view is in front of the specific elements with descriptions of the discrepancy or inquiry and then assign a responsible person to follow up on and verify the issue. A notification will be sent to the responsible person and then recorded in the system. Fig. 3 shows an example where management staff marked their request in the system at headquarters and assigned site staff to verify the dimension of the site elements. It then prompts senior management to inspect the site virtually after images have been uploaded by site staff. Once the inquiry has been verified, the responsible person replies to the inquiry. The superintendent can manage whether the inquiry or discrepancy has been verified by the responsible person and follow up on the issue.

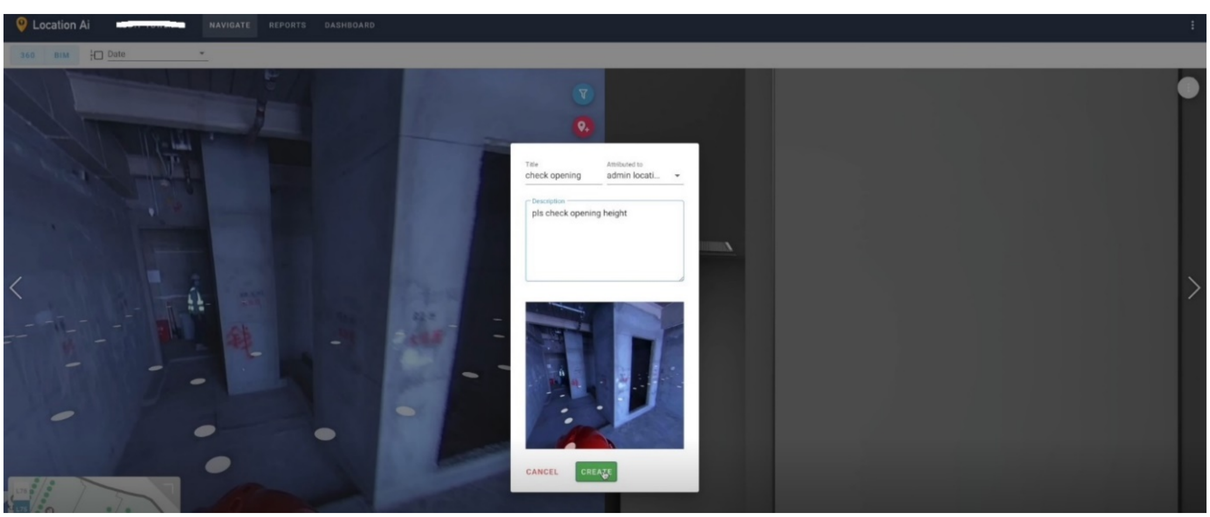

Fig. 3. Defects marking

A powerful cloud-based platform is necessary for remote storage, upload, download, and access. A backend platform is developed through the integration of computing technology, and service providers can subscribe to this platform. Several global cloud service providers offer stable cloud-based service at competitive costs, thus solving technical issues related to information technology.

The case study successfully demonstrated how engineers from different fields integrate their knowledge using information technology to achieve the digital twin concept.

4.3 Implications

The digital twin concept, especially GIS and BIM application, is a global trend in positioning and image synchronization. The case study provides useful experience and valuable information for further improvement and development. A clear and tidy site without obstructions is necessary during site video capturing, improving the outcome of offshore visualization. Sufficient lighting also improves performance; video capturing should not be performed at night or on rainy days. Exact As-built height level of each floor is necessary to prevent tilting of the image. The height during video capturing should be aligned with BIM files (e.g., 1.9 m). The camera should have sufficient backup power and memory. These factors ensure the satisfactory performance of 360° images and BIM synchronization.

Sufficient geo-reference points—at least two accurate ones at the correct height—are needed when preparing digital maps to ensure that the converted digital map is easily aligned with BIM files. BIM files are complex and have a large file size, and only a few layers are needed to reduce the transfer time and file size. Files of different formats, versions, and BIM programs might not be merged. The same software and version are recommended. CGCS2000 (Mainland China standard) is slightly different from WGS84 (global standard). Thus, their files require conversion, which may cause minor deviations.

5. Positioning for further management

The location of workers and plants is needed in the next phase of construction management. This can be easily achieved by adopting the digital map, a signal map for the construction site, and a hardware sensor. Worker safety and plant tracking are easily achieved on site through GPS for outdoor scenarios and Wi-Fi for indoor scenarios. Sorour S. et al. (2015) pointed out that if the received signal strength indoors is not strong enough, then an AP can be installed to strengthen the Wi-Fi signal. Through integration with Wi-Fi positioning technology, worker positioning can be applied for worker safety management. Woo S.K. et al. (2011) introduced Wi-Fi fingerprint technology in an MTR tunnel construction project in Guangzhou, which provided accurate positioning within an average of 5 m. However, they could not provide a geofence alert as they did not have digital maps for the sites.

Offshore management will be a trend in which senior management can inspect site progress, work quality, and site staff safety remotely, and it can be assisted by the positioning of workers and plants, digital maps, and signal maps.

6. Conclusion

Offshore management is a new post-COVID-19 trend for addressing large direct or indirect costs due to travel restrictions, quarantine requirements, and risk of infection when project staff inspects cross border sites. The integration of GIS information in construction management is part of the new norm, as it provides fast, economical, and accurate location information to site supervisors and senior management for analysis, thus being a new concept in quality management and in safety and progress management.

A site progress and inspection monitoring scheme that uses 360° images and BIM synchronization was introduced in this paper. A case study from a high-rise building project in Tianjin provided flawless 360° images and BIM synchronization for site progress and defect marking function for superintendents who need to inspect sites offshore, providing a fast, low-cost progress monitoring and sustainable management system. It also helps pinpoint defects and generate reports and workflow to follow up on site inspection in case of discrepancies.

Moreover, a digital twin experience is afforded to the site superintendent through 360° images, thus enabling them to inspect the site progress and address inquiries through a web-based cloud platform remotely, avoiding issues with time, costs, and risk of pandemic infection due to cross-border travel.

Wi-Fi fingerprint application in the construction industry helps improve management because it provides the location information of workers and plants. It reduces the response time during accidents and enables quick rescue by pinpointing the exact position of the victim. It provides zoning for workers and equipment, thus helping the safety manager identify the location of workers and reduce risks if the area is too crowded or ensure further safety and health management. In the post-COVID-19 new normal in construction management, LBS for labor and equipment is essential because of its important value for projects. Through the integration of image processing with GIS, a digital twin can be successfully achieved in the construction industry.

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Evaluating the Awareness, Barriers, and Level of Adoption of Innovative Digital Technologies in the Health and Safety of High-Rise Construction in South Africa

Alireza Moghayedi[1], Mark Massyn[1], Karen Le Jeune[1] and Kathy Michell[1]

[1] Sustainability + Oriented Cyber Unit for Built Environment, Department of Construction Economics and Management
University of Cape Town, Cape Town, 7700, South Africa
alireza.moghayedi@uct.ac.za

Abstract
Innovative technologies have been used globally to improve health and safety practices in construction projects. This adoption has been proven to directly lead to significant decreases in the number of incidents experienced on construction projects. However, limited research has been done in South Africa to evaluate the level of awareness, adoption and barriers of Health and Safety (H&S) innovative technologies in high-rise construction projects. Therefore, this research seeks to fill this knowledge gap. A questionnaire survey was undertaken to collect data from H&S officers of high-rise construction projects across South Africa to answer the study objectives. Statistical analysis was employed to analyze the collected data. The study found that the South African H&S officers are moderately aware of the innovative technologies that can be implemented on high-rise construction projects to improve health and safety management practices. However, the adoption of innovative technologies in these types of construction projects is less than 20%. Furthermore, the study determined the initial cost of technology, non-availability of technologies and high skill shortage as the main barriers to adopting innovative technologies in South African high-rise construction projects. The study concludes that the extent of adopting innovative technologies in construction projects could be increased with an awareness of innovative technologies' performance and availability. The acquisition of the technical knowledge associated with the technology-based construction processes and the recognition of the use of innovative digital technologies (IDT) in H&S of high-rise construction projects in building requirements and regulations were recommended in the study.

Keywords
Level of adoption, Barriers, Health and safety, High rise construction, Innovative technologies.

1. Introduction

The Health and Safety (H&S) of construction workers in a workplace cannot be overemphasized, as scholarly works continue to acknowledge the unsafe, risky and hazardous nature of the industry (Wuni and Shen, 2020). This is because of the numerous risks inherent in undertaking construction activities on site. As much as it is almost impossible to undermine the importance of the construction industry, its uncertain and dangerous nature remains a huge concern. In undertaking construction engagements such as buildings, infrastructure repair and maintenance, some health and risky occurrences are inevitable (Wuni and Shen, 2020). Faulty equipment associated with accidents, falling from heights, high-frequency noise (that may lead to hearing dysfunctions), the collapse of structures (which sometimes cause deformities), among others, are likely factors that lead to accidents occurring (Hulme et al., 2019). Hence, many traditional models and methods have been employed by various scholars to address some of these resilient accident-related problems in the past decade (Wuni and Shen, 2020).

However, it is believed that the swift and effective implementation of innovative technology will leverage significant gains in construction project implementation and performance (Wuni and Shen, 2020). So, many scholars globally are recently advocating for an imminent shift to advanced technologies; like artificial intelligence and the use of robotics, Internet of Things (IoT), Building Information Modelling (BIM), Drone, Virtual Reality (VR), and

Augmented Reality (AR), wearables, laser scanning, photogrammetry, and sensor-based technologies, to provide a better and safe working condition (Hulme et al., 2019; Okonkwo and Wium, 2020). The trend is thus changing globally.

Great strides have been achieved in other industries to reduce injuries and fatalities and improve H&S through progressive IDT usage. However, the construction industry in many parts of the world is still grappling with this contemporary change. It is yet to grasp the opportunity that these tools and approaches offer fully, and the ultimate benefits of IDT have not been fully harnessed and capitalized upon by stakeholders in the industry, and significant changes are yet to be seen (Akinosho et al., 2020; Pradhananga et al., 2021). The industry remains a conventional, slow and fragmented, high-risk industry in adopting this transformational digital change. Unlike manufacturing, aviation and electronics, finance, entertainment, healthcare and education, construction currently trails behind (Okonkwo and Wium, 2020; Pradhananga et al., 2021).

Abdalla et al. (2017) reiterate that although virtually every job entails some risk for injury, the magnitude of risk varies widely across jobs, sectors, geographic regions, and individuals. Accordingly, the South African construction industry is rife with H&S challenges and has yet to adopt IDT, just like many other developing countries (Okonkwo and Wium, 2020). Several studies proved that using IDTs as a proactive mechanism to prevent accidents in real-time significantly improves the H&S practices in construction projects (Manzoor et al., 2021; Okonkwo et al, 2020). However, the benefits of IDT incorporation in the H&S aspects of high-rise construction are not extensively utilized and documented in South Africa. Moreover, very few empirical studies exist that establish the awareness levels of stakeholders and identify the incentives and challenges to their adoption, just like many other developing countries.

In every six fatal accidents, one occurs on a construction site, and one fatal accident occurs every 10 minutes (Okonkwo and Wium, 2020). The construction industry is responsible for about 30% to 40% of all work-related fatalities universally and worse in developing countries due to a lack of safety in the contractor organization and less robust health and management systems. As a result, fatal accidents statistics in the construction industry of developing countries far exceeds that of developed countries and are about 3 to 6 times more than their developed countries' counterparts (Okonkwo and Wium, 2020).

As construction projects increase in complexity, alternative modern construction methods and design should increase popularity. Today's complex high rise construction projects require these contemporary IDTs in design and methods, which should not be ignored. This can be addressed through a construction industry that minimizes risks and streamlines activities systematically through DIT (Newman and Humphrys, 2020). Technological transformation and innovation align with the industry 4.0 requirements needed to transform the industry into smart construction through an effective holistic transformation. Hence, by analyzing data from stakeholders of high-rise buildings, their level of awareness, incentives, challenges, and a well IDT informed working environment might be developed to mitigate H&S in the south African construction industry of high-rise buildings. However, studies did not give extensive analysis and understanding of the challenges and incentives to adopting innovative H&S technologies in high-rise construction concerning the familiarity and awareness of the H&S professionals with these technologies and their application in H&S of high-rise construction.

Hence, it becomes vital to specifically investigate the complex relationship between awareness as a skill of experts to be aware and mindful of new and popular technology that has been gaining widespread acceptance across concerned industries or markets, incentives and challenges to adoption and extent of use of these IDT in H&S of high-rise construction by professionals. Therefore, there is a need for a deep understanding of their complex relationship in order to determine the impact of awareness, the incentives required and challenges facing adoption. Thus, this study aims to provide a deep understanding of the nexus and impact of influencer factors (awareness, challenges and incentives) to the extent of IDT adoption in South African H&S professionals. This understanding will, in turn, promote the adoption of IDT H&S of high-rise construction as one of the most challenging and hazardous construction projects and provide a valuable reference for H&S professionals in decision-making and policymaking on the use of innovative H&S technologies. To achieve this aim, the following research questions will be answered:

What is the level of awareness of South African H&S professionals on innovative technologies used in high-rise construction?

What are the key incentives and barriers posed to the adoption of innovative H&S technologies in South African high-rise construction?

2. Methodology

A questionnaire survey was undertaken to determine the level of adoption of the seven most innovative H&S technologies in the construction of high-rise buildings in South Africa and their incentives and challenges in adopting these technologies.

All primary data were collected through a structured survey questionnaire. The questionnaire comprised four parts. Part 1 was designed to collect the general background, including job title, level of education, experience, company affiliation and type of high-rise buildings. Part 2 used 5 Likert scales to obtain information on the level of awareness with innovative H&S technologies. Part 3 of the questionnaire were focused on incentives and challenges on the adaptation of innovative H&S technologies, and finally, Part 4 used 5 Likert scales to evaluate the level of adoption of innovative H&S technologies in high-rise buildings by respondents' companies.

The study population consisted of all the H&S professionals that recently completed a high-rise building in South Africa. A total of 55 H&S officers were identified from the registered H&S professional with SACPCMP. A copy of the questionnaire survey was sent to all target populations (55) of the study. As a result, 47 valid responses were returned (85% response rate), and these were used for the data analysis. The data collected were analyzed using descriptive and inferential statistical techniques such as percentage, frequency, Mean Score (MS) and Relative important Index (RII).

Prior to analyzing data, the consistency of collected data was tested. The results of Cronbach's Alpha are between 0.7 and 0.95, which indicate a good consistency between the participants' responses.

3. Results

3. 1 Profile of respondents and their projects Results

Figure 2 shows that most of the respondents (64%) worked at high-rise projects as H&S officers, while 36%respondents concurrently held other job titles in addition to the H&S responsibility. The results indicate that majority of the respondents (32%) have an advanced certificate, closely followed by 30% of the respondents who have post-graduate qualifications. Advanced certificates are the minimum requirement to become an H&S professional. The findings on the respondents' experience show that 41% of respondents have between 11 and 15 years of experience with high-rise projects. In comparison, only 2% of respondents had less than five years of experience working in high-rise buildings. The demographic results of respondents indicate the credibility of the respondents. All the respondents have some level of professional qualification, and almost all (98%) have extensive experience working on high-rise projects.

Figures 1 presents the demographic analysis of the 47 H&S professionals and their completed latest high-rise project.

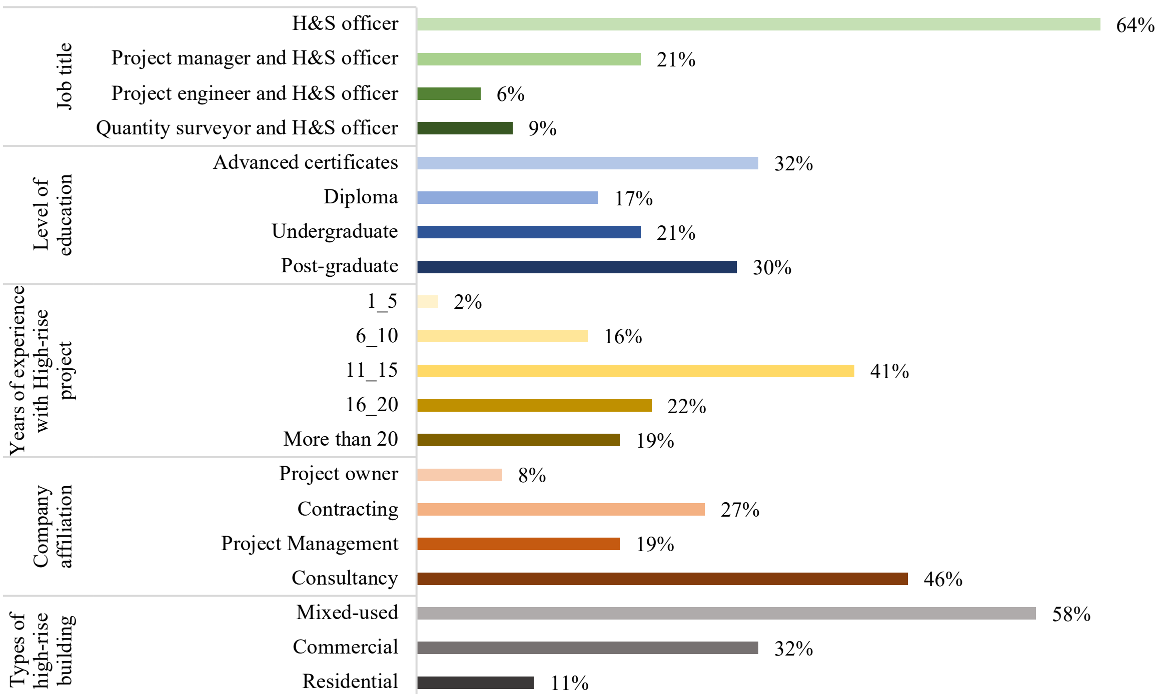

Fig. 31. Profile of respondents

Figure 1 indicates that the most common type of high-rise projects was mixed-used buildings (58%), followed by commercial buildings (32%) and residential buildings (11%). Office blocks have the highest percentage of all the buildings used (75%). The results depict that most respondents were associated with H&S consultancy companies (46%) and contracting (27%), and 19% were associated with the project management company. In contrast, 8% of respondents were project owners. About 90% of the H&S professionals worked in the private sector, and only less than 10% worked in the public sector.

3.2 Level of awareness with innovative technologies

The respondents were asked to indicate their level of awareness and familiarity with the ten suitable innovative technologies in H&S of high-rise construction buildings using a 5 Likert scale. The responses received and their Relevant Importance Index (RII) is calculated and listed in Figure 2. The RII indicates respondents' overall level of awareness with the particular innovative technology.

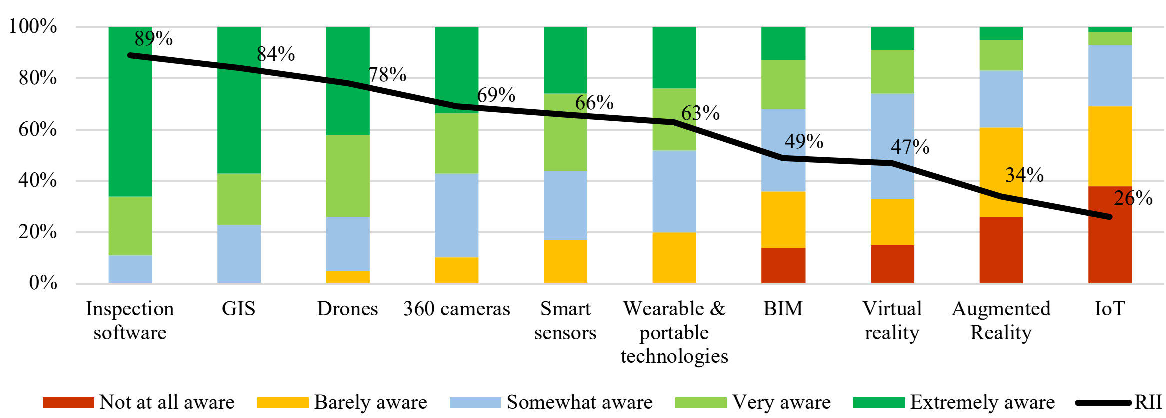

Fig. 2. Respondent's familiarity with innovative technologies

The results of respondents' awareness indicate that most of the H&S professionals who participated in the study were aware and familiar with inspection software (89%), GIS (84%), Drones (78%), 360 cameras (69%), smart sensors (66%), wearable and portable technology (63%), BIM (49%) and Virtual Reality (47%). While fewer participants were aware of Augmented Reality (34%), and limited participants were aware and familiar with IoT (26%). The overall findings on the awareness of the respondents show that the majority of the H&S professionals (60%) were aware of the latest innovative technologies that could be used in H&S of high-rise projects, which this finding is aligned with, Chen, et al. (2021).

3.3 Level of adaption of innovative technologies in high-rise projects

The respondents were asked to reveal the level of adoption of innovative technologies in their latest completed high-rise project by indicating how often they used these technologies through a 5 Likert scale. The responses received and their RII is tabulated in Figure 3. The calculated RII indicates the overall adoption of each innovative technology in 47 high-rise projects studied in this research.

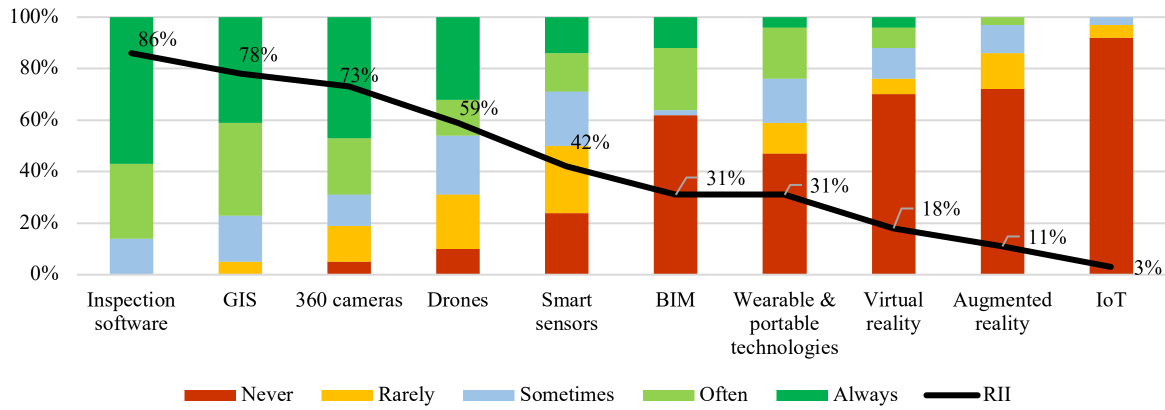

Fig. 3. Level of adoption of innovative technologies

Figure 3 presents all participants who adopted inspection software and GIS in their high-rise projects. Additionally, the level of adoption of inspection software (86%), GIS (78%) and 360 camera (73%) were very high in all the studied high-rise projects. This is supported by Li and Liu (2019). Notably, the adoption of drones as a technology recently introduced in the construction industry was high (59%). Only 10% of high-rise projects could not use the drone as innovative H&S technology. Martinez et al. (2020) also noticed the rapid increase in the adoption of drones in the construction industry.

On the other hand, the level of adaptation of smart sensors (42%), BIM (31%) and wearable and portable technologies (31%) were low. The majority of the participants never used BIM, wearable and portable technologies, VR, AR and IoT in their high-rise projects. While IoT (2.8%), AR (11.3%) and VR (17.5%) as more advanced technologies were used marginally in just a few studied high-rise projects. Despite the significant evolution in hardware and software and the increasing amount of technology used in the construction industry, there is still a need for software interoperability in virtual reality usage for displaying overlays of BIM models and laser scans or 360-degree as-built photos in a virtual environment. Hence, research and development in these areas could significantly improve their efficiency and quality (Mayer et al., 2021).

3.4 Reasons and incentives for adoption of innovative technologies in high-rise projects

The respondents who used the innovative technologies in their latest completed high-rise building were asked to choose the reasons and what motivated them to use these innovative technologies on their projects; based on the list of incentives identified from the literature. The responses and the overall score of each reason and incentive are presented in Figure 4.

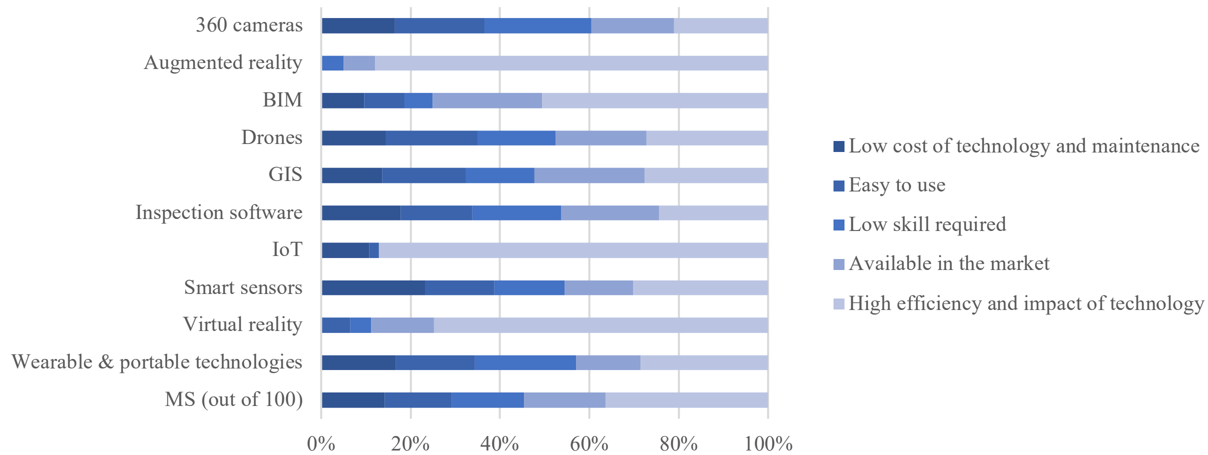

Fig. 4. The reasons and incentives for the adoption of innovative technology

As shown in Figure 4, participants' main reason and incentive to adopt innovative technologies (except 360 camera) was technology's high efficacy and impact on H&S of a high-rise building with an overall 36 score. This finding is supported by the study done by Assadzadeh (2021).

Availability in the market (18), easy to use (15), low skill required (16) and low cost of technology and maintenance (14) were respectively the other reasons for adopting innovative technologies with participants. On the other hand, the results indicate that 360 cameras were adopted because they require a low operating skill.

3.5 Barriers and challenges to adoption of innovative technologies in high-rise projects

Both respondents indicated that they had used or had not used innovative technologies on their most recently completed high-rise project were asked to identify the challenges of adopting the technologies from the provided list of challenges determined from the literature. The data collected and an overall score of challenges are depicted in Figure 5.

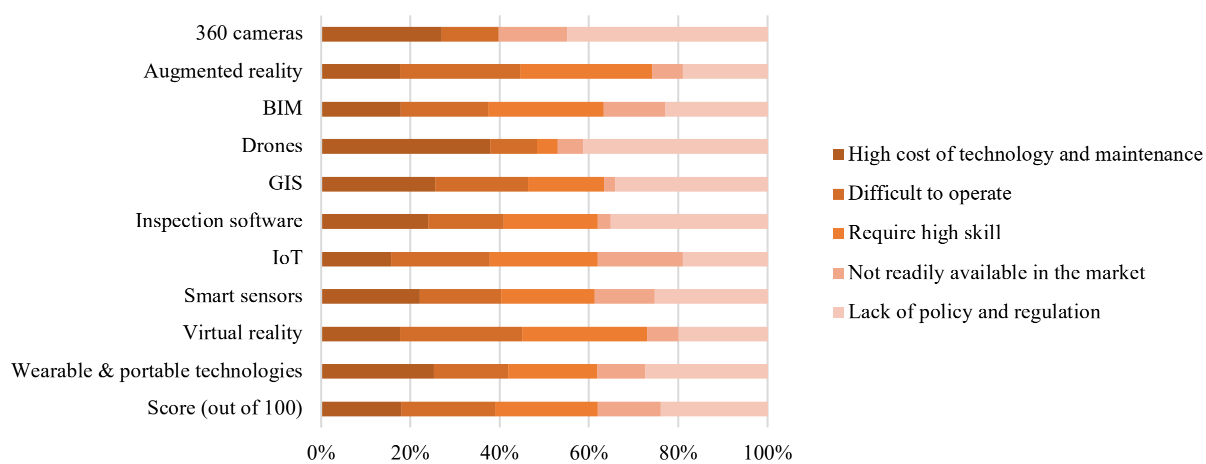

Fig. 5. The challenges on the adoption of innovative technology

The results of challenges on the adoption of innovative technologies reveal the lack of policy and regulation (24), require high skill (23), and difficulty to operate (21) are the main challenges on the adoption of innovative technologies by participants in their high-rise project. These findings are aligned with several studies that stated that policy and rules are non-existent for implementing innovative technologies (Manu et al., 2021) on lack of skill, technical knowledge (Akinosho et al. 2020), and cost (Pradhananga et al., 2021) are the key challenges to adopt innovative technologies in H&S of construction projects. Overall these five key challenges aligned with the top five barriers to adopting technologies for occupational safety and health management in construction projects defined by Nnaji and Karakhan (2020).

As shown in Figure 5, the innovative technologies can be divided into two groups based on adaptation challenges. The first group contains the innovative technologies recently introduced in the South African H&S sector, such as AR, VR, IoT, and BIM. The second group comprises the technology in the market for a while. The professionals are more familiar with the second group, such as 360 cameras, drones, GIS, inspection software, smart sensors and wearable and portable technologies. The main challenges in adopting first group technologies were difficult to operate and required high skill. In contrast, the key challenge in adopting second group technologies was the lack of policy and regulation.

4. Discussion

The study found that the South African H&S professionals are moderate to highly aware of the IDTs that can be implemented on high-rise construction projects to improve H&S management practices. In particular, the H&S professionals are extremely familiar with inspection software and GIS. Very familiar with incremental IDTs such as drones, 360 cameras, smart sensors, wearable and portable technologies and BIM. While moderately familiar with disruptive IDTs such as VR and AR and barely familiar with IoT.

Furthermore, the study findings reveal the level of adoption of overall studied IDTs in high-rise construction projects is 43%. This means almost half of the South African high-rise construction projects were adopted the combination of at least two IDTs to monitor and manage the H&S. This mediocre level of adoption of IDTs in South African high-rise construction projects is similar to the level of adoption of IDTs in the majority of developing counties and lower than the developed countries as reported by Okonkwo and Wuim, (2020) and Manu et al., (2019).

While the level of adoption of some incremental IDTs such as inspection software GIS and 360 camera is very high (>70%), the level of adoption of disruptive IDTs such as IoT, AR and VR are very low (<20%) particular IoT (3%). Ringberg et al., (2019) claimed that the extent of use of radical and disruptive innovations is significantly lower than incremental innovations. Additionally, BIM, as a most crucial radical innovation for cloud collaboration and managing project information, including H&S (8D BIM), was never used in the majority (62%) of high-rise studied construction. The low rate of adoption of BIM as an important IDTs in the construction industry could be because of the low level of familiarity of H&S professionals about BIM (49%), which is supported by research findings of Olawumi and Chan (2019) that proved the low level of adoption of BIM in the developing countries construction project is due to the lack of awareness and knowledge of construction stakeholders in developing countries.

The analysis of the incentives to adopt IDTs proved that technology's high efficiency and the impact was the key reason for adopting IDTs by H&S officers. Moghayedi et al. (2022) also claimed the high efficiency and impact of technology as the main reason to choose and use technologies for improved professional. In addition, availability in the local market, the low skill required, ease of use, and the low cost of technology and maintenance are important incentives to adopting an IDT. These incentives to adopt innovative technologies are supported by several scholars (Pradhananga et al., 2021; Okonkwo, 2020).

Furthermore, the study's findings determined the lack of policy and regulation, requiring high skill and difficulty to operate as the main challenges to adopting IDTs in South African high-rise construction projects. The conclusion of Moghayedi et al., (2021) Research also showed these challenges as the key barriers to adopting innovative technologies in construction projects. Okonkwo, 2020 found that the government policies and technical instructions will, to no small extent, influence innovation in the construction industry.

The study found only those H&S professionals who never implement IDTs on their projects identified cost and maintenance as barriers to adopting IDTs. The last point may be debated because how can those who did not implement the technologies deem it high to use and maintain the technology unless they have had prior exposure to it. This proved that the high cost of technology and maintenance is just a perception of professionals without any insight contributing to adoption reluctance as Okonkwo, (2020). highlighted the reluctance as one of the non-technical issues to adopt innovation in the construction industry. The research findings provide empirical evidence for the need to create awareness about the advantages and application of IDTs in H&S of construction projects and the use of awareness to reduce the effect of challenges and increase incentives to adopt IDTs on high-rise construction projects. At the same time, the negative impacts of the challenges to the adoption of IDTs will be substantially reduced if there is an awareness about the advantages and application of IDTs in the H&S of high-rise construction. This means that the awareness about H&S IDTs will convince the project stakeholders about the short-term and long-term advantages of

H&S IDTs over conventional H&S methods. The implementation of IDTs is advantageous in H&S management of construction projects; however, these advantages are not enough to provoke usage unless there is regular training provided by H&S professional bodies to improve the technical knowledge and awareness of professionals about IDTs, since personal learning gaps may develop, leading to users giving up on adopting of IDTs and ultimately developing negative perceptions towards use IDTs (Pradhananga et al., 2021; Okonkwo, 2020; Wuni and Shen, 2020 Manu et al., 2019). Furthermore, sufficient policies and technical instructions should be instituted by government and professional bodies for facilitating the adaptation of IDTs on H&S management of high-rise construction projects. Improve the technical knowledge of H&S professionals, Improve the efficiency of technology on H&S management, reduce the complexity of technology and accessibility to technologies in the local market.

5. Conclusions

The study sought to determine the level of awareness of H&S professionals on IDTs and incentives and challenges to adopting IDTs on the level of adoption of IDTs in South African high-rise construction projects.

It emerged from the research that the main key influencer on the decision to adopt IDTs in construction dramatically depends on the awareness of the H&S professionals. It was also found that the current negative impact of challenges to the adoption of IDTs could be counteracted by the positive impact of incentives to the adoption of IDTs. However, by addressing the challenges such as implementing appropriate rules and policies for using IDTs in construction projects in developing countries such as South Africa and reducing the complexity of technology, the positive impact of incentives on adopting IDTs will be significantly enhanced.

Based on the research findings, the study concludes that the extent of the adoption of IDTs in construction projects will be increased with an awareness of H&S professionals on the performance and availability of IDTs. Therefore, the technical knowledge acquired with the technology-based construction processes and the recognition of the use of innovative technologies in H&S of high-rise construction projects in contract requirements and regulations are highly recommended.

The findings were generated to cater for the level of awareness of South African H&S professionals, key incentives and challenges to adopting IDTs and finally, the various IDTs employed on the H&S of South African high-rise construction projects.

A large population of South African H&S professionals are unfamiliar with disruptive and radical H&S IDTs, and they cannot implement something they are unfamiliar with IDTs. Therefore, to improve the common knowledge and level of awareness of H&S professionals on IDTs, the important role of public training, such as continuous professional developments providing by H&S professional bodies and technology developers, are undeniable.

Finally, due to the lack of implementing BIM as a digital platform for managing and collaborative information between the various IDTs and project stakeholders, the adopted IDTs in projects could not be used optimally, and the investment in IDTs was not maximized. Therefore, to optimize the adaptation of IDTs and maximize the investment, the study recommends implementing BIM and digital information management in the projects as fundamental IDTs to collect, manage, and share information among all project resources (human and non-human).

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ID 71

The Embodied Energy Assessment of Various Building Assemblies in Residential Building Construction

Abdul Rauf[1*], Daniel Efurosibina Attoye[1] and Robert Crawford[2]

[1] United Arab Emirates University, Al Ain, UAE
[2] The University of Melbourne, Melbourne, Australia
a.rauf@uaeu.ac.ae

Abstract
Energy consumption in the construction and building industry is associated with significant depletion of natural resources, release of greenhouse gases emissions and related environmental impacts worldwide. An understanding of the direct and indirect, operational, and embodied, as well as life cycle consumption patterns due to building architecture plays a major role in reducing the negative impact of buildings. A review of existing literature shows that there is much less research on the impact of embodied energy and there is a need to provide a clear basis to substantiate its veracity. Previous studies on embodied energy have mainly focused on the overall embodied energy of different building types. However, there is limited focus on the embodied energy associated with various assemblies in a building. In efforts to reduce the embodied energy of buildings, it is important to understand the energy associated with various assemblies in a building. Therefore, this research was conducted to investigate the life cycle embodied energy (LCEE) consumed by various building assemblies in a residential building to provide relatable data for professionals. The findings indicate two levels of interest; firstly, life cycle embodied energy of the case study was found to be 13096.47 GJ with the initial embodied energy being 7390.5 GJ (56%) and the recurrent embodied energy was 5690.01 GJ (43%). Secondly, the study presents the embodied energy impacts of various building assemblies and revealed that while the wall assembly was highest, responsible for 25% of the LCEE, the floors contributed 18% and the roof, 6%. The study reveals the significance of embodied energy consciousness in envelope design, as well as the design and specification of building assemblies.

Keywords
Life cycle embodied energy; initial embodied energy; recurrent embodied energy; Building Assemblies; Building materials; Input Output Hybrid Analysis

1. Introduction
In the last decade, it was predicted that global energy demand will rise by 36% between 2008 and 2035 at an average of 1.15% per year (Birol, 2013). Another prediction suggests that by 2050, global energy demand will rise to 50% (EIA, 2019). In general, energy consumption has a monumental impact on the environment and is frequently associated with environmental damage and global warming.

However, building construction, operation and related activities accounts for a significant percentage of this impacts. In 2017, 36% of global energy was consumed by buildings and also accounted for to 40% of energy-related carbon dioxide (CO2) emissions (IEA & UNEP, 2018). Using the United Arab Emirates as the context of study, this paper sheds light on subtle and overlooked aspects of this situation., It is easy to understand that building impact can be negative and problematic, on the other hand, global population is on the increase and thus, more buildings are needed. Between 2005 and 2010, the UAE population rose by from about 4.1 million to 8.3 million (UAE Federal Competiveness and Statistics Authority, 2020), and by 2019, about 9.8 million (Department of Economic Studies, 2020). Comparatively, the UAE has contributed over $443bn of awards towards building and infrastructure projects since 2004, it ranks as the highest contributor in the Gulf Corporation Countries (GCC) accounting for nearly 41 per cent of the value. Thus, as population rises, investments in the construction industry rises. The world population is predicted to rise to 9.7 billion by 2050 (United Nations et al., 2019),and it is expected that 230 billion m^2 of new building floor area will be added by (IEA & UNEP, 2018). Since buildings involve multiples stakeholders, both technical and non-technical stakeholders in the building industry need to be engaged in developing and promoting strategic solutions to improve building sustainability accompanied by the reduction of negative environmental impacts.

There are multiple studies which have focused primarily on the reduction of the operational energy consumed by buildings (Birgisdottir et al., 2017; Mirabella et al., 2018), leading to a clear understanding of how to reduce the impact of buildings in this regard by improving research accuracy in related calculations and design. As an example, a Danish study reports that about 70% reduction in operational energy has been achieved (Danish Government, 2014). Also, multiple studies report the achievement of NetZero designs based on operational energy reduction (Crawley et al., 2009; Kolokotsa et al., 2011). Conversely a survey of research databases, shows that there are fewer studies which give detailed focus on the embodied energy consumed in building construction. This gap in literature requires more focus on embodied energy analysis due to the fact that some studies have reported the significant and critical role which embodied energy plays (Crawford, 2014; Rauf, 2016).

In previous studies, we have assessed embodied energy based on material replacement and maintenance activities over a building's service life (Crawford, 2014; Crawford et al., 2010; Rauf & Crawford, 2015). Recently, we carried out a detailed investigation of the initial, recurrent and life cycle embodied energy of a villa in the UAE. The aim of the current paper, however, is the broader discussion regarding the veracity of this research area, and along with two key considerations. Firstly, this paper explores this embodied energy of building assemblies such as the roof, walls and floors -this is the technical focus of the paper. Secondly, the paper presents the calculated embodied energy data as a starting point to facilitate stakeholder engagement and interactions by providing market-ready practice oriented data on the topic.

1.1 Life cycle embodied energy analysis

The process used in quantifying embodied energy across a building's life cycle is called life cycle embodied energy analysis (LCEA). The approach draws its merit from the fundamentals of life cycle energy analysis, covers a cradle to site (Lolli et al., 2017; Resalati et al., 2020) or cradle to cradle (Rauf, 2016; Rauf & Crawford, 2015) scope and helps researchers to investigate multiple aspects of energy consumption across the building lifespan (Rauf & Crawford, 2013).

There are strategic benefits associated with the application of this approach in view of the potential improvements which it provides for both building and component design, as well as material selection and specification, and potentially, building construction. This is because the definition of the system boundary for the calculation process for life cycle embodied energy analysis covers associated energy demand from manufacturing, construction and maintenance and as well as the demolition phases of the building (Dixit et al., 2014). In specific terms, it incorporates the initial embodied energy used for construction, the recurrent embodied energy associated with replacement and maintenance of components or materials, and the demolition embodied energy required in demolition and disposal of materials.

1.1.1 Embodied energy assessment methods

Some studies have applied software or online tools in the calculation process (Azzouz et al., 2017; Dascalaki et al., 2021; Wen et al., 2015); these tools draw from three fundamental methods used in the systematic process applied in the quantification of a building's embodied energy. These are the process analysis, input-output analysis, and hybrid analysis (R. Crawford, 2011; Rauf, 2016). In this section, focus is given to these fundamental approaches as backbone of embodied energy calculation. The methods have different system boundaries and energy inputs applied in the analysis process (Dixit, 2017), as well as unique strengths and weaknesses.

The application of process analysis approach comprises a combination of process, product, and location-specific data which is used in the evaluation of environmental flows and effect which makes it the most accurate method. This approach starts with the energy input required from manufactures at the last stage and walks backwards to account for each energy input calculated. Computation results however, then to be incomplete due to the fact that detailed data for many of core production process are unaccounted for and the upstream supply chain in inherent with certain complexities (Treloar et al., 2001). To substantiate this, one study conducted by Crawford [15] reports that a 59% truncation error is associated with the use of this approach (Crawford, 2008).

Input–output analysis on the other hand, uses economic data as its basis; tracing, quantifying, and ordering the energy required in production of product. The availability of inter-industry transactions (input–output tables) which are periodically reported in some countries is used in defining the energy flows for respective national economies. This is aligned with monetary flows between various sectors, drawn from fuel tariffs and are used to create an energy-based input–output model. Although this approach is systemically complete -providing energy flows within an entire supply chain, it creates a combination of dissimilar products, sort of a procedural black box in individual economic sectors (Baird et al., 1997; Crawford, 2011). In some cases, product price estimation/assumptions, usage of economic data, and multiple or double counting of energy embodied in delivered fuels may lead to different errors in computation (Dixit, 2017; Treloar, 1998).

The third approach is called the hybrid analysis which combines process and input-output analysis approaches, and allows researchers to use both methods simultaneously; to maximize their strengths, and minimize their limitations (Crawford, 2011; Treloar & Crawford, 2010). The hybrid approach, however, can be a process-based hybrid analysis or an input-output hybrid analysis. In process-based hybrid analysis, the calculation uses delivered quantities for each material, using product and input-output data to complete the upstream system boundary (Treloar, 1998). Due to the fact that many direct inputs to the process under review may be omitted, the system boundary tends to be incomplete and this hybrid approach has similar weaknesses with process analysis (R. Crawford, 2011). On the other hand, input–output-based hybrid analysis resolves these truncation issues by using input–output data to fill missing data and complete the system boundary (Crawford et al., 2010; Rauf, 2016).

1.2 Building assemblies in construction

In construction, major decisions are made during the early design phase where stakeholder engagement reveals subjective choices in design decision-making. One aspect of construction work which has a definitive impact comprises of the various building assemblies such as wall, roofs and floors used in the construction. The choice of appropriate building materials for these assemblies is thus, considered as an important step in design development due to its potential impact on building performance. As a design variable, Nassar et al (2003) studied building assemblies such wall, roof, floors, windows in line with various performance metrices. This study developed a practice tool with facilitates the designer's decision-making process and information regarding trade-offs beginning with an assembly-based abstract representation of the building. Although this study did not consider embodied energy in the elaboration of performance metrics research shows the importance of this consideration (Nassar et al., 2003). For example, a study by Mayer & Bechthold (2018) reported that embodied energy assessment plays a vital role in building assembly design decisions (Mayer & Bechthold, 2018).

Furthermore, in comprehensive energy performance study by Crawford et al (2015) the authors reported the development of a tool to be used at early design stage, which helps in minimizing life cycle energy demand of building assemblies. The tool considers the significant role of embodied energy considerations along with heating and cooling loads (Crawford et al., 2015). However, this tool is based on comprehensive energy performance data for different assemblies for Australian climate zones only and cannot be used in other countries. Therefore, it is important to study the significance of embodied energy associated with different building assemblies around the world, including UAE.

A study by Silvestre et al (2014) presented a broad understanding of the environmental impact of buildings; asserting that it is associated with material characteristics such as their initial embodied energy. The authors also referenced a previous review on LCA investigations and reported that only 63% of reviewed studies carried out an evaluation of the embodied energy (Silvestre et al., 2014). The aforementioned studies, connectively, indicate that there is a significant merit in evaluating embodied energy of building assemblies. Although it is important to note the significant role played by operational energy in determining energy demand, extensive research has explored this area but much less have focused on embodied energy impacts of building assemblies (See Figure 1).

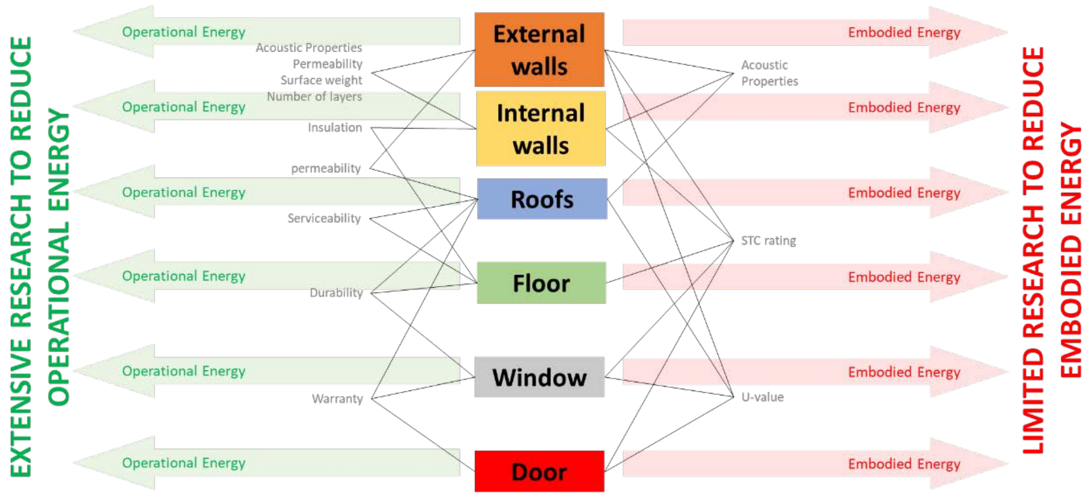

Fig. 1. Design metrics for building assemblies showing limited research on embodied energy aspects (Adapted from (Nassar et al., 2003; Rauf, 2016; Rauf & Crawford, 2015)

2. Method

To conduct this study, a case study UAE residential villa was used to simulate a real exploration of the embodied energy associated with the various building assemblies used in the construction. The use of a real case provided actual figures and material quantities from the Bill of Quantities associated with the architectural design which were then used to calculate the initial embodied energy and recurrent embodied energy values.

The selected representative case study villa is located in Al Ain, UAE (See Figure 2). The two storey house has a total floor area of 532m^2, a concrete column and beam superstructure, concrete solid and hollow blocks, double glazed aluminum windows and a concrete roof. Wall, floor, and roof assemblies are evaluated as a composite element which comprises both the structure and the finishes which were respectively made of ceramic tiles and paint, marble and ceramic, as cement tiles only. The door assemblies were primarily made of hardwood (teak) and were composed of both the door frame, while the double glazing with aluminum frame was used for the window assemblies. A detailed bill of quantities was used to quantify the life cycle embodied energy of the house. The building's structure is made up of concrete columns and beams, while the external floor is assumed to be covered with outdoor stone interlocking paving blocks,

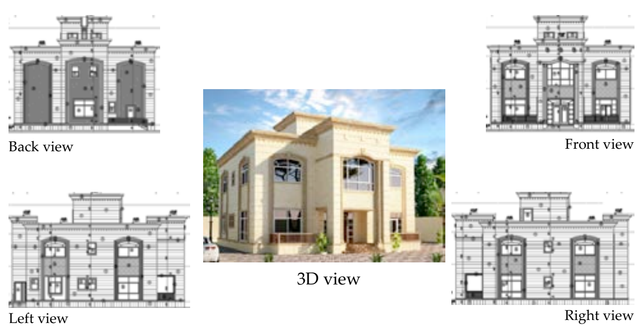

Fig. 2. 3D view and Elevations of the case study villa

2.1 Calculation procedure for initial and recurrent embodied energy

The Initial embodied energy of the case study villa was calculated by using the input-output-based hybrid analysis approach. The following calculation approach was used for each material/component:

$$A \, x \, B = C \tag{1}$$

Where:

A is the Delivered quantities of materials (in kg, LM, m^3 or m^2)
B is the Hybrid embodied energy (in GJ)
C is the Process-based hybrid embodied energy (in GJ)

In addition, energy embodied consumed by non-material inputs such as the provision of finance, insurance, transport etc. necessary to support the construction process was calculated to complete the system boundary. This result, referred to as the remainder of energy inputs was then added to the process-based hybrid embodied energy figure. Further explanation of the input-output-based hybrid analysis approach is available elsewhere (Rauf & Crawford, 2015).

To calculate the recurrent embodied energy of the villa, the replacement period or the number of times each individual material/component would likely be replaced with was used to extrapolate the additional energy consumed over the assumed building lifespan of 50 years. In other words, values of the initial embodied energy, delivered material quantities, replacement periods, and embodied energy coefficients were combined with direct and indirect energy associated with the induvial material manufacture. As before, non-material inputs related to material replacement over the lifespan was added. The embodied energy, multiplied by the number of replacements for each material was summed to find the total recurrent embodied energy for the case study villa. For the number of replacements required for each material the applied approach was by dividing the service life of the house by the service life of the material, then subtracting 1 which represents the material used in initial construction at Year Zero. Next, this was rounded up to the nearest whole number in order to complete the computation and infer those materials can only be replaced in whole numbers. Previous research shows further details that explains the application of the input-output-based hybrid analysis (Rauf & Crawford, 2015).

As stated earlier in the Introduction, this investigation is an extension of previous studies that applied the steps listed above. These studies broadly used the bill of quantities to calculate the life cycle embodied energy in various scenarios; however, the current emphasis is the “Building Assemblies”. This is targeted at promoting the presentation and communication of the need for embodied energy research, and the results of the study to professionals in the building construction industry.

3. Results and Discussion

Broadly summarizing the results, the assessment showed that the embodied energy associated with the initial construction of the case study villa was found to be 7390.5 GJ (13.9 GJ/m^2). This value includes the energy embodied associated with material manufacturing, transportation, initial building construction, as well as supporting services. Additionally, the recurrent embodied energy consumed over the 50-years building service life was found to be 5690.01 GJ (10.7 GJ/m^2). The sum of these values gives the life cycle embodied energy of the case study villa which was found to be 13096.47 GJ (24.62 GJ/m^2). Thus, the initial and recurrent embodied energy were found to constitute 56% and 43% of the life cycle embodied energy, as shown in Figure 2.

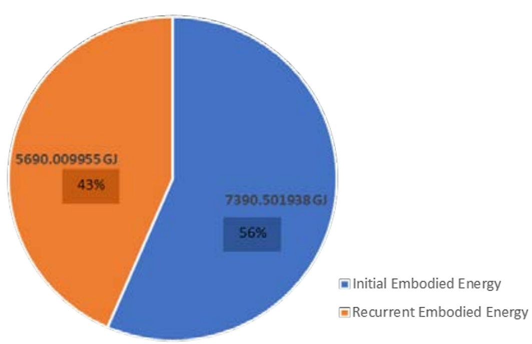

Fig. 3. Proportion of initial and recurrent embodied energy

Figure 3 suggests that material replacement over the building life span can consume almost as much embodied energy as that which was used in the initial construction. This finding reflects the need for proper design and material selection to minimize life cycle energy costs. Alternative building designs, materials specifications, and components installed may thus help in long-term life cycle expenses.

Figure 4 below shows the embodied energy associated with the various building assemblies used in the construction of the villa. For the initial embodied energy, the highest value was 2322.31GJ which was consumed by the Walls while the lowest was 330.38 GJ consumed in constructing the building's Frame Structure. This shows that although both assemblies are critical to the integrity of the construction, they do not have the same life cycle impact, and also suggests that the walls play a much larger role in both initial and recurrent embodied energy impacts. Although this may be due to a much larger area along with need to paint them many times during the life of building.

For recurrent embodied energy the assembly with the highest value was the Floor, which was 1193.2 GJ, although the Other building aspects -electrical, AC and sanitary consumed more (2254.58GJ). The assembly with the lowest recurrent embodied energy was the Frame Structure of the building which was considered as zero due to the fact that the building frame is presumed to last as long as the building service life and thus requires no replacement. There is therefore clear evidence to suggest that materials with longer service life have much less impact or contribution to recurrent embodied energy. This makes a case for material durability and longer lifespans without the need for replacement and repair.

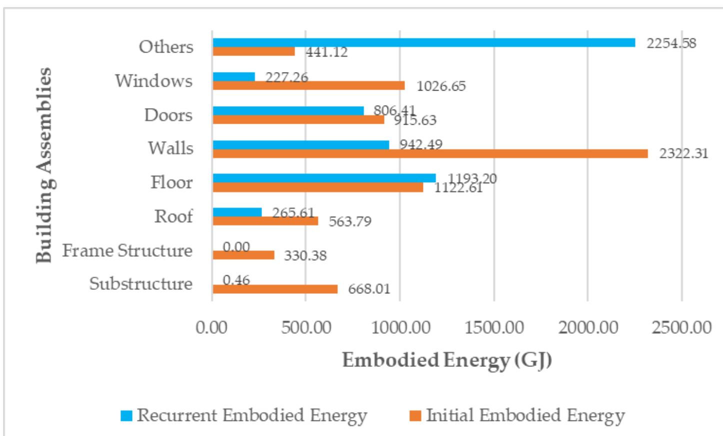

Fig. 4. Comparison of Initial vs Recurrent embodied energy of the case study house based on Building Assemblies

The current study focuses on only initial and recurrent embodied energies to approximate the life cycle embodied energy as other studies show the demolition embodied energy may be as low as 1% of the LCEE (Rauf, 2016;). Figure 5 below shows the LCEE for the villa in three comparative charts: for the initial, recurrent, and the life cycle embodied energies. Specifically focusing on the LCEE, the figure shows that of all the Building Assemblies, the highest consumer of embodied energy is the Walls (25%), followed by Floors (18%) and then Doors (13%).

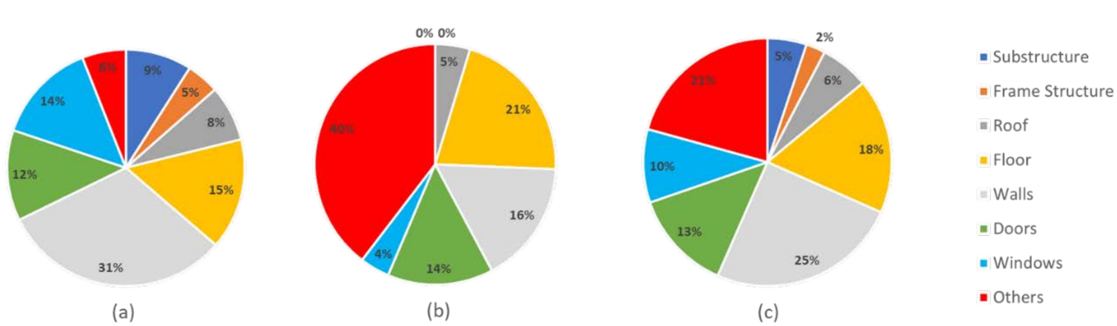

Fig. 5. (a)Initial, (b)Recurrent and (c) Life cycle embodied energy of the case study villa based on Building Assemblies

The results of the LCEE indicate that walls consume a significant amount of embodied energy, which warrants deeper investigation. Considering the area per square metre, the walls cover 1902.4m^2 which is significantly more than the other assemblies, for example the total floor area was 532m^2. However, the floors are responsible for 18% of the LCEE while the Walls are responsible for 25%. Thus, although the Wall area is almost 3 times the floor area, the LCEE contribution of the Walls is less than double LCEE of the Floor. The cause of this results may lie with the type of material used on the construction of both assemblies. Thus, this makes a case for further research to examine the embodied energy associated with materials which make up building assemblies. These results, however, clearly suggest that the Wall assembly provides the greatest opportunity to reduce life cycle embodied energy.

4. Conclusions

This research was conducted to assess the life cycle embodied energy impact of building assemblies in UAE villas, and to provide market-ready data that can be used in communicating the importance of embodied energy to practice professionals in the construction industry. A case study residential villa in the UAE was used in this investigation. The input-output hybrid analysis method was used in this study, as it is considered the most comprehensive and reliable embodied energy assessment method. Based on the building's architectural design, the findings show that the initial embodied energy was 56% of the LCEE and the recurrent embodied energy was 43%. The study also shows that comparing the life cycle embodied energy of the building assemblies, Walls were responsible for highest embodied energy (25%). The findings also showed that the floor and door assemblies were responsible for 18% and 13% respectively. This study helps in defining the focus for design review and remediation; showing professionals which components have the greatest impact in the long term and providing a guide to design specification for both the building and building assemblies.

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Crime Prevention through Environmental Design (CPTED) In Pakistani Construction Industry – Benchmarking of Stakeholders' Awareness

[1,2]Muhammad Umer, [2]Prof. Rizwan U. Farooqui, [1]Dr. Eric M. Wetzel

[1]Auburn University, Auburn, AL, 36849
[2]NED University of Engineering and Technology, Karachi, 75270
mzu0009@auburn.edu

Abstract

While in Karachi, one cannot ignore the fortress-type homes transformed into cages. Nobody wants to live in a fortress but if the crime statistics for Pakistan are put into perspective, the need for physical security has become critical over several years. Physical security is addressed by the intricate operation of several components to provide a secure environment. It has been observed that crime prevention stresses upon the built environment attributes in which building design can be value-added to reduce susceptibility to offense. Therefore, this study aims to assess the level of perception and awareness of key stakeholders about Crime Prevention through Environmental Design (CPTED) concepts, within the geographical boundaries of Karachi city. For the study, Contractors, Consultants, and Architects are considered as the target audience for the primary data collection. From the analysis of the responses, it can be concluded that the stakeholders feel that by including certain attributes in the design stage, the built environment can be made safer from the start. Residents' perception of safety depends on housing quality.

Keywords

Crime Prevention Through Environmental Design, Crime Prevention, Secure Environment.

1. Introduction

Like many similar cities to Karachi, one of the first things that any tourist will notice is the architecture and how the buildings appear on the skyline. Many buildings have multiple stories of caged windows, balconies, and doors; an issue that greatly reduces the aesthetic and suggests a high rate of crime in the city (Tabrizi & Madanipour, 2006).

If attention is drawn towards Pakistan, the data in Fig 1 has been extracted from Pakistan Statistical Yearbook (2019) namely Total Burglary-Dacoity incidents versus the Police Stations. Over the years, the government has invested large sums to improve the policing infrastructure. This has also been fruitful in reducing burglary crime to a certain extent. If the engineering community can join hands and address the challenge from an engineering point of view; it can play a vital role in a money scarce economy. One of such established approaches is termed Crime Prevention Through Environmental Design (CPTED), it is a pre-emptive method of crime prevention that aims to reduce the opportunities for crime to occur during the first phases of facility development (Sakip and Abdullah, 2012).

This study assessed the level of awareness and perception of CPTED principles in the local construction industry. For the study, the Contractors, Architects, and Design Consultants were considered as the target audience for the primary data collection. The surveyed organizations operated within the geographical boundaries of Karachi city. To be able to address a problem, the first step is to understand the stakeholders in terms of their level of perception and awareness. And to that end, this study is the first attempt to minimize the research gap. The study had been undertaken to benchmark the awareness and perception of primary stakeholders of the AEC industry concerning CPTED. The outcomes of the study include convergence and divergence of perception and awareness of the selected stakeholders from the local industry.

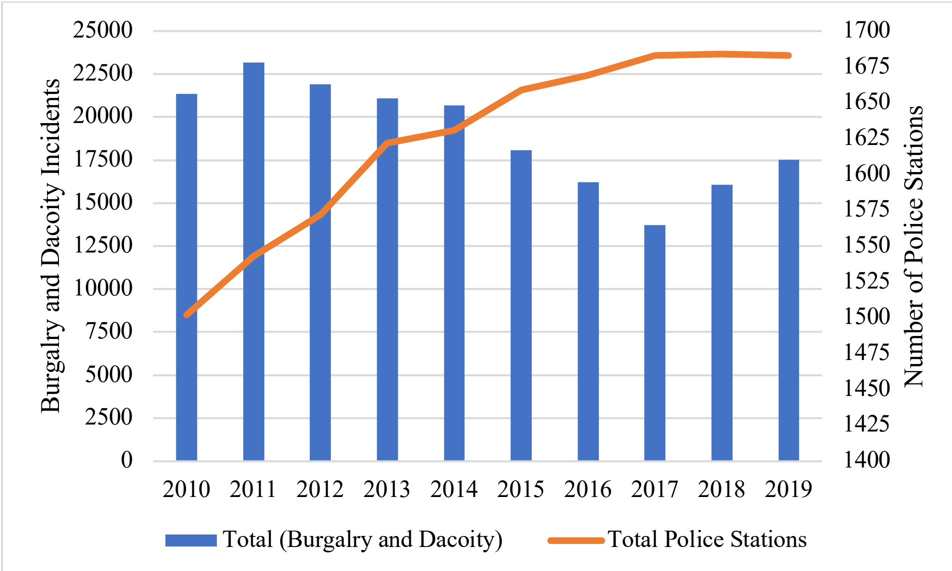

Fig 1: Total Burglary-Dacoity VS Police Stations-Data Source: Pakistan Statistical Yearbook (2019).

2. Literature Review

The process of documenting minimum requirements for physical security combinations in a risk environment is labor-intensive (Garcia, 2001). Therefore, in recent years, crime prevention has gotten a lot of attention. It entails the management of the environment in which people live and work, as well as analysis of the elements that make some surroundings more vulnerable to crime than others. Criminal prevention lays some attention on the built environment's attributes and strategies to improve the layout to lessen crime vulnerability. The success of CPTED is based on five main components of (i) Natural surveillance, (ii) Access control (iii) Territoriality, (iv) Exterior maintenance, and (v) Activity Support (Sakip and Abdullah, 2012). Each one of the listed components will be elaborated in the succeeding sections and subsections.

2.1. Natural Surveillance

Residents and their agents can benefit from natural surveillance opportunities provided by the physical design, (Painter and Tilley, 1999). To maximize visibility, it encompasses the placement and usage of physical structures, mechanical and electrical systems, and people. If offenders believe they are being watched, the danger of being caught increases, and they are less likely to commit an offense (Weisel, 2002).

2.2. Access Control

The notion of 'access control' centers on limiting opportunities for crime by barring access to possible targets and instilling in offenders a heightened sense of danger. It focuses on entrance management and design tactics, as well as gardening, fencing, exits, and lighting, to direct walkers and vehicles in a smooth flow while deterring criminal activity (Cozens, 2002). This idea entails using design to control the flow of people into and out of a certain place (Parnaby, 2007).

2.3. Territoriality

Historically, territoriality has been defined as a tactic that uses reinforcing conceptions of property to instill a sense of proprietorship in lawful users of space, hence reducing criminal prospects and discouraging unauthorized users (Cozens et al., 2005; Ham-Rowbottom et al., 1999). According to studies, burglars choose more vulnerable properties in their decision-making process, and these environmental indicators help to safeguard privacy (Brown and Altman, 1981). Increased occupancy signs, together with dogs, alarms, and close neighbors, are powerful deterrents for intruders (Weisel, 2002).

2.4. Exterior Maintenance

The superiority of housing quality has an encouraging and substantial link with occupants' perceptions of safety, whereas victimization and housing quality have a negative relationship (Austin et al., 2002). Litter, vandalism, graffiti, burned-out lights, and unkempt trees and plants can all be blamed for maintenance issues. Maintenance efforts cover a wide range of activities aimed at keeping the home looking neat and tidy. In comparison to burgled residents, non-burgled residents exhibited more pride in the appearance of their homes in a previous study (Brown and Altman, 1983). Furthermore, another study discovered that poor care and a lack of outside décor were linked to crime susceptibility (Cozens, 2005, 2008; McKay, 2007).

2.5. Activity Support

The construction of a setting that makes it more likely for genuine users to use the space and, as a result, acts as extra surveillance. Although many people consider activity support to be a separate concept of CPTED, the goal is to improve surveillance, therefore the two principles can be merged (Armitage, 2013).

3. Research Methodology

Scanning pertinent secondary data in the form of research publications was the first step of this effort. Data was gathered for this purpose, as well as the creation of a knowledge base for the exercise. The investigation, however, necessitated a large amount of primary data. To do so, a survey was launched to collect more replies from the target audience. The survey results were then examined to draw conclusions and make recommendations for improvement.

To aid the gathering of data through primary sources a thorough literature review was needed. Hence, existing literature in Crime Prevention through Environmental Design formed the secondary data source. The questionnaire for the survey was formulated by screening and comprehending relevant literature within the CPTED domain. In particular, the research conducted by Marzbali et al., (2012) was especially concentrated upon. It was used to extract the checklist to establish definitions for each of the CPTED Aspects. The questionnaire structure was comprised of the following sections.

- Part A: Assessing the awareness and perception of primary stakeholders of the AEC industry concerning CPTED. The data was collected on a five-point Likert Scale where 1 represented, 'Lowest Agreement' and 5 represented, 'Highest Agreement' respectively. Part A was subdivided into five CPTED aspects. The list developed by Marzbali et al., (2012) has been referred to for this benchmarking study. The statements for each of the five CPTED Aspects are as follows:
    - Aspect-I: Natural Surveillance — Number of Statements: 10 (A1-A10)
    - Aspect II: Access Control — Number of Statements: 08 (B1-B8)
    - Aspect III: Territoriality — Number of Statements: 10 (C1-C10)
    - Aspect IV: Exterior Maintenance — Number of Statements: 08 (D1-D8)
    - Aspect V: Activity Support — Number of Statements: 06 (E1-E6)
- Part B: Demographic information of the respondents and the participating organizations.

The collected data was analyzed qualitatively with the calculation of weighted averages as per the Likert Scale (Highest Agreement to Lowest Agreement). Based on the values, the factors were ranked to meet the objectives set for this study

4. Data Results, Analysis and Discussion

The study had been undertaken to benchmark the awareness and perception of primary stakeholders of the AEC industry concerning CPTED. The data was collected on a 5-point Likert Scale; where 1 represented, 'Lowest Agreement' and 5 represented, 'Highest Agreement' respectively. For the data collected, a weighted average was calculated (the same have been presented in Table 2 to Table 6. The three highest agreed (weighted average) factors that define each CPTED Aspect are plotted in Figure 2 to Figure 6 respectively. The summary of response rate is summarized in Table 1.

Table 1: Survey Response Summary

Target Audience	Total Sent	Total Responses

Contractors	30	13
Design Consultants	30	09
Architects	30	09
Total (%)	90 (100%)	31 (34%)

4.1. Awareness and Perception Concerning CPTED

The awareness and perception concerning CPTED are evaluated based on five elements (as discussed in Section 5.1 to 5.5. They are Aspect-I: Natural Surveillance; Aspect II: Access control; Aspect III: Territoriality; Aspect IV: Exterior Maintenance; Aspect V: Activity Support respectively. Using the responses received, an agreement weighted average (W.A) was calculated for each of the statements for all three stakeholders. The analysis included sorting the statements with respect to their respective weighted averages in descending order, this was carried out for all three stakeholders. Once the sorting was complete, the top three statements were selected to be presented in Table 2- Table 6 below.

Each of the analyses presented in succeeding tables is looked upon in two aspects. Firstly, what are the common top three statements among the stakeholders. Secondly, based on the agreement weighted averages, is there any deduction that can be drawn for awareness and perception threshold for the three stakeholders surveyed.

4.1.1. Aspect-I: Natural Surveillance

The top three agreed statements and respective weighted average that define the Natural Surveillance aspect is presented in Table 2 below.

Table 2: Stakeholders' Top 3 Agreement Statements to Define, 'Natural Surveillance'

Rank	Contractor	Architect	Consultant
1st	A3. The physical design has the capacity to promote natural surveillance opportunities for residents (*W.A=3.53)	A1. By including certain principles in new construction, from the design stage, we can make the built environment safer from the start (*W.A=2.07).	A6. If offenders perceive that they can be observed, they may be less likely to offend (*W.A=1.93).
2nd	A4. Surveillance (such as neighborhood Watch) is part of the capable guardianship (*W.A=3.47).	A10. The flow of activities can be channeled to put more people/ observers near a potential crime area (*W.A=1.93).	A8. Landscape elements which remove or reduce visibility opportunities can provide concealment places for offenders (*W.A=1.86).
3rd	A1. By including certain principles in new construction, from the design stage, we can make the built environment safer from the start (*W.A=3.33).	A3. The physical design has the capacity to promote natural surveillance opportunities for residents (*W.A=1.80)	A9. Failure to trim trees and shrubs around a building has no contribution in providing opportunities for burglars (*W.A=1.86).

* W.A= Weighted Average

From observing the analysis presented in Table 2, it can be observed that the two stakeholders (Contractors and Architects) consider physical design to provide natural surveillance opportunities and buildings can be made safer by including certain parameters from the start. Although statements A3 and A1 occur in the top three for both stakeholders, the disparity in the weighted average score (W.A) suggests weak awareness of Architects. However, the Consultants do not have the same perception; in fact, neither of their top three statements are common with the other two stakeholders. This hint at vastly different awareness level between Consultants and Architect-Contractor group. In addition, for Consultants, the top three statements lie within the 'Lower Agreement': respective Likert Scale of '2'. This itself suggests lacking awareness about related concepts.

4.1.2. Aspect II: Access Control

The top three agreed statements and respective weighted average that define the Access Control aspect is summarized in Table 3 below.

Table 3: Stakeholders' Top 3 Agreement Statements to Define, 'Access Control'

Rank	Contractor	Architect	Consultant
1st	B7. Properly located entrances and exits can direct both foot and vehicular traffic in ways that decrease criminal opportunities (*W.A=3.33).	B1. Opportunities for crime can be tremendously reduced by denying access to potential targets (*W.A=2.40).	B8. Proper landscaping and lighting can subtly direct both foot and vehicular traffic in ways that decrease criminal opportunities (*W.A=2.13).
2nd	B2. A high perception of risk to offenders can be achieved by denying access to certain places (*W.A=3.27).	B8. Proper landscaping and lighting can subtly direct both foot and vehicular traffic in ways that decreases criminal opportunities (*W.A=2.06).	B4. The design of a facility can be managed to control the ingress and egress of persons to and from a specific space (*W.A=2.06).
3rd	B6. Access control to and from a building facility is sufficiently achieved in individual dwellings or commercial establishments using adequate locks, doors, and window barriers (*W.A=3.27).	B4. The design of a facility can be managed to control the ingress and egress of persons to and from a specific space (*W.A=1.67).	B1. Opportunities for crime can be tremendously reduced by denying access to potential targets (*W.A=1.53).

* W.A= Weighted Average

As summarized in Table 3, Architects-Consultants share some common perceptions regarding the Access Control Aspect that denying access can lead towards reduction in opportunities. However, both Architects-Consultants selected that through landscaping, provisions can be made that provide opportunities for pedestrian and vehicular traffic to decrease criminal opportunities, but the disparity in the respective weighted averages (W.A of 2.40 VS W.A of 1.53) hint at a lacking awareness amongst the Consultants. However, an interesting finding to note is that none of the statements are common for Contractors, it seems that they perceive the Access Control Aspect of CPTED very differently from the other two stakeholders.

4.1.3. Aspect III: Territoriality

The top three agreed statements and respective weighted average that define the Territoriality aspect is shown in Table 4 below.

Table 4: Stakeholders' Top 3 Agreement Statements to Define, 'Territoriality'

Rank	Contractor	Architect	Consultant
1st	C10. Territorial reinforcement can work because of users' familiarity with each other and the surroundings (*W.A=3.33).	C10. Territorial reinforcement can work because of users' familiarity with each other and the surroundings (*W.A=2.67).	C9. Territorial reinforcement can work even with its ambiguous directness (*W.A=2.40).
2nd	C4. Surveillance and access control may be, contributed toward fostering territorially (*W.A=3.27).	C1. Landscape planting is ineffective in marking the difference between private and public spaces, is used to define property lines (*W.A=2.33).	C6. Increasing occupancy signs is an effective device to deter burglars (*W.A=2.20).
3rd	C5. Reinforcing notions of property that bring a sense of ownership in legitimate users of space (*W.A=3.07).	C9. Territorial reinforcement can work even with its ambiguous directness (*W.A=2.27).	C1. Landscape planting is ineffective in marking the difference between private and public spaces, is used to define property lines (*W.A=2.07).

* W.A= Weighted Average

As per the analysis of the data collected, it can be observed that Architects-Consultant share a common perception because they have commonly selected landscaping planting and territorial reinforcement as statements to define the Territoriality aspect. However, the lower value of weighted average for agreement for the statement establishes a lacking of Consultants' awareness thresholds. Whereas Contractors and Architects share a moderately common perception as they both share one common statement amongst themselves. According to them the top statement to define Territorial Aspect is the functionality of territorial reinforcement because of the user's familiarity with it. With the weighted averages closer to each other, it can be deduced that the awareness level is similar.

4.1.4. Aspect IV: Exterior Maintenance

The top three agreed statements and respective weighted average that define the Exterior Maintenance aspect is presented in Table 5 below.

Table 5: Stakeholders' Top 3 Agreement Statements to Define, 'Exterior Maintenance'

Rank	Contractor	Architect	Consultant
1st	D1. Enhancement, maintenance, and management of the built environment encourage the users of the area to respect their surroundings (*W.A=3.60).	D1. Enhancement, maintenance, and management of the built environment encourage the users of the area to respect their surroundings (*W.A=2.20).	D5. There is a positive relationship between victimization and housing quality (*W.A=2.27).
2nd	D4. Housing quality has a positive and significant relationship with residents' perception of safety (*W.A=3.40).	D4. Housing quality has a positive and significant relationship with residents' perception of safety (*W.A=2.20).	D4. Housing quality has a positive and significant relationship with residents' perception of safety (*W.A=2.13).
3rd	D3. The quality of the home environment has a persistent effect on the individual's quality of life (*W.A=3.40).	D3. The quality of the home environment has a persistent effect on the individual's quality of life (*W.A=2.13).	D8. Experience has revealed that poor maintenance and lack of exterior decoration were associated with vulnerability to crime (*W.A=2.07).

* W.A= Weighted Average

As per the data collected, the initial analysis suggests a similarity of perception between Contractors and Architects for the Exterior Maintenance Aspect. This can be asserted by observing the fact that for both stakeholders the top three statements to define the respective aspect of CPTED is the same However, a closer inspection reveals the fact that both stakeholders' awareness thresholds are vastly different. Contractors' perception is comparatively on a higher side since weighted averages being greater than 3.00 and for Architects the same statements have a weighted average on the lower side of the Likert Scale. In addition, housing quality and its relationship with resident safety is rated at a medium importance level by Architects and Consultants and at higher importance by Contractors. However, housing quality and its relationship with resident safety is rated by all three stakeholders as one of the top three significant parameters to define CPTED in general and the Exterior Maintenance Aspect of CPTED; in particular.

4.1.5. Aspect V: Activity Support

The top three agreed statements and respective weighted average that define the Activity Support aspect is depicted in Table 6 below.

Table 6: Stakeholders' Top 3 Agreement Statements to Define, 'Activity Support'

Rank	Contractor	Architect	Consultant
1st	E1. The design of the space, besides fulfilling functional objectives, should create an aesthetically pleasing environment that a person can enjoy (*W.A=3.60).	E1. The design of the space, besides fulfilling functional objectives, should create an aesthetically pleasing environment that a person can enjoy (*W.A=1.93).	E6. Bright and vibrant finishes create a sense of safety (*W.A=2.27).
2nd	E3. Unused and unusable "dead spaces" should be avoided (*W.A=3.40).	E3. Unused and unusable "dead spaces" should be avoided (*W.A=1.80).	E1. The design of the space, besides fulfilling functional objectives, should create an aesthetically pleasing environment that a person can enjoy (*W.A=2.13).
3rd	E2. The security aspects should be considered as part and parcel of designing the space and fulfilling aesthetic values (*W.A=3.33).	E4. The design of the space should address nighttime use (*W.A=1.73).	E3. Unused and unusable "dead spaces" should be avoided (*W.A=1.87).

* W.A= Weighted Average

From the overview of Table 6, it can be deduced that Contractors and Architects share a common perception of the Activity Support Aspect of CPTED (two out of three common statements) but after a closer inspection of the agreement weighted averages, it becomes apparent that Contractors have a better awareness threshold in comparison to Architects. Similarly, for the Architects and Consultant group, they too share two common statements amongst them but with a smaller difference for the agreement weighted averages. This indicates a similar level of awareness for the Architects and Consultants. In addition, with varying degrees of agreement, all three stakeholders agree that dead spaces should be avoided to promote the activity support aspect of CPTED. This hints at a similar awareness level for the Architects and Consultants.

5. Conclusions

From the analysis of the collected data, the summary of the results is presented in Table 7. The thought process in formulating the table is the presentation of Common Perception Group of Stakeholders, Moderately Common Perception Group, and Majorly Different Perception Stakeholder. following conclusions can be drafted for each of the five aspects of CPTED. For inferential statistics, 1 tail heteroscedastic t-test b/w Common Perception Group was carried out at the level of significance 0.05.

Table 7: Summary of Analysis

CPTED Aspect	Common Perception Group	Moderately Common Perception Group	Majorly Different Perception Stakeholder	Remarks	Inferential Statistics
Aspect-I	Contractor-Architect	-	Consultant	2 out of the top three statements common between Contractor-Architect; No statement is common for Consultants.	The t-test is significant to establish Contractors' perception to be better than Architects
Aspect II	Architect-Consultant	-	Contractor	2 out of the top three statements common between Architect-Consultant; No statement is common for Contractor.	The t-test is insignificant to establish Architects' perception to be better than Consultants.
Aspect III	Architect-Consultant	Contractor-Architect	-	2 out of the top three statements common between Architect-Consultant; 1 out of top three statements common between Contractor-Architect	The t-test is insignificant to establish Architects' perception to be better than Consultants.
Aspect IV	Contractor-Architect	Architect-Consultant	-	All three statements are common between Contractor-Architect; 1 out of the top three statements common between Architect-Consultant	The t-test is significant to establish Contractors' perception to be better than Architects.
Aspect V	Contractor-Architect Architect - Consultant	-	-	2 out of the top three statements common between Contractor-Architect and Architect-Consultant respectively.	The t-test is significant to establish Contractors' perception to be better than Architects. The t-test is insignificant to establish Architects' perception to be better than Consultants.

The study had been undertaken to benchmark the awareness and perception of primary stakeholders of the AEC industry concerning CPTED. Based on data analysis, the following conclusions are drawn.

Aspect I- Natural Surveillance: Based on the top three common agreement factors defining Aspect-I, Contractor-Architect shared some commonality of awareness and was tested statistically that Contractors' awareness threshold was better than its comparison stakeholder. Consultants had been found to have a different perception owing to the non-commonality of any of their top three statements with either of the other two stakeholders.

Aspect II- Access Control: On the basis of the top three common agreement factors defining Aspect-II, Architects-Consultants shared some commonality of awareness and were tested statistically to establish that Architects do not have a better awareness threshold. Contractors had been found to have a different perception owing to the non-commonality of any of their top three statements with either of the other two stakeholders.

Aspect III-Territoriality: Driving upon the values of the top three common agreement factors that were used to define Aspect-III; Architect-Consultant shared some cohesion of awareness. Upon statistical testing, it was insignificant to state that Architects' perception was better than Consultants.

Aspect IV- Exterior Maintenance: Centered around the top three common agreement factors defining Aspect-IV, Contractor-Architect were observed to converge into a common awareness about Aspect-IV. When it was tested, the result suggests that it is significant to establish Contractors' perception to be better than Architects.

Aspect V- Activity Support: Examined based on top three common agreement factors defining Aspect-V, Contractor-Architect, and Architect – Consultant shared a commonality of awareness for the factors defining Aspect-V respectively. Statistically speaking, it is significant to establish Contractors' perception to be better than Architects and insignificant to institute Architects' perception to be better than Consultants.

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VR-Enabled Participatory Design of Educational Spaces: An Experiential Approach

Dr. Poorang Piroozfar[1,2,3,4], Mr. Imran Farooqi[1], Mr. Alex Judd[3], Mr. Simon Boseley[3], Dr. Eric R. P. Farr[2,3,4]

[1] School of Architecture, Technology and Engineering, University of Brighton, Brighton, BN2 4GJ, UK
[2] Digital Construction Lab, University of Brighton, Brighton, BN2 4GJ, UK
[3] MAVRiC Research and Enterprise Group, Shoreham-by-Sea, BN43 6AX, UK
[4] NONAMES Design Research and Studies, 1249 F Street, San Diego, CA 92101, USA
A.E.Piroozfar@brighton.ac.uk

Abstract

Classrooms can have an impact on enthusiasm towards learning and aid teaching; given the day-to-day experiences and difficulties teachers endure, they possess a unique perspective on how to better facilitate the tutoring experience in their classrooms. Existing review of literature indicated clear areas for improvement in classroom design using participatory design (PD) approaches where virtual reality (VR) technologies can be utilized as an effective tool to facilitate this collaborative process. To address some of the existing knowledge gaps in this area, a study was designed to gauge teachers' views on the teaching environment of their classrooms to be used to develop a collaborative design tool in VR. Considering the conventional nature of classroom design, the feedback collated from the survey was used to provide designers with the end-users' input they were otherwise less likely to be able to incorporate into their design. These findings were used to design a VR experiment to facilitate teacher's participation in the design process. The findings indicated that the teachers showed a surprising level of awareness of the design elements in educational spaces and the approach of this study. It was also noted that some of the teachers' implicit knowhow regarding the design and layout of their classroom was very difficult, if possible, at all, to capture and apply using more conventional collaborative approaches to design, hence the significance of the current study.

Keywords

Virtual Reality, Participatory Design, Design Collaboration, Educational Spaces, Classroom Design

1. Introduction

It has been suggested that educational architecture has become stagnant due to the 'one size fits all' attitude towards classroom design and warn against using the "evidence from the past to inform a very similar future, when what is needed is a new approach and new solutions for school design to reflect the changing needs of learning in the 21st century" (Higgins et al., 2005: p. 4). Recent developments in design theory advocate for a more significant role for space end-users which has given rise to developments and advancements in PD. It is argued that if end-users are given the opportunity to proactively participate in the design process, this will contribute to the production of more workable and useful spaces. Traditional ways to facilitate PD are relatively researched and developed. There is limited evidence to suggest that advanced technologies such as augmented reality (AR) and VR have been trialed and utilized effectively in this area. Considering this theoretical vantagepoint, when this is being applied in the design of educational spaces, teachers - similar to any other non-expert end-user groups - may struggle to understand the implications of design decisions. To address this gap in knowledge, this study aims to use VR to facilitate the participatory process in the design of educational spaces. This research starts with a working hypothesis that VR can facilitate PD above and beyond conventional methods to improve collaborative design processes. To operationalize this working theory, this study used a qualitative research methodology where a questionnaire was formulated to collect teachers' expert perspectives on design of their classrooms and how this would affect their working environment. This was used to develop a VR experiment whereby non-design-expert users could partake in the collaborative design of their classroom space. This paper addresses the process underlying the development of the VR experiment building upon the existing knowledge gathered through literature review and contextualized through the surveys carried out with a sample group of teachers in the UK. The findings indicated that teachers demonstrated a remarkable level of awareness of design elements in educational spaces and showed appreciation towards the approach of this study. The study indicated that capturing teachers' tacit knowledge of their profession can be used to inform the classroom design. However, this might not prove an easy or straightforward task to fulfill. The significance of this study lies in using an alternative and potentially more intuitive interactive approach compared to conventional collaborative approaches to design.

2. Literature Review

2. 1 Classroom Design

Classroom design offers an opportunity to enhance the teaching environment. In his revolutionary approach to pre-tertiary education, Malaguzzi suggests that spaces can reflect the actions within an environment and mirror ideas and attitudes. He believes that spaces can promote social relationships between people, choices, and activities, as well as influencing organization and cognitive learning (Edwards et al., 1993). Dudek (2000) also expresses that physical factors and dimensions of a classroom can affect the users' cognitive and social skills. Sommer and Olsen (1980) explored this through an experiment where student behavior and performance were observed during a class, across different classrooms, and concluded that participants were more engaged with the teacher in rooms that were more pleasant, which also reflects Malaguzzi's values (Edwards et al., 1993). CABE (Commission for Architecture and the Built Environment) Commissioner Emeritus, believes that the science of designing learning environments has so far been considerably underdeveloped (Higgins et al., 2005).

It has been suggested that there is a direct link between student attention and light quality (Dunn et al., 1985) which is correlated to windows and shading devices' location, size and configuration, but also affected by other factors. Windows add some positive characteristics, such as larger or more interesting views, as well as some negative ones potentially associated with glare and sun penetration (Aumann et al., 2004; Barrett et al., 2016). Internal shading systems have been suggested as a solution which are easy to operate by teachers (Barrett et al., 2016). Daylight is a significant factor that attributes towards the well-being of space users (Wurtman, 1975). However, this entails the use of large glass panes, high ceilings and openable windows which may contribute to longer reverberation times, requiring a tradeoff between acoustic distractions and daylight gain. On the other hand, artificial lighting can impact emotions, behavior, and levels of energy (Wurtman, 1975). Research shows that using full spectrum lighting mitigates all distracting factors associated with artificial lighting (Karpen, 1998). Previous research shows that the autonomic nervous system and visual cortex are both stimulated differently when different illumination colors are experienced, with blue illumination leading into increased relaxation, decreased anxiety and hostility compared to red and white illumination (Gerard, 1958 in Hathaway, 1982). Wohlfarth and Sam (1981) found that by using relaxing shades of blue the aggressive behaviors in a small group of severely handicapped children could be reduced, inducing a less stressful environment. The layout and location of storage in a classroom is another substantial design element in classrooms. Loughlin and Suina (1982) suggests that teachers may lose track of classroom supplies if they are not present within the classroom. However, McGonigal (1999) expresses the concern that an excessive amount of indoor storage encourages dust to form thereby impacting the indoor air quality.

2. 2 Virtual Reality

For a person to have full spatial cognition they must be able to establish cognitive mapping (Briggs et al., 1973 in Walmsley et al., 1990). Spatial cognition can be identified by three correlating features: "space itself, containing immovable structures and landmarks; objects within the space, which move or change state under certain conditions; and actors whose actions cause changes within the environment" (Dalgarno, 2002: p.154). This provides the necessary information required for consciousness within an environment. According to MIT.nano Immersion Lab, virtual reality can be defined as "a computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way". McLellan (1996) asserts that when implementing VR, immersion is a critical feature to comprehend an environment. Dalgarno et al. (2002) suggest immersion is only possible with a high level of interaction and fidelity of representation. Song et al. (2018) claim that by incorporating a trackball, HMD and data gloves users are more likely to experience full immersion. Fig 1 shows the different types of technology and their associated reality/virtual immersion possibilities.

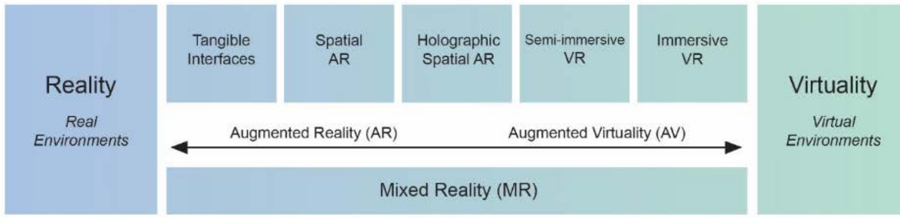

Fig. 1. Reality-virtuality continuum based on Milgram and Kishion (1994)

VR provides architectural designers with a better understanding of size and scale (Häkkilä et al., 2018), as well as the ability to effectively plan and rehearse job specific tasks (Sacks et al., 2013). Li et al. (2018), states that a VR application with a higher degree of immersion typically requires more advanced hardware. Sometimes this is not possible, and they add that designing VR technologies requires a technology trade off. Freina and Ott (2015), believes that the implementation of VR is usually associated with a high cost. Kavanagh et al. (2017) counter argues this by suggesting that VR can still be achieved through the use of smartphone applications and a cardboard headset.

2. 3 Design collaboration and participatory design

Chiu (2002) believes organization and structure can be used to ensure collaboration between teams with different end goals in a project. Craig and Zimring (2000) argue that unstructured collaboration can be more efficient, as it is less fatiguing while still offering diverse perspectives absent of any self-interest, which has been the case in design studios for years. Holmlid (2012) explains PD as end-users contributing experience to help designers better understand their needs and wants. Expanding on this, he refers to the Gulliver project in Cologne, where homeless people were involved in the design process of a self-help center. On the contrary, Molapo and Marsden (2013) warn that relying on non-technical participants disproportionately may lead to statutory non-compliance in design. Korpela et al. (1998) believe that community members that will use the space should also be involved in the design process to provide a broad range of perspectives. Blomberg et al. (1993) believe that collaborative design methods may be more beneficial to the end users than they could be to the designers. Demirbilek and Demirkan (2004) also add that the logistics required for collaboration can be time and resource consuming. Hussain (2010) believes participants that lack some basic understanding of the project may shy away from collaboration and further adds that offering some pre-understanding can create an environment where participants feel secure to share opinions. Brun-Cottan and Wall (1995) assert that in PD, the gap in technical understanding can be bridged with the use of graphical information.

3. Research Design and Methodology

This paper presents the process devised to support the design and development of a research instrument for a research project which aims to gauge the educational space users' expert views and their participatory design experience using VR technologies. A critical review of the literature was carried out to construct the underpinning of this study around PD, application of VR technologies, and design of educational spaces (classrooms). The study uses a mixed methodology. The primary research methods consisted of an online questionnaire designed for school teaching staff. The data collated from the literature was used to inform the design of the questionnaire. The questionnaire was designed to record participants' background (age, gender, teaching subject, key teaching stages), their understanding of VR (the concept and how design elements might affect their teaching) and their professional opinion regarding classroom design factors as indicated in this study. All data collection procedures were designed and conducted according to GDPR and were vetted and approved by the University of Brighton's Tier 1 Research Ethics Committee.

4. Data Collection and Analysis

4. 1 Participants Background

10 teachers participated in the survey (gender: 8 Female/2 Male and age range: 4: 18–24, 1: 25-34, 3: 35-44 and 2: 45-50). The participants were mixed in their teaching subject (2: languages, 3: science teachers, 1: English, 1: humanities, 1: teaching assistant, 2: did not specified) and their key stages [3: key stages 1/2 (primary) and 7: key stages 3/4 (secondary)].

4. 2 Understanding of the Study Background and Context

The participants were asked if they were familiar with VR (Yes: 8/ No: 2), and their awareness of design elements within a classroom (No: 4/ Yes: 6). When asked to provide additional comments, participants stated: “poor layouts encourage disruptive behavior” and can “increase difficulty to navigate the classroom”, “the location of windows affects the visibility of the display white board”. Furthermore, the availability of technology in the classroom was also raised as a general concern. Subsequently, the participants were asked if they were satisfied with the layout of their classrooms (No: 6/ Yes: 4), and when asked to provide further clarification “creating a calming environment through display boards” and “ensuring adequate storage was provided” were some of the positive points noted, while “limited natural daylighting”, “uninspiring layouts”, “insufficient displays boards”, “storage in other classrooms” and some H&S concerns were among the negative points raised.

The next question was aimed to determine whether these factors impede teaching styles (No: 3/ Yes: 5/ No answer: 2). Participants highlighted reduced classroom size as having an impact on decisions on group work, small whiteboard impacting quality of notes and large windows creating acoustic [noise] distractions. The question about the participant's ideal classroom indicated that the majority were in agreement that acoustic performance, layout flexibility and natural lighting were elements to be included. It was also mentioned that the classroom's internal finishes should be easy to maintain, and modern equipment [no specifics were given] should be provided.

4. 3 Classroom Design

The teachers were asked if, in their current practice, the level of lighting is changed to suit specific teaching activities (Y: 7/ N: 3). The general consensus was that a low level of lighting was used when presenting digital media and when students are copying notes from the boards, and higher level of lighting were utilized when students were reading or having a group discussion. Dimming was used to calm the students down; this was achieved through dimmers when available, blinds and/or by switching main lights off. Participants were then asked if they find their current lighting fixtures practical (Y: 6/ N: 4) and they described fluorescent lighting as undesirable due to high glare and preferred having two independent lighting sources to be able to afford broader control. The next question was aimed at determining the preferred lighting warmth in the classroom (Warm: 4/ Neutral: 6/ Cool: 0).

The next series of questions were aimed at teacher’s opinions of their classroom layout including how often they changed the layout and if the layouts provided enough circulation spaces. The majority of respondents found their current layouts convenient (Convenient: 5/ Inconvenient: 3/ Not noticed: 2). When asked about how many times per week they changed the layout, the majority did not change the layout (0:6/ 1-2:2/ 3-4:1/ 5+:1). Most teachers felt they were not provided with sufficient circulation space (N:6/ Y:4). There was a mutual opinion among all the responses that a lack of circulation space creates a static teaching environment, impeding creative teaching styles and “causing difficulty in 1-on-1 teaching”. Participants were then asked if there were any visual distractions and if so, what the source of those distractions were (Y:9/ N:1). It was noted that “large windows provide acoustic [noise] and visual distractions”. It was also mentioned that impact “noises from floors above can cause disruptions”. The majority of teachers also stated that the internal shading devices do not contribute to any distraction (No distraction:7/ distraction: 3).

When asked about white board preference, the majority favored using an interactive whiteboard over traditional whiteboards with marker pens (Interactive:9/ Traditional:1). It was expressed that these smart boards are now a necessity as they can easily facilitate other learning resources and applications including “YouTube” and “PowerPoint”. Most participants preferred the whiteboard(s) on one wall only (Single wall:6 Two walls:4); some believed that creating a singular point of interest will help retain students’ attention, whereas some others suggested that display on multiple walls will ensure all students have eyesight of information being displayed.
The next set of questions aimed to understand the participant’s current use of storage cupboards and preferred location. The number of usages per day showed some interesting patterns where the majority of participants used the storage three times or more per day (1:1/ 2:2/ 3+:7). They also stated that they preferred to have their storage within the classroom as opposed to a storage room (within classroom: 9/ storage room: 1).

When asked how many display boards participants would prefer, the majority chose more than one (1:1/ 2:2/ 3:4/ 4+:3). When asked where the participants would prefer the location of the entrance door, a mixed response of Front:4, Back:4 and Middle:2 was provided. It was also noted that multiple entrances would be desirable, and that having the door located at the back would minimize distractions from hallways and arrival of late students.

When asked about window preference, majority of teachers preferred an openable window (Openable:9/ Fixed:1); out of nine who preferred openable windows, six preferred horizontal [casement] and three vertical [sash].

When asked if participants preferred a specific wall color, the majority said yes (Y:7/ N:3), explaining that neutral colors should be closer to white to avoid students getting distracted and to give an optical illusion of a larger room. Conversely, It was highlighted that [pure] white walls may be subject to easier and faster wear and tear, whilst also reducing stimulation of students.

The participants were then given a chance to mention any additional features they would have liked to have control over to improve the overall learning experience of their pupils'. A point was raised about including an automatic shading device that can adjust according to the natural light intensity. Comments were also made in regards to providing additional storage and more comfortable [ergonomic] chairs for students.

5. Discussion of Findings and Concluding Comments

5. 1 Significance of Primary data for development of the application

This research built upon the existing literature to set the boundaries of the experiment in identifying the elements and factors which could and should have been incorporated in the design of the VR experiment. However, we extended the scope of this study by including primary data collected from a sample of school teachers in key stages 1-2 and 3-4 in the UK pre-tertiary education system. It was important to bear in mind that there was significant non-conformity between the primary data with what was suggested by the literature, the primary data was prioritized in development of the VR experiment. For instance, current research did not conform to previous research where it has been suggested that storage should be within teachers' eyesight (Loughlin & Suina, 1982). However, participants voiced concerns regarding storage being poorly placed. Therefore, static storage placement was considered in this study and an option to enable teachers to dynamically place storage in their preferred locations was left out for future research.

5. 2 Primary and secondary data alignment for application development

Previous research suggests that participants' involvement in PD is subject to their comprehension of the assignment (Hussain, 2010). Although participants in the current study were familiar with VR technologies, they had not utilized it. This indicates the importance of incorporating an application tutorial, ensuring participants are capable of running the application without any external assistance. Previous research also indicates that the PD process can be time consuming (Bodker, 1996), the tutorial aims to minimize the practice period.

Although light colors were documented as a means to increase stimulation and decrease anxiety in previous research (Gerard, 1958 in Hathaway, 1982), the primary data did not record any teachers' use of different colored lighting. It has been suggested that participants are unable to differentiate effects of different colors shown to them on a piece of paper out of context. It was found that teachers use different levels of light intensity (lux) depending on the task and the use of digital media. This research aimed to address this gap from a slightly different angle by providing the participants with an ability to control the light warmth levels (Kelvin). This can be expanded to light intensity and color in future research.

5. 3 Promoting proactive user participation in design process

Current research concurs with previous research where it has been suggested that spaces present opportunities to nurture cognitive thinking; where teachers asserted that poor classroom layouts affect behavior and the ability to physically access students. Giving teachers the ability to re-configure their classroom layout with variety encourages involvement in the design review process without conflicting participants with a predetermined 'correct' result. This in turn creates a user-friendly platform, enabling teachers' participation in the design process without needing to have specialized design knowledge, expertise, or experience.

Classroom layouts are subject to change depending on activities considering that physical factors can affect students cognitive and social skills (Dudek, 2000). Comparatively, the primary data showed that teachers felt space restriction forced them to stick with static teaching, which hindered creativity in teaching. To use VR to help plan job specific tasks (Sacks et al., 2013), the VR application developed in this study presented participants with the ability to create typical layouts for multiple activities. Additionally, the approach used by teachers can help broaden the designers' comprehension of teaching needs and requirements. Following on from this research, the next stage of this study will consider ways to document the teacher's decisions, so a design feedback loop can be established to help future designers of educational spaces.

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ID 74

The Future of Automated Plant in Construction – A UK Perspective

Cormac Browne[1*], Ross Walker[2†], Ianto Guy[1], Tim Embley[3], Muneer Akhtar[4], Amer Essa[4], Annette Pass[4], Simon Smith[2], Alex Wright[1]

[1] Transport Research Laboratory (TRL), RG40 3GA, Wokingham, UK
[2] University of Edinburgh, EH8 9YL, Edinburgh, UK
[3] Costain, SL6 4UB, Maidenhead, UK
[4] National Highways, GU1 4LZ, Guildford, UK
cbrowne@trl.co.uk

Abstract

Within the construction industry, heavy mobile machinery is typically known as plant. Plant has seen a transformation from its earliest, animal powered form, through steam and combustion engine driven machines through to the modern multifunctional devices applied in construction across the globe. However, construction is facing a number of significant social, environmental, and technical challenges. In response there has been a rising interest in the use of digital and automated technologies which can be applied to the construction sector. One particular aspect of this is the use of Connected and Autonomous Plant (CAP) to replace traditional, human operated machinery. Incorporating CAP as part of the wider digitalisation of the construction industry promises to deliver gains in productivity, safety, welfare, sustainability, quality, and cost. However, the achievement of these benefits will require a step change in the approach to the design and construction of plant, and in the way that plant operates on construction sites.

This paper presents a potential future for the deployment of plant on construction sites. It discusses how sites could evolve to accommodate the new role of CAP and how people and CAP will need to work together. It discusses how National Highways have been seeking to drive transformation in construction through the development of a vision and roadmap for CAP, which encourages all stakeholders to collaborate and aims to catalyse the development and adoption of these technologies.

Keywords

Connected Autonomous Plant, Construction, Automation, Autonomy, Digitalisation.

1. Introduction

The UK construction industry is facing a number of significant challenges, including the climate crisis, an aging workforce, and rising material and production costs. In response to these challenges there has been a rising interest in the use of digital and automated technologies which can be applied to the construction sector, (Leeds, 2017) and (Jones, 2018). One particular aspect of this is the use of Connected and Autonomous Plant (CAP) to replace traditional, human operated machinery, (McKinsey & Company, 2020) and (HM Government, 2022). The removal of human involvement in plant operation could enable significant improvements to be made in the safety and welfare of construction workers, through the transition to a skilled workforce managing the deployment and operation of automated machines in construction activities, delivering significant improvements to productivity, efficiency, and quality, (Korec, 2006), (Caterpillar, 2016), and (McKinsey & Company, 2021).

However, although industry is clear in expressing its desire for change, there are concerns about the ability to implement these new methods of construction, particularly in the context of the current approach to commissioning and delivering construction projects. The development and implementation of new technologies is expensive and currently these costs are borne by contractors and operators using the equipment, even though the benefits are passed to clients. Furthermore, the plant hire model under which UK construction operate poses challenges to the adoption of new technologies due to the impact on the operation, readiness, and profitability of those ventures. While innovators and early adopters can see the benefits of the new methods, it is likely technology may not have the greatest influence on the rate of adoption – for example if commercial incentives are not clear, decision makers will not select or develop new methods, resulting in inevitable delay.

This paper discusses the background of plant within the construction sector and explores what constitutes the developing CAP technologies. It then sets out a vision for how plant might be deployed as part of the ongoing digitalisation of the construction industry and the activities that National Highways and partners have been undertaking to implement this vision on their current and future construction sites.

2. Background

2.1 History of Plant

Plant includes pieces of mobile heavy machinery which are used to carry out construction activities. The original forms of heavy machinery were human or animal powered assemblies of simple machines, such as the block and tackle or wheel and axle, which were used to provide mechanical advantage when carrying out heavy labour. With the advent of the industrial revolution of the 18th and 19th centuries the human or animal powered nature of these devices changed, initially via steam, through to the internal combustion engine. This provided greater productivity due to the increased capacity of these machines and was instrumental in the delivery of the large-scale infrastructure projects of the 19th and 20th centuries. In modern usage, plant typically refers to Earth-Moving Machines such as dump trucks, excavators, compactors, etc., which remain a core focus on today's jobsites. When we consider automation in construction, it is clear that this will remain the case and such machines will continue as a hugely important strand of what constitutes CAP.

However, there is merit in considering if we should extend the definition of plant beyond its current definition. If we consider plant to be any machine which assists in construction, which would be in-keeping with the Latin origin of the word ('plantere' - to fix in place or to form and make) and the case law definition of "apparatus used for carrying on the business" (HM Revenue & Customs, 2016), this would extend plant to include physically smaller technologies that could be deployed on construction sites. For example, this could include the use of UAVs for surveying, small robotic technologies for pre-marking or laying out sites, or assistive technologies such as collaborative robots for the movement and placement of material.

Plant in UK Road Construction As the landscape of construction in the UK has changed, so has the plant needed to fulfil projects. For example - the greenfield motorway building projects of the sixties and seventies required extensive earth-moving as the high-speed nature of these roads required limited gradient and curve. The roads were unable to follow natural contours of the land and had to be cut into, and elevated above, the natural landscape, (Yeadon, 1990). These projects favoured motorscrapers that were very efficient at moving large volumes of earth. Indeed, these volumes peaked at 48 million m^3 in 1978 and dropped to 30 million m^3 by 1984, (Barker, 1988), as most major routes were in-place. Today much of the work is spread across minor road improvements, bypasses and widening schemes. Although the total volumes of earth moved are still high, the projects tend to require specialised earth-moving, which suits the more versatile dumper / excavator combination, (Alkass & Harris, 1988). This is important to note, as versatile machines that are capable of carrying out many different tasks are more difficult to fully automate, (Dadhich, Bodin, & Andersson, 2016). Hence the emerging examples of CAP currently deploy semi-autonomous functionality and task focused autonomy (e.g., automated grading control on excavators), (Singh, 1997), (Caterpillar, 2016), (Winter, 2020).

2.2 Connectivity

The "Connected" part of CAP refers to plant's ability to communicate with other plant, and other external networks and systems. Sharing information from onboard telematics supports a wide range of uses that can optimise plant operation – for example reducing idle times or improving haul routes. It is likely to become a key constituent of automation, as an enabling technology. Connectivity also allows machines and their environment to be represented in high-fidelity real-time digital twins (Walker, Smith, & Bosché, 2021) to facilitate further automation, as well as simulation-based optimisation of construction sites. This is explored further in Section 3.2.

2.3 Automation vs Autonomy

It is important to distinguish between Automation and Autonomy of construction plant. Automation refers to the conversion of a (well defined) task which is typically carried out by a human to one which is carried out by a machine or computer. Autonomy considers the capacity of a system to operate as an independent unit to complete a task, without being controlled or manipulated by another system or human. For many aspects of construction, the goal will be to establish an automated system to complete the task with no requirement that it operates independently or outside defined and well understood operational constraints. This is explored further below.

However, despite having made this distinction, the term Autonomous is often used to cover both aspects when discussing both on- and off-road vehicles and is intended to imply the lack of a human role in any of the operations of the vehicle. For example, if one piece of plant is carrying out a repetitive well-defined task such as excavating a trench and placing it into a dump truck which transports it to a spoil site, this situation would be described as autonomous activity although each machine is not acting as an independent, self-sufficient unit.

2.4 Operational Design Domain

Whilst the autonomous operation of individual items of plant continues to evolve, it is important to consider that the capability that will be achievable by an item of plant on site will be strongly influenced by the environment in which the plant is operating. This is defined within the Operational Design Domain (ODD) of the plant, which determines the environment and conditions in which the plant can be expected to operate. There are two aspects of the ODD to consider – the basic ODD of that piece of plant (that is, the environment in which this plant could successfully operate even if it had a human controller – e.g., could this equipment work on this grade?) and the ODD of the automating system (the operational environment in which the autonomous system can safely complete tasks without needing human intervention). It is important to note that construction brings unique challenges in both defining an ODD and ensuring that the plant remains within it:

- Construction sites are of variable size and form.
- Construction sites are dynamic, always changing environments.
- Construction sites are exposed to external uncontrollable factors.
- Operations are regularly concerned with modifying the environment in some way.

This greatly contrasts with the situation for on-road vehicles, where one can safely assume that the vehicle will be operating within a defined environment that was created for it to be operating there. However, the routes through which CAP evolves will affect how ODDs may need to be defined and modified - which may themselves be limited or controlled through the use of a well-defined and controlled site, as discussed in the following sections of this paper.

3. Future of Plant Operation

3.1 Approaches to Automating Plant

There are two broad approaches to automating plant:

1. The plant has relatively little perceptive and decision-making ability but is used in an environment which has high quality centralised control infrastructure
2. The plant is equipped with a control system of sufficient perceptive and decision making quality that it can effectively be treated in the same way as a human driven machine with minimal support from the infrastructure

Many current off-highway automated vehicle systems centralise the control of multiple vehicles into a central computer. The decision-making process for each vehicle resides in the worksite's central computer. The tasks undertaken are entirely deterministic with little or no tactical decision making required. Each vehicle has a relatively simplistic perception and control system to allow it to carry out instructions from the centralised control infrastructure. Any deviation from the normal operating procedure, e.g., if an obstacle is encountered, has to be dealt with by the central control system, or its human supervisor, and usually results in the vehicle pausing while the problem is resolved. The ODD for these types of vehicles is limited to sites where a control system and its associated infrastructure (mapping, communications, etc.) is available. Vehicles designed to operate in such a system cannot operate independently and would be defined as *Automated* but not *Autonomous*.

Therefore, on a construction site, the first of the above approaches could be achieved using a central control model. Each item of construction plant (CAP) would operate as a 'dumb' robot, carrying out instructions from the central system. The central system would hold a digital model of the site in its current state and a model of the intended product. Computer aided manufacturing software would guide the process of changing the site from its current state to the intended product. The site could operate in the same way as an automated production line in a factory – the 'robots' would carry out instructions passed to them from the central system, without the need for each item of plant to have any 'understanding' of its task. The plant would pass information back to the central system to continuously update the current model.

The second of the above approaches is likely to present the greater challenge to the development of CAP. However, it is unlikely that fully autonomous heavy construction plant will ever be desirable within the construction industry – by its nature, construction requires some central oversight to ensure that each process is contributing to the ultimate goal of the project. It may be technically possible to develop highly autonomous plant that is able to take on much of the tactical level decision making for the process being undertaken, in much the same way that a human machine operator might. Such machines might be able to:

- Select their own path to a work location and position themselves appropriately for the task at hand
- Set themselves up for work, ensuring stability, access, and clearance for themselves and collaborating plant, e.g., dumpers working with excavators
- Plan the task, e.g., choosing where to place spoil so that a trench can be easily backfilled
- Choose the appropriate attachments for a particular task, e.g., excavator bucket
- Continuously monitor the progress and quality of the task

However, the automation of these tactical level tasks is by no means trivial, especially when applied to complex tasks like excavation. Autonomy of this nature will, in many instances, require construction plant to have a holistic 'understanding' of the site and plant that it is collaborating with. Therefore, the provision of a future, connected site that facilitates the implementation of central control and lower levels of in-plant complexity becomes attractive.

3.2 Providing Future Site Infrastructure for CAP

On-highway automated vehicles are designed to function on roads that have little or no dedicated infrastructure to automated driving – this is because of the significant challenge providing the required infrastructure on a sufficient proportion of the road network that would make on-highway automated vehicles that rely on this type of infrastructure feasible. The assumption that on-highway automated vehicles will operate without supporting infrastructure increases the challenge of automating these vehicles because of the complexity of the perception task, e.g., accurately identifying the presence and status of traffic lights. On a worksite there is the opportunity to provide physical and digital infrastructure elements to the site itself to assist the process of automating operations. For example, it may be possible to reach a high level of automation, with a relatively unsophisticated automated vehicle, if that vehicle can be centrally controlled by a computer that has an accurate and up to date High Definition map, a low latency communication system and a robust access control system to ensure the worksite is kept clear of intruders. Such an approach to automation has been successfully adopted within the mining industry, particularly in the Australian and South American mining sectors, (Ralston, Reid, Hargrave, & Hainsworth, 2014), (Rogers, et al., 2019), (Ali & Frimpong, 2020). However, there are associated challenges and negative impacts when introducing automation to a sector – once again, the mining industry provides some relevant examples to the construction industry. Particular challenges range from impacts on job security, income, and other human factors (Paredes & Fleming-Muñoz, 2021) and (Lynas & Horberry, 2011), issues with development amongst disadvantaged sectors of the population (Holcombe & Kemp, 2018), to cybersecurity challenges with implementation (Tubis, 2020).

Key infrastructure elements for highly automated construction therefore include:

- High definition 'digital twin' of the site, updated in real time
- High bandwidth, low latency, two-way communication
- High precision, low latency location services

The availability of each of these infrastructure elements enables more centralised control and co-operation and reduces the necessity for high levels of processing power and autonomy within individual machines. These infrastructure elements are strongly interdependent: there is no point having a central system that doesn't have a clear picture of what is currently happening on site and what needs to happen next; there is no point having that information if you can't share instructions with machines on the site or receive updates from them on their progress; and there is no point doing any of it if the machines are not able to position themselves accurately on the site and in the plan. However, this infrastructure is technology agnostic. Whether the site uses RTK-GPS or a projected laser grid, 5G, or Wi-Fi is immaterial, provided the capability of the method chosen is sufficient for the purpose at hand.

Taken to its ultimate conclusion, it is foreseeable that it would be necessary for site infrastructure to provide location services with millimetre accuracy, the facility to bidirectionally transfer gigabits of data per second and have a digital twin with a four-dimensional plan of the site, updated many times per second. As sites transition from their current manual systems towards automated alternatives there is likely to be a steady ratcheting in the capability of all three areas of infrastructure, with the key stumbling block being the availability of data management systems capable of processing the information provided to them in real time. However, this is not a fundamental technical barrier but simply the result of market inertia, which has slowed the development of BIM, CAD, and digital twin software relative to the development of location and communication systems. This element of the transition to fully automated sites will require a fundamental shift in the way designers of construction projects work - moving away from the simple creation of final snapshots fixed in time, to four dimensional products that take full account of the tasks involved in each stage of the construction process. While the potential technical barriers to delivering the required site infrastructure are likely to be easy to overcome, the organisational shift in the relationship between designers, surveyors and site operators may prove to be more of a challenge.

In the interim period the steady ratcheting of capability is likely to be driven via distributed technologies built into individual machines supported by existing cellular communication networks. Thus, surveying equipment will capture data that can be shared with 3D machine control systems, those 3D machine control systems will be able to record and upload their work to central data hubs and so on, (Barazzetti, Previtali, & Sciaoni, 2020) and (Walker, Smith, & Bosché, 2021). The key capability difference between this model, which currently operates on some sites, and the model for our future fully automated site, is the future-site's need for high-bandwidth low latency communication that is constantly available and protected against any interruption. Thus, rather than sharing data on the (current) 'as-and-when' basis, the central system will communicate constantly with machines to ensure that the latest information on the state of the site is always shared. Whilst it is conceivable that this capability may be furnished by external sources, such as 5G, these communication systems are likely to require a high safety rating to meet the needs for a secure, reliable, and safe fully automated site.

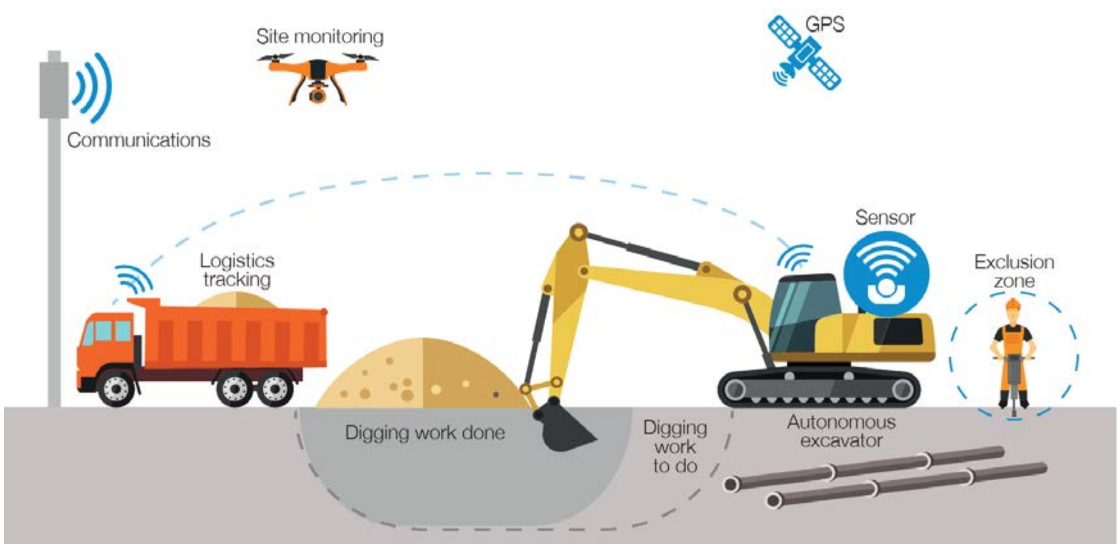

Figure 32 The Connected Site

3.3 The interaction between humans and Plant on the future site

As automation of construction evolves the human-plant boundary and interactions will need to change to accommodate the new capabilities of CAP. There are multiple aspects to this problem – firstly, it is important to consider the safety elements of automated plant operating alongside humans. Currently, a large number of construction activities take place with humans and plant in close proximity. For example, excavation of trenches with a human determining the depth, or the use of banksmen to monitor the movements of plant onsite. If automated plant is to be used in these circumstances it is crucial that the behaviour of the plant is consistent with the expectations of the workers operating alongside it. Although a non-standard approach may be determined to give greater operational benefits, there is a significant safety risk associated with the plant executing this manoeuvre if the workers do not expect it.

Potential solutions to this problem include restricting the behaviour of the plant to being "human-like" or removing any workers from operating alongside the plant. The latter of these strategies has been successfully deployed in mines and ports that are operating automated machines for productivity improvements. In addition, there is the potential for creating dynamic exclusion zones that wrap around the human workers as they move throughout the site, which interact with the plant onsite to create a digital zone that the plant cannot enter, *Figure 32*.

An additional complexity is how the deployment of automated systems will impact the livelihoods of existing plant operators. Although fully automated systems for complex tasks are not yet viable, a number of assistive tools have been developed which reduce the skill requirements for operating plant whilst achieving high quality outcomes. This is beneficial to the overall construction site, by alleviating the labour shortage the industry faces, but has adverse outcomes on the highly skilled existing operators. There is a need to manage a transition from plant operators to plant supervisors, who have the necessary experience to judge the performance of (semi-)automated plant operating on a construction site and maintain their operations. This has the potential to exist as one skilled professional managing multiple pieces of automated plant, intervening when necessary.

4. A Roadmap to the Future of CAP

In the above we have discussed a subset of the range of challenges and barriers to delivering automation in construction. To understand the wider challenges and actions needed to address them, in 2020 National Highways published a first-of-a-kind Roadmap for Connected and Autonomous Plant, (Highways England et al., 2020). This Roadmap drew on the expertise of over 75 stakeholder organisations. Through consultation, questionnaires and workshops the development of the Roadmap identified the wide range of barriers to the adoption of CAP, including: the lack of a legislative framework that permits and facilitates the use of automation; the need for greater financial investment and recognition of the benefits that would be achieved; contractual programmes which do not incentivise the use of CAP; and the difficulties in developing technology and connectivity across the wide range of plant used in the construction sector. The Roadmap developed a programme of activities across nine workstreams to stimulate the widespread deployment of CAP as a series of roadmap milestones are achieved.

The Roadmap was jointly launched by National Highways and the Infrastructure Industry Innovation Partnership[1] (i3P) in June 2020. The Roadmap predicts that, if the deployment of CAP within the UK construction sector can replicate the productivity and efficiency benefits that automation achieved in the manufacturing sector, benefits of £200Bn could be achieved by 2040. However, this requires that the steps outlined in the Roadmap are rapidly acted upon – a delay of 5 years would see the 2040 savings reduced by over 50% due to delays in the deployment of the beneficial technologies and innovations.

A particular milestone identified within the Roadmap was the need to develop a taxonomy for classifying the automated capabilities of construction plant. The Roadmap suggested that the creation of such a taxonomy would provide a unified language for the industry to understand how plant developed by different Original Equipment Manufacturers (OEMs) and third party, retrofitted solutions could be used to achieve tasks with reduced or no human intervention. This would facilitate the specification of development strategies, contracts, standards, and procurement strategies that could be readily understood across the industry, promoting a unified direction. To this end, National Highways commissioned the development of a taxonomy for the automated capability of plant, which has been published by National Highways and TRL, (National Highways, TRL, 2022).

5. Conclusions

The construction industry currently faces significant challenges but also great opportunity to transform the nature of the sector by adopting the digital revolution that other industries have already embraced. We have presented a potential future for the deployment of plant on construction sites and discussed how sites could evolve to accommodate the new role of Connected and Autonomous Plant (CAP). Whilst there is wide scope for the development of technologies deployed on individual plant to automate its operation, we have seen that plant must operate in a wide range of challenging conditions, or Operating Design Domains, which themselves place greater challenges on the development of these technologies. These barriers could be lowered through the deployment of connectivity and intelligence within the site itself, managed via central control systems and implemented through pervasive high-speed communications. The monitoring, communication and processing technologies that will achieve this future site infrastructure are already emerging. Finally, we have discussed how National Highways have developed a roadmap for CAP to understand the

[1] https://www.i3p.org.uk/en/

challenges that must be overcome. This roadmap highlights the technical, social, environmental, and commercial b enefits that will be achieved through the delivery of the vision for autonomy across construction sites and seeks to drive transformation in construction and encourage all stakeholders to develop and embrace this new future.

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An Investigation of the Adoption of BIM and Value Engineering Barriers in the South African Construction Industry

(Refilwe Masetlwa)[1], (Innocent Musonda)[2], (Chioma Okoro)[3]

[1&2] Construction Management and Quantity Surveying Department, Faculty of Engineering and the Built Environment (CARINBE) University of Johannesburg, South Africa.
[3] Department of Finance and Investment Management, College of Business and Economics, University of Johannesburg, South Africa.

Abstract

BIM has proven to be a great tool to facilitate Value Engineering. BIM and Value Engineering are tools that help projects be completed on time and within budget and can increase stakeholder involvement. This paper, therefore, presents findings on the barriers contributing to the level of implementation of BIM and Value Engineering in the South African construction industry.

Primary data was obtained through unstructured interviews. BIM experts and construction professionals who work with BIM were interviewed. Secondary data was obtained through a systematic review of literature from different academic sites, namely, google scholar, Scopus, Taylor Francis and ASCE Library, based on keywords related to the study.

The findings confirm that BIM and VE are practised in the construction industry in South Africa, and the participants found them to be a valuable experience that is efficient and effective. The findings also confirm that although BIM is used, there are barriers to its adoption, which affect Value Engineering processes. These include lack of skills, high cost, lack of government involvement, BIM Infancy, IT Infrastructure and Resistance to change.

The study addresses barriers that construction professionals encounter in implementing BIM and VE. This could lead to efficient problem-solving techniques and strategies based on the identified barriers.

Keywords

BIM, Value Engineering, Stakeholder buy-in

1. Introduction

BIM is a process or system that facilitates management, communication, and information exchange throughout the construction process, from feasibility studies to design, construction, handover, operation, and demolition. Building Information Modeling (BIM) is a collaborative way of working enabled by digital technologies that allow for more efficient designing, creating, and maintaining our assets (Hashemi, 2014).

Value engineering's primary goal is to reduce the facility's life-cycle cost, whereas constructability optimises the entire construction process. It is typically applied during the design phase in most cases of industry implementation. In contrast, practical constructability applications should ideally begin during the conceptual and planning stages and continue through construction (Hassan, 2018). Therefore, applying BIM in value engineering could be efficient and effective. BIM and Value Engineering are both tools that play an essential role in the construction industry, and combining them results in high-quality projects. Previous research on BIM adoption in Value Engineering processes has been published; for example, Li et al. (2021) investigated how BIM can be integrated with Value Engineering and demonstrated the benefits. The study proposed a framework based on the analytic hierarchy process (AHP) and the entropy method to calculate the weight and coefficient.

Further, Nath et al. (2015) proposed a BIM-based workflow for reengineering creating shop drawings. The study applied this method to a building component (a window) to increase productivity. Shin et al. (2016) proposed a value engineering idea validation system based on BIM that includes three modules: life cycle costing, energy savings

costing, and energy performance analysis. Each module estimates the effects of the Value Engineering concept by utilising BIM data that automatically or semi-automatically consolidates the idea.
Therefore, the purpose of this paper was to investigate the barriers that contribute to the level of implementation of BIM and Value Engineering in the South African construction industry

2. Methods

A phenomenological, qualitative design was adopted in this study. Being mainly exploratory, it was carried out using a pre-prepared unstructured interview guide. The first stage was an extensive investigation for literature review that was conducted to clearly understand the key barriers and main influence factors to BIM implementation, whereas the second stage is unstructured interviews. Unstructured interviews were chosen because of their adaptability. According to Jamshed (2014:87), unstructured interviews are controlled conversations that bend towards the researcher's interests. This type of interview should be referred to as a narrative interview (Stuckey, 2013:4).

The tool facilitated conversations with 13 purposively selected construction professionals acquainted with BIM (Palinkas et al., 2015). The selection consisted of BIM Managers, BIM Coordinators, BIM technicians, Construction Projects Managers and Quantity Surveyors who have implemented BIM within their organisations and on multidisciplinary projects. Probing questions were asked about their experiences with adopting BIM in Value Engineering processes and impediments to widespread and optimal implementation of BIM in South Africa.
The interviews were conducted between December 2020 and February 2021. Due to the pandemic, the interviews had to be done via Zoom; each interview lasted between 40 to 60 minutes. The research was carried out in Johannesburg and Cape Town, South Africa. According to the researcher's search, most BIM experts were based in Johannesburg and Cape Town. The participants' rights needed to take precedence over-collecting data to complete this study. The researcher adopted Guba and Lincoln's (1989) proposal on the importance of being morally and legally responsible when conducting a research project involving human participants. As a result, before and during the data collection process, the researcher prioritised the following; Permission to conduct the research was sought and granted by the University of Johannesburg's Faculty Higher Degrees Committee and the Research Ethics Committee. Before conducting interviews, participants were asked to sign a consent form indicating their willingness to participate in the study voluntarily. Participants were informed that they could withdraw from the study if they had any doubts or concerns about researching the items in the interview questions. Before analysing the responses, the researcher ensured that they were anonymised and took special care not to reveal potentially identifying details such as locations, names of construction sites, and names of participants. The researcher put safeguards in place to protect the confidentiality of participants at all stages of the research cycle.

Thematic analysis was used to analyse data gathered from the interviews. The goal of thematic analysis is to identify themes, which are patterns in data that are important or interesting, and then use these themes to say something about an issue or address the themes (Clarke and Braun, 2013). An excellent thematic analysis does much more than summarise the data; it interprets and makes sense (Clarke and Braun,2013). Thematic analysis was performed on the survey data using Braun and Clarke's (2006) six stages of analysis: familiarising oneself with the data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and reporting. The inductive thematic analysis procedure was used to analyse the data.

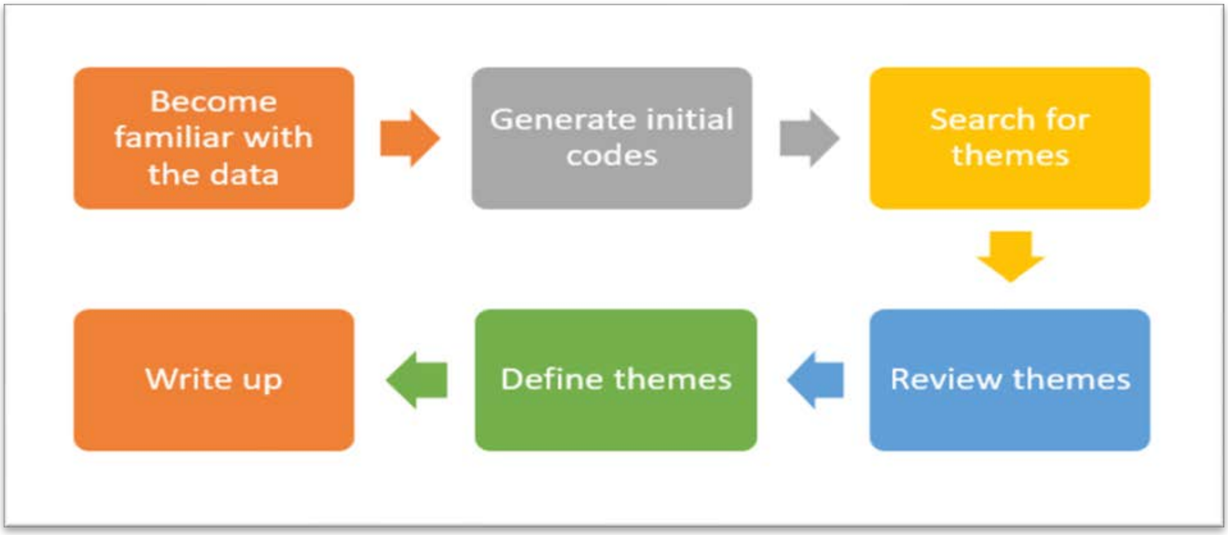

Figure 4: Braun & Clarke's six-phase framework for doing a thematic analysis

3. Results

3. 1 Results/Findings

The study's findings confirm that BIM and Value Engineering are used in the South African construction industry; additionally, participants believe it is an important and valuable experience. These findings show that Value Engineering is necessary, efficient, and beneficial. Furthermore, they demonstrate that Value Engineering produces successful outcomes when combined with BIM. All participants agree that they use BIM and Value Engineering; additionally, they believe that incorporating BIM into Value Engineering is a good idea; however, the participants also stated barriers to BIM adoption. These barriers automatically affect Value Engineering processes.

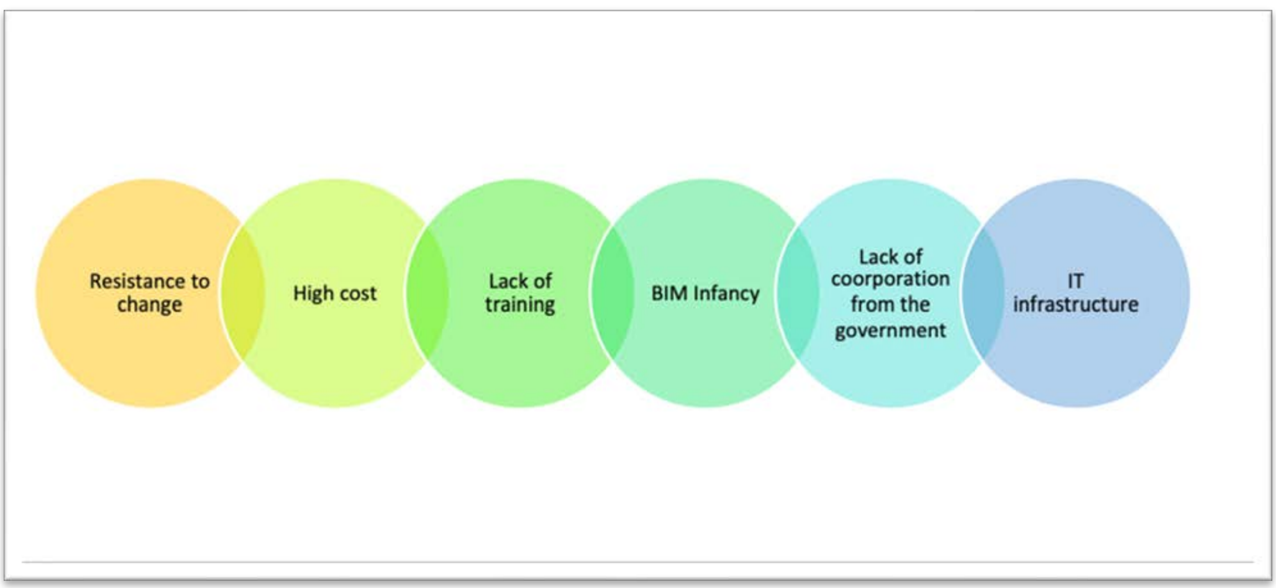

Figure 1: BIM Barriers

4. Discussion

Value Engineering processes are improved by using BIM (Li et al., 2021:3). Value Engineering function analysis is strengthened by BIM fundamental functions such as visualisation, function simulation, clash detection, and information integration. Other benefits of using BIM include faster information extraction and real-time engineering changes, both of which are used to improve the cost analysis of the value study and, as a result, the performance of the Value Engineering analysis (Park et al.,2016). BIM is more than just a new 3D modelling software; it is a comprehensive solution for simulating and combining all Value Engineering and other building performance data. As a result, Value Engineering would be more accurate and timely in providing all relevant information to users at the appropriate location and time (Lee and Na, 2018:309).

The adoption of BIM in Value Engineering is a success in different developed countries where BIM is seamless, where the government provides support, and where the IT infrastructure is impeccable; the two processes are efficient and effective and have made a difference in the construction industry. Various authors have successfully implemented BIM at different stages of Value Engineering processes. For example, Ranjbaran (2013) proposed an automated, integrated model for value analysis used in both the creative and evaluation phases of the Value Engineering job plan. The model provides the user and the Value Engineering team with visualisation capabilities and a comprehensive computational platform that considers various factors. Similarly, Li et al. (2021) investigated and demonstrated the benefits of integrating BIM with VE. The study proposed a framework based on the analytic hierarchy process (AHP) and the entropy method to calculate the weight and coefficient. A case study method of a high-rise building project in China was used to validate the framework and demonstrate how BIM can be integrated with Value Engineering.

Below is what the study has found; These are the barriers to adopting BIM, affecting the adoption of BIM in Value Engineering processes.

Resistance to change

South Africa is still lagging in BIM adoption because most stakeholders are resistant to change. One of the main points raised by participants was the unwillingness of most stakeholders to change. This is what the participants had to say:

"People do not like changing what they use; they would rather stick to AutoCad and drawing on drawing board."

– *Participant 2*

"People are comfortable in their ways of doing things. We consider working in the traditional ways we have always done. Then now you are talking about BIM talking about those within the industry before becoming a thing, Being reluctant to adopt it because it means it is a switchback."

- *Participant 11*

High Cost

BIM incurs several direct costs affecting all design and project team members. According to the findings of this study, these costs are incredibly high, and not everyone can afford them; thus, they impact the implementation of BIM and Value Engineering. This is what the participants had to say:

"Yeah, I have picked it up, so we are very behind in building information models."

- *Participant 9*

"The technology is quite expensive, so the smaller companies do not afford the BIM solutions."

- *Participant 6*

"Public perception says it costs money."

- *Participant 5*

With most participants agreeing that the lack of BIM is due to high costs, Ahmed (2018:107) cites the high cost of BIM purchasing as a significant barrier to BIM implementation. According to Ogwueleka and Ikediashi (2017:309), one of the general challenges encountered when adopting BIM is high cost.

Lack of Training

One of the barriers to BIM adoption is a lack of training. On the contrary, most employers do not train their employees, and some employees do not want to be prepared because they believe they have advanced in their careers. According to Liu et al. (2015:64), the high cost of training and education contributes to a lack of training. This is what the participants had to say:

"But also on the technology side, some guys do not believe in training up their people."
- *Participant 1*

"The biggest problem is human resource development and training. So we also try and get companies to realise that they need to reinvest in their people. It is not the software and computers that make the company. It is the people themselves, So it continues education and training, teaching them how to adopt the new technology."
- *Participant 2*

BIM Infancy

BIM adoption in South Africa is still limited; many companies have not adopted BIM. In South Africa, BIM is still in its infancy. Numerous organisations still do not use it. It is not as popular in developing countries as in developed countries. This is what the participants had to say:

"The construction industry has not adopted BIM only a few companies."
- *Participant 2*

"BIM is still lagging in South Africa."
- *Participant 13*

"Adapting, because BIM is still new in SA."
- *Participant 2*

BIM adoption in South Africa is still limited; many companies have not adopted BIM. Mtya and Windapo (2019:215) agree that BIM adoption by construction organisations in South Africa is still in its early stages. According to the literature, the BIM movement has not benefited the South African built environment.

Lack of corporation from the government

This study confirms that one of the barriers to BIM adoption is a lack of government support. Anything that has the government's support makes things easier. The government plays a significant role in the implementation of any initiative. The government's support makes it easier for other stakeholders to join in. Governments should take the lead in BIM adoption, utilising their administrative functions fully and actively participating in the promotion process.

"Uh, so that one that it is not being driven by clients or by Government Departments. Two, I think once clients and government departments do realise that there are benefits they can make and receive from it. Not only in terms of, you know, clash detection and avoiding rework when executing and building the structure. Using this modelling software, the design team can work out many of those issues upfront. You know, and then asset management and life-cycle management of the building with digital Twins."
– *Participant 12*

"The government has been quite slow with the adoption of BIM. We have been in meetings with them, but unfortunately, nothing materialised; but hopefully, soon that will change."
- *Participant 6*

According to (Ogwueleka and Ikediashi, 2017), one of the significant challenges in adopting BIM technologies is a lack of government direction. According to Farooq et al. (2020), to reap the benefits of BIM technology, the government and all project stakeholders must collaborate to overcome the barrier of priority.

IT Infrastructure

The internet is crucially significant in BIM. Strong internet connections are required to enjoy the benefits of BIM fully. According to Siebelink et al. (2021), internet speed can be a barrier to data exchange. Furthermore, because some projects are in extremely remote areas, the Internet connection quality at project locations affects external collaboration.

This is what participants said;

"In South Africa, there is still a lack of technology infrastructure, i.e. internet and speed of communication."
- *Participant 4*

"For BIM to function effortlessly, basic internet requirements are needed, and South Africa is still battling with that."
- *Participant 2*

The adoption of BIM in Value Engineering is a success in different developed countries where BIM is seamless, where the government provides support, and where the IT infrastructure is impeccable. The two processes are efficient and effective and have made a difference in the construction industry. Various authors have successfully implemented BIM at various stages. For example, Ranjbaran (2013) proposed an automated, integrated model for value analysis used in both the creative and evaluation phases of the VE job plan. The model provides the user and the Value Engineering team with visualisation capabilities and a comprehensive computational platform that considers various factors.

4. Recommendations

It is suggested that the government implement BIM for the successful development and deployment of complex technology systems, strong government support is essential. This could aid in overcoming barriers to BIM adoption. Innovation is widely regarded as a critical driver of national economic growth, particularly in industrial and newly industrialised economies. BIM, as an innovation, will be critical to economic development. Many direct and indirect benefits are provided by BIM technology. It improves the labour market, encourages more collaborative working practices, and improves communication among project stakeholders, among other things.
Furthermore, VE should be made a requirement in projects. Most people do not practice VE because they believe it is time-consuming. While it is time-consuming, it is also efficient and rational. It comes with a plethora of benefits that make a significant difference.

Moreover, the government should put standards that will aid in regulation. The sooner the government does this, the sooner the construction industry will reap BIM benefits in cost, timeliness, and project quality. Interoperability is improved and promoted by standards. The development and implementation of BIM specifications and protocols can result in a consistent and effective data exchange method with significant benefits for construction projects. These Standards promote common understanding and facilitate trade by removing trade barriers.

It is worthwhile to investigate what is being done at the national level to encourage the use and implementation of BIM and legislate and possibly make it a mandatory tool in the South African construction industry. Furthermore, as an organisation tasked with developing the construction industry under the Construction Industry Development Board Act No. 38 of 2000, it is worth considering what organisations like the CIDB are doing in the implementing national and organisational levels. The CIDB's objectives, according to the Act, include promoting the construction industry's contribution to meeting national construction industry demand and advancing industry performance, efficiency, and competitiveness Ndhlela, (2018:22).

While it is not uncommon for the private sector to take the lead in driving BIM adoption and implementation, the evidence highlights the South African case's peculiarity in government agencies' inability to adequately drive BIM adoption and performances and lead in the development of guidelines. Despite this, existing standards from BIM-leading countries are being adapted for South Africa, but these are individual efforts (Akintola et al., 2017:31). While there is a demand for country-specific standards and guidelines for implementing BIM in South Africa, measures from BIM-leading countries have been adopted and adapted relatively successfully. Nonetheless, because these are individual efforts, the direct implications are project stakeholders' experiences with varying implementation patterns and, as a result, non-interoperability (Beach et al., 2015).

5. Conclusion

This research paper aims at assessing the status quo of factors contributing to the level of implementation of BIM and Value Engineering in the South African Construction Industry. The assessment was done using unstructured interviews with 13 construction professionals acquainted with BIM. The following main topics were considered in the interviews a) The significance of BIM and Value Engineering distinctly b) The efficiency of Value Engineering in BIM, c) The adoption of BIM in the South African Industry and d) factors contributing to the level of implementation of BIM and Value Engineering in the construction Industry. The key findings depict that BIM plays a vital role in Value Engineering processes. Furthermore, the key findings describe that BIM is practised in the South African construction industry; however, some factors impede the complete adoption and practice. Those factors are; 1) resistance to change, 2) High cost, 3) Lack of training, 4) BIM Infancy, 5) Lack of corporation from the government 6) IT Infrastructure.
This study clearly describes the barriers to adopting BIM and Value Engineering. With all the noted walls, solutions will then be generated, which will help enhance efficiency in the construction industry and boost the economy.

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Sustainability Culture in UAE Construction Companies – A Snapshot Assessment and Improvement Guidelines

Hasan Mahmoud[1], Mustafa Al-Tekreeti[2], Salwa Beheiry[3]

[1] Ph.D. in Engineering Systems Management, American University of Sharjah
[2] Ph.D. in Engineering Systems Management, American University of Sharjah, UAE
[3]Associate Professor at Civil Engineering Department at the American University of Sharjah, UAE, Corresponding Author
sbeheiry@aus.edu

Abstract
The construction industry is the largest employer worldwide and shifting the core values and culture of construction companies toward sustainable practices could lead to significant progress in that direction. Hence, this paper investigates the current state of integration of sustainability maxims in the United Arab Emirates (UAE) construction industry and provides guidelines that facilitate employee awareness and attitudes modification towards sustainable practices. The study was conducted via a comprehensive literature review to identify the best practices utilized by companies to realign employees' mindsets with sustainability goals. A series of interviews with experts in the UAE construction industry were then carried out to validate the approach and create tailored guidelines. The developed guidelines were used in a survey form to collect data and assess the key professionals' attitudes towards these relevant practices. The study results indicated a reasonable level of awareness and that implementation of practices to foster the culture of sustainability in the UAE construction companies is underway, with the main emphasis on training and education followed by leading initiatives and introducing incentives. The results also show that 80% of the survey participants assessed the identified practices as important, which shows a reasonably strong trend towards establishing a sustainable culture.

Keywords
Sustainable Culture; construction companies; Sustainable Practices; Green Culture; Organizational Culture; Sustainable Construction.

1. Introduction

Sustainability promotion is profoundly associated with individuals' choices and daily life practices, such as: switching off lights, recycling, using public transport, conserving water, using energy-efficient domestic appliances, choosing their energy supplier, buying eco-friendly products, and so forth. To what extent people can change their habits and adopt new sustainable practices is one of the fundamental questions asked by policymakers across the globe (Iveroth and Bengtsson, 2014). To achieve sustainable development, society needs to change the established basic assumptions, beliefs, and behaviors by nourishing its sustainable code of conduct in favor of sustainability requirements. This code of conduct is a sustainable culture representing a driving force towards a sustainable society (Robin and Poon, 2009). The construction industry is amongst the largest employers in the world. Construction companies play a crucial role in society's development and can minimize the negative impact of projects on the environment while maximizing their economic contribution (Tan et al., 2011). Throughout the past decade, construction professionals have started to change their mindsets unconsciously towards sustainability, which indicates changing to a sustainable culture (Sfakianaki, 2015). Due to this crucial role, it is imperative to change the construction culture. The purpose of the culture in any organization is to: develop a sense of identity for the organization's employees, enable commitment, improve organization stability, and provide a sense-making device that shapes and guides employee behavior. Therefore, changing organizational culture is believed to be the foundation for its efficiency, especially in the construction industry, as numerous scholars pinpoint this sector's lack of efficiency. In addition, those changes will enhance the company's shareholder value and protect its reputation among competitors (Cheung et al., 2011), (Tan et al., 2011). Most of the studies on sustainable construction practices explore the practices that enhance project sustainability without considering changing the company's culture. Therefore, it is important to explore the various practices used in the construction sector to change employees' mindsets toward sustainable practices. This is crucial, especially in the current construction environment in UAE, where there is a severe economic crisis. Therefore, this study aims to provide a set of practices that can help construction companies shift their stagnant traditional culture towards a sustainable one by changing their employees' mindset toward sustainably.

2. Literature Review

Organizational Culture

Organizational culture is considered an essential asset in building the organization's strength (Pham et al., 2018). According to Martin and Siehl, organizational culture is "the social or normative glue that holds an organization together" (Martin and Siehl, 1983). However, the most cited definition for organizational culture is "a pattern of shared basic assumptions learned by a group as it solved its problems of external adaptation and internal integration, which has worked well enough to be considered valid and, therefore, to be taught to new members as the correct way to perceive, think, and feel in relation to those problems" (Schein (Schein, 2010), p. 18). As such, organizational culture represents the organization's structure deeply rooted in beliefs, values, and employees' assumptions (Chatterjee et al., 2018). Hofstede defines the organization's culture as the 'mental software' shared by the organization's employees (Hofstede, 1994).

Hofstede intensively studied organizational culture in 50 countries and developed a framework consisting of four dimensions: power/distance, which represents how employees view power relationships such as superior/subordinate relationship; individualism/collectivism, which measures the integration degree of individuals into groups; masculinity/femininity which measures the gender equality of roles distribution among employees; and uncertainty avoidance which represent the tolerance of society for ambiguity and uncertainty (Hofstede, 1983). Understanding those dimensions within the organization helps managers change their employees' behavior and eventually changing the organizational culture by observing and measuring those variables within their organizations. Therefore, organizational culture plays a crucial role in shifting the current stagnant culture toward a sustainable culture by providing the proper climate that encourages sustainability outputs within the organization (Gürlek and Tuna, 2018).

Sustainable Pillars (Economic, Environmental, and Social)

The World Commission on Environment and Development defines sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and, 1987). By extension, sustainable development, according to Thiele, is "meeting current needs in a way that does not undermine future welfare" (Thiele, 2016). Additionally, according to Thiele, sustainability stands on three pillars: economy, ecology, and society, which can also be called the "triple bottom line" (Thiele, 2016). The ecology pillar focuses on enhancing the environment through reducing carbon footprint, waste packaging, using environmentally friendly materials, sustainable energy, water conservation, so on and so forth. The society pillar focuses on balancing individual needs with group needs by engaging the social system (organization, family, community) into organization projects to mitigate their negative impact. The economic pillar seeks profitability without compromising the other pillars by conducting risk management and proper governance strategies to reach that goal (Mikulčić et al., 2017). Within the context of the business perspective, those pillars are manifest through company practices that balance corporate financial performance with social and environmental performance (Tepe KüÇÜKoğLu, 2018). This study will focus on the three pillars of sustainability since the practices that could be applied by the company to enhance its sustainability will have an impact on all the pillars of sustainability.

Green Culture in Companies

From a corporation point of view, being a sustainable organization is not only done by supporting pollution prevention through sustainable operation practices, selling ecofriendly products, or minimizing resource allocation, but also by changing the culture of the organization to be sustainable by facilitating to their employees the adoption of sustainable behaviors and attitudes (Harris and Crane, 2002). Therefore, green organization culture is defined as integrating organizational culture with environmental management (Linnenluecke and Griffiths, 2010). Chen defined it as a symbolic and interpretive concept that guides organization processes and employees' behaviors into environmental management and protection (Chen, 2011).

The driving force of sustainability amongst project stakeholders within the construction industry is sustainable cultural development. It is categorized into awareness, concern, motivation, and implementation, where awareness represents the need for change within the organization and dissatisfaction with the current condition, which encourages the change to rectify the current condition. If stakeholders in the construction industry are aware of the negative impacts caused by construction projects such as unnecessary wastage (environment), low product quality (economic), poor on-site safety (social) caused by their current actions and performance, then their willingness to improve will increase (Robin and Poon, 2009). The concern is a product of awareness, defined as bringing the feelings about the current unsatisfied condition into the conscious attitudes of project stakeholders and integrating it with their judgments (Chakravarti et al., 1997). On the other hand, Motivation is the desire to rectify the current unsustainable activities through proper direction from the company to promote sustainability (Young et al., 2015). Lastly, Implementation is applying the intended behaviors and activities through spending money, time, and effort by construction companies to achieve sustainable changes in construction projects (Ajzen, 1991). As such, green organizational culture is the primary driver of shifting employees' behaviors and attitudes toward sustainability. Therefore, it is essential to understand the organization's practices to achieve that goal, especially within construction companies.

The Common Practices Used by Companies to Enhance Employees' Sustainable Practices

Different factors drive the implementation of sustainable practices within a company, and the main factor is the company's policies and strategies that support sustainability. Additionally, there are two types of factors that affect the implementation of those practices from the company's point of view: internal and external factors. Internal factors are financial resources, expertise, knowledge, measuring systems, and infrastructure. On the other hand, external factors are competition, social pressure, laws and regulations, and the global market (Tepe KüÇÜKoğLu, 2018).

Nevertheless, it is vital to communicate the organization's sustainable programs, goals, and initiatives with employees frequently to inform them about the applied practices properly and to allow them to report areas of improvement (Madsen and Ulhøi, 2001). Ramus supports this argument by stating that if senior managers embrace an open and democratic communication style regarding sustainable ideas, it will increase the willingness of employees to undertake sustainable initiatives adopted by the company (Ramus, 2001). Additionally, for the company to support its culture transformation toward a green culture, it is essential to implement education and training programs for its employees to increase their awareness about the importance of sustainable practices that are being or will be applied within the company (Van Rensburg et al., 2017). Furthermore, the organization's commitment toward ongoing sustainable training enables employees to incorporate what they learned into their day-to-day activities, which will positively impact the environment (Liao, 2018). Additionally, environmental awareness training can help the organization to: change the organization's environmental philosophy, cope with the complex regulatory climate and the heightened liability concerns (Cook and Seith, 1992). On the other hand, sustainability training conducted by companies may lead to many benefits such as compliance with regulatory requirements, positive public image, encouraging employees to become environmentally aware, and increasing employees' motivation to engage with proactive environmental management measures (Ndzibah et al., 2010).

Apart from that, employees' empowerment has a considerable positive impact on their motivation and commitment towards engaging and implementing sustainable practices. Company management can promote this empowerment by changing their organizational structure and core values. Similarly, the traditional hierarchy of an organization (top-down) inhibits employees' empowerment. For this reason, it is preferable to adopt a flatter, horizontal organizational structure to promote this empowerment (Schultz, 2014). Moreover, shifting decision-making abilities from managers down to employees will allow more power and freedom to make suggestions and implement new sustainable practices (Tariq et al., 2016). Empowering employees affects Employee Involvement (EI), which Cotton describes as "a participative process to use the entire capacity of workers, designed to encourage employee commitment to organizational success" (Cotton, 1994). EI has a positive impact on changing the organization's culture to reduce the pollutants caused by projects through the employees as part of their responsibility towards the new core values of the organization. Therefore, EI plays a critical factor in ensuring a successful culture change (Alt et al., 2015).

Furthermore, to encourage employees to participate in environmental practices, a well-designed rewards system is required. Rewards refer to benefits, whether extrinsic or intrinsic, that employees receive from their performance in a particular task (Meyer, 2016). The rewards system applied by a company can reinforce continuous motivation and increase commitment from the company's employees to be more environmentally responsible. However, incentives must be in parallel with corporate environmental objectives to reflect the organization's commitment to enhancing environmental performance (Baird et al., 2018). The rewards can take different forms, whether recognition awards or financial rewards such as profit-sharing programs, pay rises, recognition programs, incentives and benefits, monetary rewards (the strongest motivation for employees' involvement in environmental practices). These rewards will motivate employees to innovate and adopt sustainable practices (Govindarajulu and Daily, 2004). However, some companies may use different rewards systems to motivate their employees through innovative non-monetary rewards such as time off from work, paid vacations, favored parking, or gift certificates (Bragg, 2000).

Construction and Companies Sustainable Cultures

Construction has many definitions in the modern world; some consider construction to be the science of constructing buildings and projects, while others define it as the art of constructing buildings and projects (Carty, 1995). Nevertheless, construction is one of the largest industries and is considered one of the most advanced and evolved in the modern world. It has evolved from building with stones and other primitive materials to building massive structures with advanced materials and systems (Newton, 2016).

Sustainable aspects and responsibilities are rooted in the definition of the construction industry. The multitude of interactions between the stakeholders in the construction industry makes it the best candidate to promote and apply sustainability in its organizational culture. Many studies and reports have been done to identify the key aspects and practices that construction companies adopt to enhance the sustainability aspects of the business and build the sustainability principles in their organizational cultures. All of which indicated that the first step to promote sustainability in the construction industry is to initiate the change within the company's culture, which will eventually reflect on the whole industry. This concept of change comes from the stakeholders' influence on the industry, called "influential factors." Based on their disciplines and functional roles, stakeholders are categorized into five groups: government, developers, consultants (architects, structural engineers), contractors (main contractors, subcontractors, suppliers), and non-professionally recognized participants (sits supervisors, foremen, sits agents). Each stakeholder has different influences and powers in changing the construction culture, which means that the higher the influential factors (depending on the stakeholders' group), the greater the magnitude of the implemented change. Government authorities initiate the regulations of sustainability that govern the other construction stakeholders' groups. On the other side, developers are responsible for hiring consultants, and contractors should influence the consultants' and contractors' sustainable outputs (Robin and Poon, 2009). Therefore, the most crucial step to enhance sustainable practices and thus the green culture starts with the commitment of regulatory bodies involved in the construction industry toward sustainability practices.

Alternatively, in their report that dissects the issue of sustainability reporting in the construction and real estate sector, The Global Reporting Initiative (GRI) (2008) shows that construction and real estate companies tend to focus on the social aspects of sustainability in all the reported indicators (GRI, 2008). These indicators include training and development in sustainability, community involvement, participation in local community programs, diversity, and equal opportunity.

Much research has been done on projects sustainability, but only a little research is done to promote sustainable culture in construction companies. Akadiri et al. developed a framework that implements sustainability in the building sector, which identified several practices that can promote the culture of sustainability if implemented. Such practices touch on the company's organizational culture that aids in delivering more sustainable projects (Akadiri et al., 2012). Some of these practices are reviewing each project to understand its sustainable aspects with all stakeholders, securing a commitment from the stakeholders to a continuous improvement on sustainable performance, managing sustainable activities by setting goals and targets to give feedback and self-regulation of the process to supports the learning process and teaching the stakeholders about the interaction between the environment and development.

Another study by Trufil and Hunter (2006) to evaluate the relationship between the sustainability concepts and the competitiveness of small and medium construction companies concluded that it is fundamental for companies to build their reporting systems in a way where stakeholders can report gaps in the practices undertaken by the company to the management. Another practice that the authors mentioned is that companies must assist the stakeholders in incorporating the best practices they perceive to be valid and functional to aid in developing a sustainable culture in the company (Trufil and Hunter, 2006).

Similarly, Tohidi and Jabbari (2012) argue for the efficiency of the reporting system by emphasizing the idea that the change, the drive, and the steering should come from senior management as they are the source of trust and leadership in any organization (Tohidi and Jabbari, 2012). On the other hand, Lee et al. (2014) highlighted that the concept of sustainability should be driven from the corporate level down to the micro-project level, with an emphasis on the role of education and training of employees to enhance their knowledge allowing them to play an influential role in the development of the community. Moreover, employees can benefit from drawing upon ideas from the community they are part of, making them a more effective part of society (Lee et al., 2014).

The United Arab Emirates Current Sustainable Practices and Future Trends

The economy of the United Arab Emirates is fast-developing based on three main axes: oil and gas, trade and logistics, and real estate and construction. Moreover, any decline in any of these axes can harm the overall economy and the quality of life. Recent reports predicted that real estate prices would fall another 5 to 10% this year due to the large gap between supply and demand before it stabilizes in 2020 (Standard and Poors, 2019).

As a result, the construction industry in the United Arab Emirates is currently undergoing a considerable risk of insolvency as the overall real estate market is falling and the financial situation is unstable. During such times, construction companies must sustain their existence through many measures both economically and strategically. From this, construction companies in the United Arab Emirates have realized the importance of sustainability and sustainable development on their overall performance.

Many construction companies and organizations include sustainability in their vision and mission statements. They realized the importance of developing sustainable practices in their organizational culture, which will eventually reflect on how they operate and deliver projects. Some examples of these organizations are the Al Naboodah Group and Dubai Multi Commodities Centre Authority (DMCC) organizations. Both these entities have reported their sustainability goals and records, and they have shown that the main driver for sustainable development and the main contributor to the sustainable culture are the stakeholders. They deem that the stakeholders, with some direction and advice from the management, can achieve significant benefits and rewards for their organizations and communities (Al Naboodah Group, 2017) (DMCC Authority, 2017).

Therefore, sustainable practices centered on the inclusion of stakeholders, engagement of employees, and the development of initiatives can have a significant impact on the positive change of the organizational culture. This study will consider the essential practices identified from the literature to develop and identify the most important practices that could assist construction companies in fostering the shift towards sustainable organizational cultures.

3. Methodology

To accomplish the objectives of this study, the authors carried out an extensive literature review to deduce the available practices that aid the promotion of the sustainability culture in organizations. The literature investigation focused on the drivers and practices that could change employees' mindsets in the construction industry to a more sustainable one to propagate into the whole construction industry. The investigated studies had recommended methods used in construction companies to change their stagnant culture to a more dynamic culture that allows for development. Moreover, the literature review also built the required understanding of the dynamics of change in organizations to identify the critical concepts that underline changes in organizational cultures.

Furthermore, the literature investigation allowed for collecting qualitative data through the interviews with industry experts to explore the practices applied in their companies to enhance employees' sustainable practices. Additionally, the interviews also allowed the experts to provide future sustainable practices that could positively impact the promotion of sustainable organizational culture. Finally, an investigation to validate the study results was done via electronic surveys with professionals in the construction industry. The interview targeted the collection of the level of importance of the identified practices via a Likert scale. Finally, the results were reported in a guideline format that could significantly impact the promotion of sustainability and sustainable practices in UAE construction companies if applied.

Data Nature and Collection

There are two types of data collected for this study. The first type of data is qualitative data in the form of practices that promote changes in the construction companies' culture from the current status to a more sustainable culture. After collecting practices from the literature, the authors sought to validate and seek the opinion of industry experts on the collected practices and the inclusion of current and recommended practices in the UAE construction market. The authors targeted industry experts with more than ten years of experience and are committed to sustainability in their professional practice. The sampling method for identifying the participants was convenient sampling since the targeted participants were specialized. Five industry expertise were interviewed to validate the collected practices. Table 1 below demonstrates the profile of the interviewees and their roles and experience level.

Table 32. Interviewees Background and Experience Level.

Sr.	Education Level	Type of Organization	Role	Experience	Involvement in Sustainability
1	Master's Degree in Civil Engineering	Private Construction Company	Owner and General manager	32 Years	Highly committed to sustainability with a focus on sustainable construction methods
2	Bachelor's Degree in Mechanical Engineering	Private Construction Company	Projects Director	27 Years	Committed to sustainability and focused on waste reduction and recycling to minimize the impact on society
3	Bachelor's Degree in Civil Engineering	Semi-Government Developer	Technical Manager	17 Years	A proponent of sustainable development and focused on Life Cycle analysis for projects and development to maximize the utility and minimize the impact on the environment and community
4	Master's Degree in Construction Management	Government Entity	Head of Department	12 Years	Pro-environment preservation and focused on implementing sustainable development practices within the department vision and mission
5	Bachelor's Degree in Business Management	Private Construction Consultancy Firm	Business Development Manager	23 Years	Highly committed to promoting sustainability in the organization by educating and involving stakeholders internally and externally to promote sustainable development.

Upon collecting the data, a guideline consisting of the set of practices was developed to assist construction companies in changing their organizational culture to a more sustainable one by changing the employees' mindsets. Table 2 below lists the set of practices extracted from the literature which were the bases of the interviews.

Table 2. Interviewees Background and Experience Level.

Sr.	Practices	Nature of the practices	Reference
1	Influential factors	The commitment of authoritative bodies involved in the construction industry toward sustainability practices	(Robin and Poon, 2009)
2	Communicate	Embrace an open and democratic communication style regarding environmental ideas	(Madsen and Ulhøi, 2001) , Ramus, 2001)
3	Green education and training programs	Increase employee's awareness about the importance of sustainable practices	(Van Rensburg et al., 2017), (Liao, 2018), (Cook and Seith, 1992), (Ndzibah et al., 2010), Interviewees Response

4	Empowered employees	Moving decision-making power from managers down to employees will allow them more power and freedom to make suggestions and implement new sustainable practices. Empowering employees affects Employee Involvement	(Schultz, 2014), (Tariq et al., 2016), (Cotton, 1994), (Alt et al., 2015)
5		Reinforce the continuous motivation and increase commitment from the company's employees to be environmentally responsible.	(Meyer, 2016), (Baird et al., 2018), Interviewees Response
6	Rewards system	Financial rewards: profit-sharing programs, pay increases, recognition programs, incentives and benefits, monetary rewards	(Govindarajulu and Daily, 2004)
7		Non-monetary rewards such as time off from work, paid vacations, favored parking, or gift certificates	(Bragg, 2000)
8	Include all stakeholders in making the decision	To understand the complexity of the sustainable concept.	(Akadiri et al., 2012)
9	Setting goals and targets	To managing sustainable activities and concepts and give feedback and self-regulation of the process which supports the learning process	Akadiri et al., 2012)
10	Monitoring companies' reporting systems	where stakeholders can report gaps in the practices undertaken by the company and can report them to the management	(Trufil and Hunter,2006)

After developing the guideline, the authors sought to validate the developed guideline via electronic surveys with professionals from the construction industry to seek their feedback on the efficiency of the practices to change the mindset of employees to a more sustainable one. The targeted participants were professionals in the construction industry in junior to senior positions working in construction companies. A total of 38 surveys were sent to professionals in the construction industry and 30 surveys were filled achieving a 78.9% rate of response. Figure 1 below illustrates the level of experience the participants had.

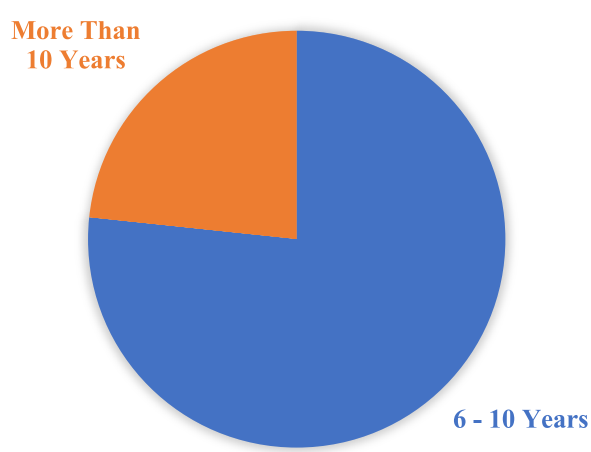

Fig. 33. Respondents Years of Experience.

The interview collected the participants' opinions on the practices via a Likert scale that ranged from 1 to 5, Not Important to Extremely Important, respectively. The questions were framed to ask the respondents the importance of the practice's efficiency to change their minds to adopt a more sustainable mindset.

3. Results

3. 1 Sustainable Practices and Guideline Development

The conducted interviews with the five professionals from different companies were done to examine their organizations' current and previous practices and what they would recommend as good practices that could help promote the sustainability concept in construction companies.

All interviewees have more than ten years of experience in the construction industry, and all of them are in managerial roles where they were able to enforce and implement practices and procedures in their organizations. When the interviewees were asked to comment on UAE-based companies' practices to promote sustainability, they all agreed that implementing sustainable practices in construction in the UAE seems to be behind the rest of the world. However, in recent years there has been more emphasis on implementing these practices. Due to the demographic of the society that makes up most employees within the construction industry in the UAE, no understanding or level of education emphasizes the importance of sustainability.

There are tends amongst this demographic of only doing the bare minimum in their allotted tasks, and a lot of the time sustainable practices take a back seat in favor of just getting the job done. This mentality needs to change, and it can only change through education, training, and enforcing/rewarding certain practices. All interviewees had the same answers and shared the same belief when asked about the practices done in their organizations to promote sustainability. Table 3 below illustrates the responses of the interviewees.

Table 3. Interviewees Response on Current Practices.

Sr.	Education Level	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5
1	Encouraging staff to lead and champion initiatives that support the practice of sustainability.	×		×		×
2	Providing training and mentoring for junior staff on the concept of sustainability and the outcomes of sustainability.	×	×		×	
3	Providing incentives for employees to reduce consumption of papers and other office appliances.		×	×	×	
4	Engaging the staff in community activities could bring them closer to the people they serve.	×			×	×
5	Starting initiatives to lead by example.		×		×	

On the other hand, when the interviewees were asked about recommendations they could give or suggestions they could offer to enhance further the promotion of sustainability in their organization's cultures, they gave insightful responses, as illustrated in Table 4 below.

Table 4. Interviewees Response on Recommended Practices.

Sr.	Education Level	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5

1	Rewarding champions and considering the sustainability contributions in staff evaluations.		×	×		×
2	Involving the staff in the conception and the application of sustainability concepts in projects.	×		×	×	×
3	Creating departments in their organizations that foster and enhance employees' understanding of sustainability which eventually will allow employees to be creative		×		×	×
4	Government authorities should set goals and monitor them closely to achieve sustainable cultures.	×		×	×	

Table 5 below portrays the summary of the previous practices found from both the literature review and the interviewees' responses. Combining all practices builds the guideline that can assist construction companies in promoting sustainability within their organizations.

Table 5. Sustainable Guidelines to Enhance Construction Companies' Sustainable Culture.

Sr.	Practices	Nature of the practices	Reference
1	Influential factors	The commitment of authoritative bodies involved in the construction industry toward sustainability practices	(Robin and Poon, 2009)
2	Communicate	Embrace an open and democratic communication style regarding environmental ideas	(Madsen and Ulhøi, 2001) , Ramus, 2001)
3	Green education and training programs	Increase employee's awareness about the importance of sustainable practices	(Van Rensburg et al., 2017), (Liao, 2018), (Cook and Seith, 1992), (Ndzibah et al., 2010), Interviewees Response
4	Empowered employees	Moving decision-making power from managers down to employees will allow them more power and freedom to make suggestions and implement new sustainable practices. Empowering employees affects Employee Involvement	(Schultz, 2014), (Tariq et al., 2016), (Cotton, 1994), (Alt et al., 2015)
5		Reinforce the continuous motivation and increase commitment from the company's employees to be environmentally responsible.	(Meyer, 2016), (Baird et al., 2018), Interviewees Response
6	Rewards system	Financial rewards: profit-sharing programs, pay increases, recognition programs, incentives and benefits, monetary rewards	(Govindarajulu and Daily, 2004)
7		Non-monetary rewards such as time off from work, paid vacations, favored parking, or gift certificates	(Bragg, 2000)
8	Include all stakeholders in making the decision	To understand the complexity of the sustainable concept.	(Akadiri et al., 2012)

9	Setting goals and targets	To managing sustainable activities and concepts and give feedback and self-regulation of the process which supports the learning process	Akadiri et al., 2012)
10	Monitoring companies' reporting systems	where stakeholders can report gaps in the practices undertaken by the company and can report them to the management	(Trufil and Hunter,2006)
11	Providing incentives for employees	To reduce consumption of papers and other office appliances.	Interviewees Response
12	Engaging the staff in community activities	To bring them closer to the people they serve.	Interviewees Response
13	Starting initiatives	Leading by example	Interviewees Response
14	Staff involvement	Include the staff in the conception and the application of sustainability concepts in projects	Interviewees Response
15	Creating sustainable departments	Foster and enhance employees' understanding of sustainability, which eventually will allow employees to be creative.	Interviewees Response

3.6 Guideline Validation

The authors conducted electronic surveys with 30 industry professionals in junior to senior positions to validate the developed guideline. The interviews sought the professional opinion of the respondents on the efficiency of the developed guideline to change their mentality to be more sustainable. The results of the interviews are illustrated in Table 6 below, where the percentage represents the percentage of participants that have chosen the level of importance and efficiency.

Table 6. Results of the Guideline Validation Interviews.

Practice	Not Important	Somewhat Important	Important	Very Important	Extremely Important	Important to Extremely Important
Influential Factors	0%	0%	0%	30%	70%	100%
Communicate	0%	0%	17%	23%	60%	100%
Green Education and Training Programs	0%	0%	7%	30%	63%	100%
Empowered Employees	0%	0%	7%	53%	40%	100%
Rewards System	0%	0%	3%	27%	70%	100%
Include All Stakeholders in Making the Decision	0%	7%	33%	23%	37%	93%
Setting Goals and Targets	0%	3%	3%	50%	43%	97%
Monitoring Companies' Reporting Systems	10%	10%	17%	27%	37%	80%
Providing Incentives for Employees	0%	0%	0%	20%	80%	100%

Engaging the Staff in Community Activities	0%	7%	3%	27%	63%	93%
Starting Initiatives	0%	3%	7%	37%	53%	97%
Staff Involvement	3%	7%	20%	0%	70%	90%
Creating Sustainable Departments	0%	7%	10%	13%	70%	93%

4. Discussion

Climate change forces construction companies to change their practices to become more sustainable, and for that, a change to the employees' mindsets is essential. The driving force for this change comes from laws and regulations, social pressure, financial resources, and the availability of expertise and knowledge. For companies to implement those changes, they must have the full support of their managers to initiate cultural transformation to be more sustainable. To realize this cultural transformation, companies must initiate green education and training programs for the employees to increase their awareness of protecting the environment through their practices. In addition, companies must change their communication style to be more open to inform company employees about new environmental policies and practices to support this initiative.

The collection of practices from the literature resulted in identifying ten practices that are recommended to have a positive impact on changing employees' mindsets toward more sustainable culture. On the other hand, the five identified practices from the interviews with the industry experts provided insight into adopting sustainable practices in the UAE construction industry on organization levels. From the response of the experts, it was found that construction companies in the UAE implement practices to nurture the culture of sustainability in their organizations, and they do that through many practices with the main emphasis on training and educating their staff, and then leading initiatives and incentivizing the adoption of them.

On the other hand, for recommended practices to further enhance the implementation of sustainable company cultures, the experts suggested that including a sustainability indicator in employees' evaluations and rewarding sustainability champions as well as the role of the government in enforcing the sustainability concept can immensely benefit the initiative of adoption of sustainability in construction companies. It was also concluded that the concept of sustainable cultures in the construction industry exists but with a minimal application. Thus, there is a venue for improving the current state sustainability and sustainable culture on the corporate level of the construction industry. The fifteen identified practices can aid construction companies in fostering a sustainable culture in their organizations.

Moreover, the study results show a significant promise for the developed guideline since the validation analysis results indicated that 80% or more of the participants in the interviews indicated that all of the reported practices are important to extremely important. As such, this validates the efficacy of the guidelines in changing the mindset of employees in construction companies to adopt more sustainable practices and sustainability exercises in their professional life to change the overall organizational culture to be more sustainable.

5. Conclusions

To create the proper climate that supports transformation to sustainable organizational culture, companies must empower their employees to increase employee involvement in this cultural shift. Also, companies can motivate employees to be part of this initiative through rewards systems, whether monetary or non-monetary, for sustainable practices adopted by employees. In this study, best practices to improve corporate culture were collected from the literature and five industry experts were interviewed to obtain their input on implementing practices that promote sustainability in their organizations and provide recommendations on future practices that can be implemented; from the results of the interviews, a guideline for the development of the adoption of sustainable practice was built.

After which, the guideline was validated via electronic surveys answered by 30 construction professionals, in which 80% or more indicated that identified practices are essential and efficient in promoting sustainable culture in construction companies. In conclusion, all experts agreed that the concept of sustainability in company culture is lightly practiced in the UAE, and further efforts are needed to develop and enhance it. The developed guidelines can be a starting point to building frameworks for implementation.

This study recommends applying the developed guideline on a construction company to observe the impact of the application on adopting sustainable organizational culture. On the other hand, the study's main limitation is collecting data due to the COVID-19 pandemic outbreak; however, the authors sought industry connections and relationships to collect data.

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Building Information Modelling at the Design Conceptual Phase and Effect on Project Quality and Budget: A Review

Ntsako Khumalo[1], Innocent Musonda[2], Adetayo Onososen[3]
[1] University of Johannesburg, South Africa
[2] Center of Applied Research and Innovation in the Built Environment (CARINBE)
[3] Faculty of Engineering and the Built Environment
ntsakomakhense20@gmail.com

Abstract
Building Information Modelling is revolutionizing the workflow and processes in the industry and the design approach in creating building models. Among the stages of design, conceptualisation is being affected by BIM adoption as well. BIM has brought a lot of benefits to design but still designers are struggling to implement BIM at the very early stage of the design process. Thus, this study has been conducted to investigate how BIM is transforming concept design process and what could be the possible answer to overcome the barriers of BIM adoption at conceptualisation. From previous studies, the transformation of the design process within BIM methodology is explained and also general features of concept design stage are depicted to study its transformation within the evolution of Information Modelling. The study preferred reporting items for systematic reviews and Meta-Analyses (PRISMA) was used to identify inefficiency in construction design and conceptual phase, its effect on project quality and budget. To identify benefits and barriers to BIM at the design and conceptual phase this study presents preliminary findings based on twenty journal articles from an extensive review of a larger study. Findings from the review of the journal articles revealed the benefits and barriers to BIM at the design and conceptual phase and identify inefficiency in construction design and conceptual phase and its effects on project quality and budget.

Keywords
Building information modelling, Design, conceptual phase, systematic review.

1. Introduction

The five leading causes of delay in construction projects, according to Alinaitwe et al. (2013), comprise scope change, payment delays, high cost of capital, poor monitoring and control and political insecurity and instability. An inadequate experience by the contractor, poor project planning, site management, and change orders was among the 15 leading causes of delay in Turkey, according to Alinaitwe et al. (2013), BIM offers the potential to address these challenges and improve construction industry performance. BIM is an innovative technology and process to virtually design and manage construction projects (Azhar, 2013).

BIM has been adopted in the construction sector over the last two decades and it has the capacity to transform and enhance performance by decreasing inefficiencies, improving productivity and increasing collaboration among project stakeholders (Abanda et al., 2018). Adoption of BIM offers the visualization of design, fast creation of alternative designs, automatic examination of model reliability, production of reports and building performance forecasting (Sacks et al., 2013). Despite the potential benefits of BIM, its implementation rate has been slow owing to various barriers (Walasek and Barszcz, 2017).

As in other countries, BIM is gaining the attention of South Africa construction practitioners. However, there are many challenges which affect BIM adoption in South Africa (Karafin et al.,2016). following Tuvi (2017), that there is a need to investigate the barriers to BIM adoption in the South Africa construction sector. Using the PRISMA methods based on twenty journal articles the study investigate how BIM is transforming concept design process and what could be the possible answer to overcome the barriers of BIM adoption at conceptualisation.

2. Methods

Systematic reviews are important in summarising the empirical evidence related to technology or method that helps in suggesting feasibilities for further research in the same area. Sometimes, contradiction or support of the hypothesis can be achieved through a systematic review. systematic review approach following Meta-Analyses (PRISMA) protocol to review a large number of refereed papers published between 2013 to 2021was adopted.

The systematic review has allowed us to gather all the relevant and valid information concerning implementing building information modelling at the design conceptual phase on project quality and budget. through its rigorous and well-defined approach that perform strict rules and a clearly defined protocol. It aims to limit systematic error (bias), mainly by attempting to identify, appraise, and synthesize all relevant studies by using a specific methodology (Wen and Gheisari, 2020).

2.1 Inclusion and exclusion criteria

Inclusion criteria:

The article should relate to BIM in design and conceptual phase.
The publication must have a transparent methodology.
The research must come from trusted publication outlets and must be journals in order to ensure rigour in the quality of examined literature.
The publication year of the papers must be published between 2013 to 2021
Paper had to be written in English.

Exclusion criteria:

The exclusion criteria were applied using the OR logical operator between them. The application of the search string in the Scopus database allowed us to generate 20 articles. We started the articles filtering phase by applying the inclusion criteria. We limited our field of study to journal articles published between 2013 to 2021 and written in English. Then, based on their title, keywords, abstract, and perhaps the full text, we have been able to select the articles that will allow us to answer the research questions. The exclusion process resulted in a total of twenty papers from the Scopus database.

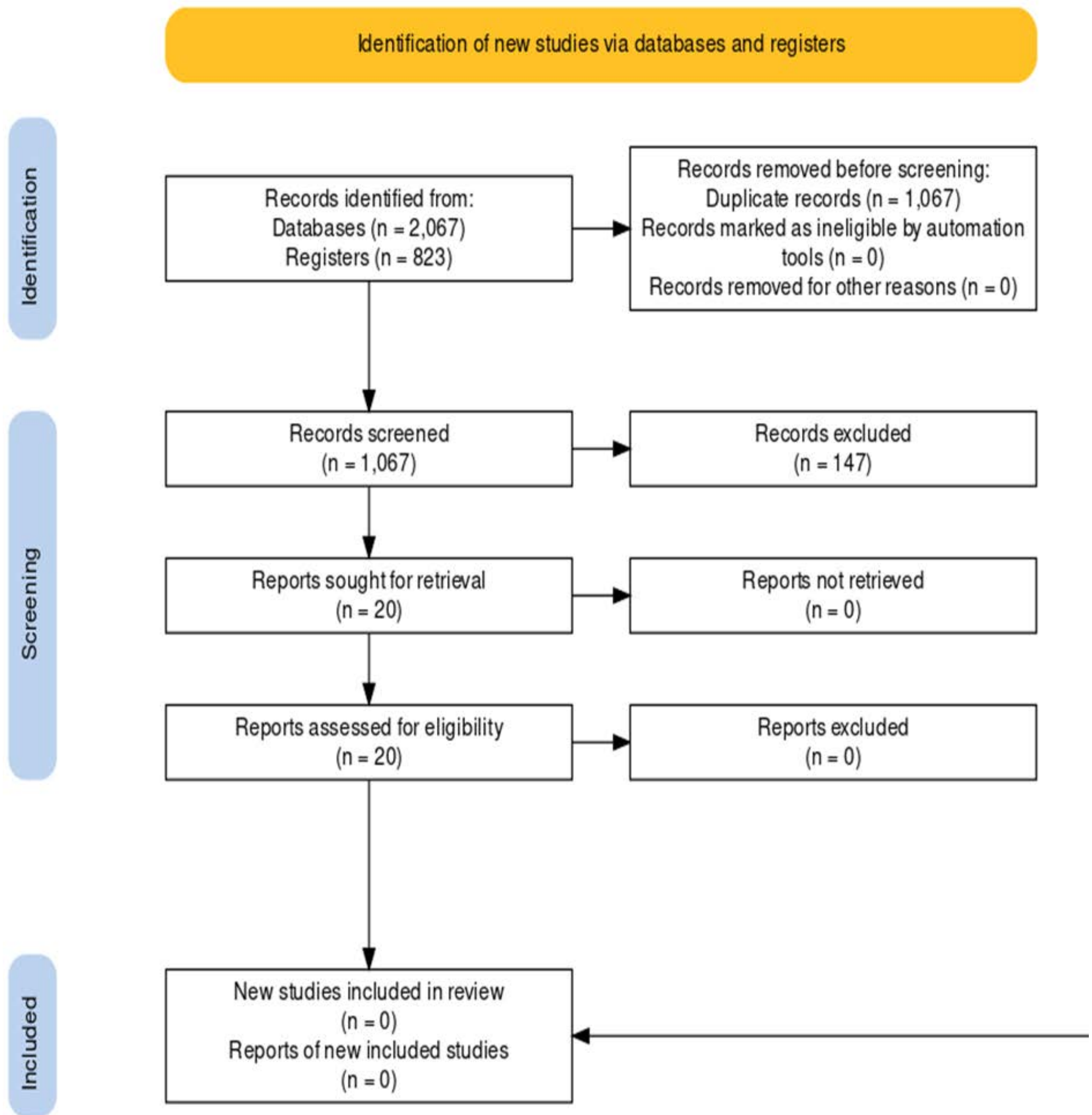
2.2 Selection: Research strategy

Through the Scopus digital libraries, we have done our search by using different methods with a specific configuration of the search string. Scopus is considered as the largest database of citations and abstracts from peer-reviewed bibliographies and quality websites and has a broad coverage of different disciplines and topics (Onososen and Musonda, 2022). It includes intelligent tools to track, analyse, and visualize searches (Saka and Chan, 2019).

Table 1. Systematic review process

Database- SCOPUS	Database- SCOPUS
Criteria	Filters
Restriction	Topic (Title, abstract, keywords
Documents type	Article
Language	English
Years	2013 to 2012

2.3 Fig. 1. PRISMA flow diagram



3. Results

3.1 Results

Findings from the literatures related to the objectives depict that BIM is affecting how we formulate design solutions and changes the design process in three stages: conceptual design, construction documents and engineering services by providing earlier accurate visualisation, interrelated changes, accurate drawings and cost estimation from 3D model, improving collaboration and sustainable design. Besides, at concept design stage, sketching is a critical activity in achieving a creative solution and 3D modelling is a common expression of ideas. Architects most of the times review the options on aesthetics specifically at this stage. Besides, some digital design methods such as generative approach have introduced new ways of design to create more exotic and innovation shapes. When the concept is finalised, the architect and the engineers start doing analysis looking into design possibilities to optimise the design. Early-stage analyses are not properly done because they are not fast and integrated to design. Findings from the literature regarding the actual benefits of BIM in conceptualization, BIM technology potentials and limitations and existing challenges will be further discussed in conjunction with the fieldwork's findings.

4. Discussion

Table 33. Barries to BIM Adoption

Barries to BIM Adoption	Sources
High initial cost.	(Ismail et al.,2017) (Saka and Chan, 2020)
Lack of awareness about BIM benefits.	(latiffie et al.,2016) (Saka and Chan, 2020)
Legal issue.	(Bosch-Sijtsena et al.,2017)
Lack of BIM experts.	(McAuley et al.,2017) (Saka and Chan, 2020)
Data ownership issue.	(Park and Kim.,2017) (Enshassi et al.,2016)
Lack of standardized tools and protocols.	(McAuley et al.,2017)
Interoperability between software programs.	(Onososen and Musonda, 2022)
Insufficient governmental support.	(Onososen and Musonda, 2022)
Inadequate training on the use of BIM.	(Onososen and Musonda, 2022)
Absence of contractual requirement for BIM implementation.	(Ahmed et al.,2014)

Table 2. BIM Benefits Through the Building Life Cycle

Benefits of BIM use	Sources
Pre-construction:	
Enables faster and more accurate cost estimation.	(Khosrowshahi.,2017)
Resolve design clashes earlier through visualizing the model.	(Latiffi el al.,2016)
Better concept and feasibility.	(Eastman et al.,2016)
Effective design reviews leading to sustainable design.	(Khosrowshahi., 2017)
Construction:	
Reduce site congestion and improve health and safety.	(Khosrowshahi.,2017)
BIM allows better site utilization.	(Deshpande.,2014)
Improve planning of resources and sequencing alternatives.	(Enshassi et al.,2018)
Post construction:	
Makes asset management faster, more accurate and with more information.	Husain et al.,2014)
Ability to schedule and easy access to information during maintenance.	(Enshassi et al., 2018)

Table 3. BIM Technology potentials & limitations from literature review

BIM technology potentials	Sources
Sketch Up for solid modelling.	(Sketch Up, 2016)
PriMus for bills of quantities.	(ACCA, 2015)
BIM vision in Poland.	(Kogut P. 2015)
BIM Server as a platform to handle IFC data and open BIM for attribute data enrichment, related to building elements.	(Saygi et al. 2013)
Grasshopper 3D as a graphical algorithm editor integrated with	

Rhino's 3D modelling tool.	(Naboni &Paoletti 2015)

Table 4. BIM Adoption Rate in Various Countries

Country	BIM adoption rate (year and sources)
Australia	67%, 2016 (Red Stack BIM services, 2016)
Canada	78%, 2018 (Macabe et al, 2018)
China	67%, 2014 (Jin et al, 2015)
Denmark	78%, 2016 (Malleson, 2016)
Estonia	51%, 2015 (Usesoft AS,2016)
Japan	46%, 2016 (Malleson, 2016)
Poland	23%, 2015 (Juszczyk et al., 2015)
United Kingdom	74%, 2018 (Malleson, 2018)
United State	79%, 2015 (Gerges et al.,2017)

Table 5. BIM digital objects

Clusters	Description	Sources
Scan to BIM	BIM objects that can be monitored and retrieved via point cloud data via laser scanning and photogrammetry.	Adan et al. (2018)
Interoperability	BIM objects are discussed in the context of stakeholder information exchange interoperability. Research conducted developed a plethora of process maps to identify potential. BIM users and IER	Arayici et al. (2018)
Clash detection	Clash and error detection can be achieved using: i) visual representations and error detections (e.g. Solibri clash detection software).	Sabart (2018)
3D printing and Additive manufacturing	The integration of 3D printing and BIM in manufacturing is a new area of research that has not been explored fully.	Goessens et al. (2018)

5. Conclusions

This study looks into the impact of BIM in concept design stage. It has basically investigated the literatures on how BIM is transforming the general process of design and by pointing out features of concept design stage, it shows what specific requirements have not been met in conventional design process that will shift conceptualization toward adopting BIM. One major fact is that the need for integrated fast analysis to look into design possibilities and to help design decision-making process has not been fulfilled in traditional concept design. BIM is an answer to the inefficiencies of conventional processes and has brought a number of benefits to the design process making it more integrated and collaborative, however not all the areas of concept design is supported by the idea of information modelling and designers are still struggling to achieve a best conceptual design solution in a short time. Technology enhancement can be very helpful in this regard but other areas such as updated mind-sets, a proper methodology for design and supports for a creative thinking process in concept design are as important as having an ideal collaborative technology in hand. Through this study, new exciting research opportunities have been found for future research. Ultimately, we encourage further work that could provide valuable information to practitioners and support new research and academic findings.

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Resilience in Construction Robotics and Human-Robot Teams for Industrialised Construction

Adetayo Onososen[1], Innocent Musonda[2], Molusiwa Ramabodu[3] and Motheo Meta Tjebane [4]

[1, 2,4] Center of Applied Research and Innovation in the Built Environment (CARINBE)
Department of Quantity Surveying and Construction Management
Faculty of Engineering and the Built Environment
[3] Department of Quantity Surveying and Construction Management
Faculty of Engineering and the Built Environment
Onososen@outlook.com

Abstract
Recent conversations in the built environment have been centered on the need for the built environment to be resilient and responsive. This has become imperative due to recent shock events such as the pandemics, which has revealed the sector's vulnerability in the face of shock events. However, sectors cannot be resilient and responsive when systems, processes and workflows are not built to be resilient. This paper, therefore, brings to the fore issues on the resilience of construction robotics, indicators for resilience in construction robotics, and why resilience is inevitable. Through a PRISMA construed systematic literature review, the paper links different theories and concepts from the social sciences and engineering to answer its applicability to the research objectives for built environment resilience. The study's findings inspire further conversations on the resilience of emerging digital technologies for the fourth industrial revolution and their potential to achieve a resilient and responsive AEC sector.

Keywords
Resilience, Construction Robotics, Human-Robot Teams, AEC

1. Introduction

Building new construction processes, workflows, and methods is integral to the emergence of fourth industrial technologies in the face of rapid urbanisation and shock events that require the AEC sector to adapt to increasing infrastructure delivery. Industrialised construction can improve construction processes by adopting automation and robotics (Rad, Mojtahedi and Ostwald, 2021). This has been necessitated by declining productivity, delivery of infrastructure on schedule, high incidence of hazards and risk on-site, the strain on construction workers, shortage of skills due to ageing workforce and the overall need to improve quality. As signified by Autodesk (2019), there would be a major increase in the use of industrialised construction (IC) to deliver infrastructure by 2035. By using IC, you can reduce labor costs, improve safety, decrease delays, improve product quality, enhance productivity, and improve dexterity - things that traditional construction methods would not normally accomplish (Bogue; 2018, Autodesk, 2019; Andersson, Cäker, Tengblad, and Wickelgren, 2019). With the need for manufacturers of autonomous systems, robotics, and collaborative robots to converge and mass-produce highly bespoke complex systems for construction usage, it is imperative to improve these systems' ability to aid the construction industry's resilience. Systems in an environment must be resilient to afford resilience to the environment. Moreso, autonomous systems must be resilient to deal with unanticipated circumstances in improving the overall responsiveness of the AEC to shock events (Zieba et al., 2009). Resilience describes how a human-machine system responds to unforeseen events, whether technical systems failures, human errors, or external circumstances (Zieba et al., 2009). Conversations on driving research and discussions on resilient robotics and collaborative teams are important to reinforcing the existing vulnerabilities in the built environment.

If not resilient and able to respond, collaborative construction robots could easily be relegated to tools or equipment rather than perceived as teammates on a worksite. Resilience is imperative to improve construction collaborative robots' productivity, durability, and reliability. Therefore, given the preceding, this study avails existing insights in resilience for autonomous systems, identifies indicators for resilience in construction robotics and highlights the importance of resilience in construction robotics to achieve a responsive AEC sector.

2. Methods

This work is based on a Systematic Literature Review(SLR) conducted to identify scientific papers discussing and evaluating resilience in autonomous systems, indicators for resilience and the importance of resilience in construction robotics adoption. According to Dieste et al. (2021) SLR method handles scientific research document analysis in a precise, transparent, and explicit manner. The methodical, explicit, and repeatable strategy used in this method, which involves several steps, ensure rigour and comprehensibility in the literature review process. The keywords of the study were searched in electronic search engines such as Google Scholar, Emerald Insight, Web of Science, Scopus, and ScienceDirect. These databases are extensive and can be accessed by academic institutions. Some databases offer advanced search capabilities that can help find relevant studies more precisely.

Furthermore, these databases have been used in similar studies related to construction robotics and resilience. Multiple databases expanded the search scope while minimising biases associated with a single database (Tennakoon et al., 2021). The defined keywords are linked using Boolean connectors "AND" to facilitate an advanced search related to the research area in these search strings. To avoid errors in selecting studies and avoid methodological errors, efforts were made to assess and examine search terms and inclusion and exclusion criteria to minimise errors (Nwajei, 2021). The inclusion and exclusion criteria are shown below in Table 1

Table 1: Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion criteria
Must be written in English	Not written in English
Documents must be peer-reviewed journals and book chapters	Any publication, not peer-reviewed journal or book chapter
Must be built environment and/or construction industry	Not related built environment and/or construction industry

This systematic review is conducted using PRISMA, a widely recognised standard procedure for conducting systematic reviews and meta-analyses. This way, the review can be planned before starting, and methods can be justified for their applicability while avoiding biased decisions (Wijewickrama et al., 2020).

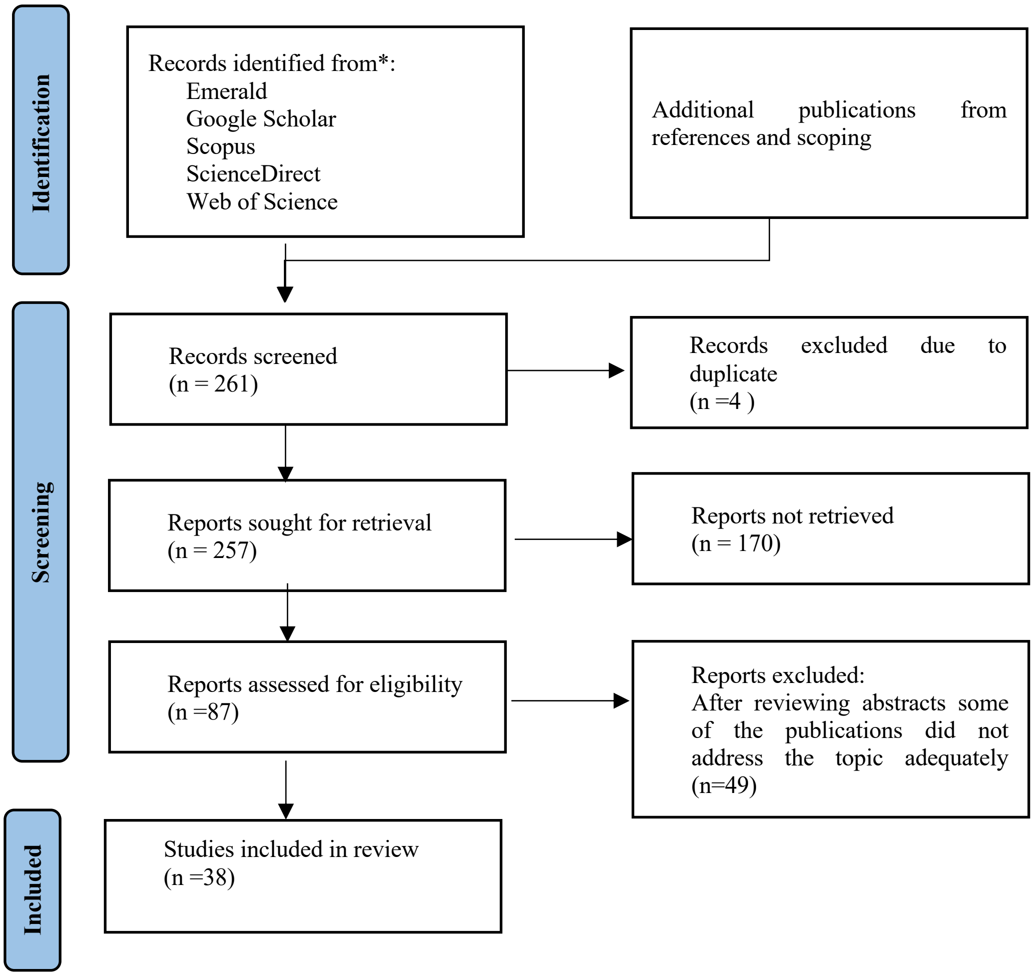

Fig 1. Research Method using PRISMA approach (Adapted from Page et al. (2021)

3. Results and Discussion

3.1 Wave of Publication Outputs

As demonstrated in Fig 2, construction robotics resilience studies are emerging in the AEC sector with low output in publications signifying constrained conversations on the thematic area. Given post-covid-19 research development and interests, it is projected that these areas will grow significantly as researchers are beginning to rethink the resilience of the construction sector.

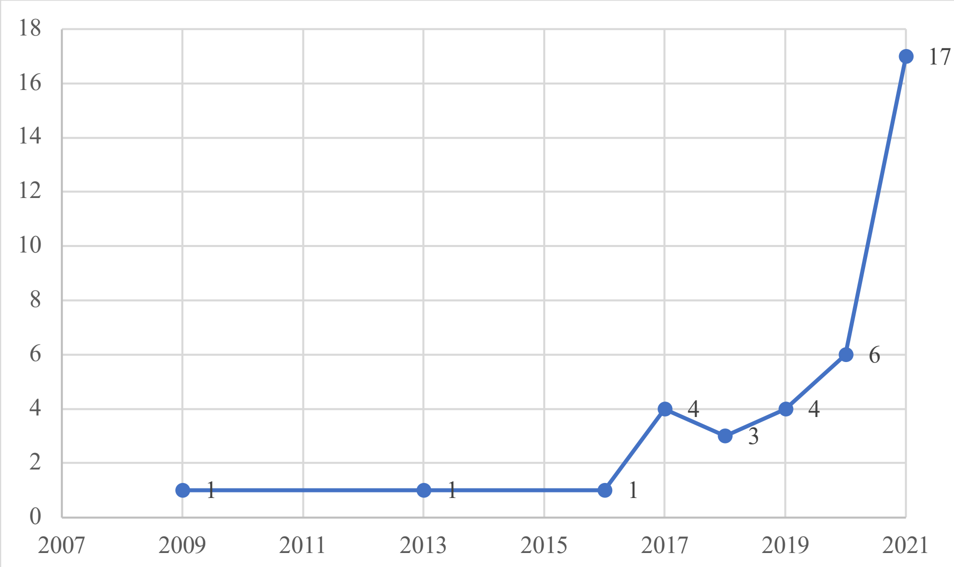

Fig 2. Research Method using PRISMA approach (Adapted from Page et al. (2021)

3.2 Overview of Important Documents towards resilience in construction robotics

Table 2 presents the research themes with directions towards the emerging conversation on the resilience of robotics in the construction industry. The thematic areas are discussed further in the next section.

Table 2: Research themes, study aims and method approach

Title	Authors/year	Aim	Method	Publisher
A Survey on Blockchain in Robotics: Issues, Opportunities, Challenges and Future Directions	Aditya, Singh, Singh, Kalla, 2021	A review of blockchain technology	literature review	Journal of Network and Computer Applications
Creating a case for innovation acceleration in the New Zealand building industry	Adafin, Rotimi, MacGregor, Tookey, Potangaroa, 2021	Pathways to Innovation acceleration	Mixed method	Construction Innovation
Systematic analysis of driverless technologies	Edwards,Akhter, Rillie, Chileshe, Lai, Roberts, Ejohwomu, 2021	Barriers, adoption issues, current development processes in driverless technologies	Mixed method and SLR	Journal of Engineering, Design and Technology
Toward digitalisation in the construction industry with immersive and drones technologies: a critical literature review	Elghaish, Matarneh, Talebi, Kagioglou, Hosseini, Abrishami, 2021	Literature review on digitatlization of the construction industry	SLR	Smart and Sustainable Built Environment
Digital project driven supply chains: a new paradigm	Bhattacharya and Chatterjee, 2021	Proposed an integrated framework for digital project-driven supply chains (PDSC) in AECO value chain.	Mixed method	Supply Chain Management: An International Journal
3D-Printing of Ultra-High-Performance Concrete for Robotic Bridge Construction	Javed, Mantawy, Azizinamini, 2021	Framework and performance metrics for materials and 3D-printing systems for bridge applications.		Journal of the Transport Research Board

Augmented reality and digital twin system for interaction with construction machinery	Hasan, Lee, Moon, Kwon, Jinwoo, Lee, 2021	AR & Digital Twins for Construction machinery	Model	Journal of Asian Architecture and Building Engineering
Industry 4.0, Disaster Risk Management, and Infrastructure Resilience: A Systematic Review and Bibliometric Analysis	Habibi, Mojtahedi, Ostwald, 2021	Analysed the application of I4.0 in disaster risk management	A Systematic Review and Bibliometric Analysis	Buildings
Propositions for a Resilient, post-COVID-19 Future for the AEC Industry	Nassereddine, Seo, Rybkowski, Schranz, Urban, 2021	Propositions for a resilient, post-COVID-19 future for the construction industry	literature review and modelling	Frontiers in the built environment
Robotic technologies for on-site building construction: A systematic review	Gharbia,Chang - Richards, Lu, Zhong, Li, 2021	A systematic review on robotics technologies for on-site building construction.	Systematic literature review	Journal of Building Engineering
Cloud Manufacturing, Internet of Things-Assisted Manufacturing and 3D Printing Technology: Reliable Tools for Sustainable Construction	Singh et al, 2021	The opportunities and challenges of construction digital technologies to achieve sustainability.	Literature review	Sustainability
Robotics as an Enabler of Resiliency to Disasters: Promises and Pitfalls	Wang et al, 2021	Examines how robots can make human and natural environments more resilient	Literature review	Resilience in the Digital Age
The Integration of Lean and Resilience Paradigms: A Systematic Review Identifying Current and Future Research Directions	Rad, Mojtahedi and Ostwald, 2021	SLR of articles context-intervention-mechanism outcome framework	Systematic Review	Sustainability
Modelling construction 4.0 as a vaccine for ensuring construction supply chain resilience amid COVID-19 pandemic	Osunsanmi, Aigbavboa, Thwala and Molusiwa, 2021	Modelled construction 4.0 as a tool for supply chain resilience in the construction industry.	survey questionnaire	Journal of Engineering, Design and Technology
A systematic review of factors affecting post-disaster reconstruction projects resilience	Charles, Chang-Richards and Yiu, 2021	literature on resilience factors applied to post-disaster reconstruction projects	SLR	International Journal of Disaster Resilience in the Built Environment
Trusting Automation: Designing for Responsivity and Resilience	Chiou and Lee, 2021	Reviewed articles related to human trust in automation in complex work environments	Literature review	Human Factors and Ergonomics Society
Towards commissioning, resilience and added value of Augmented Reality in robotics: Overcoming technical obstacles to industrial applicability	Jens Lambrecht, Kästner, Guhl , Krüger, 2021	Presents approaches towards distributed, hardware-agnostic microservice architecture with standard interfaces	Literature review	Robotics and Computer–Integrated Manufacturing
Ontology-based semantic modelling to support knowledge-based document classification on disaster-resilient construction practices	Dhakal, Zhang, Lv, 2020	Ontology-based semantic model for representing disaster resistance in construction job sites	Ontology development	International Journal of Construction Management
Distributed Situational Awareness in Robot Swarms	Jones, Milner, Sooriyabanda,Hauert, 2020	Provides situational awareness on swarms of low-cost robots	literature review	Advanced Intelligent Systems
Construction Automation and Robotics for High-Rise Buildings: Development Priorities and Key Challenges	Cai et al, 2020	Examined future development of robotics in the construction and maintenance of high-rise buildings	Quantitative research using Questionnaire surveys	Journal of Construction Engineering and Management
COVID, resilience, and the built environment	Keenan, 2020	Examined relationships between public and private sector resilience planning activities	Literature review	Environment Systems and Decisions

A digital supply chain twin for managing the disruption risks and resilience in the era of Industry 4.0	Ivanov & Dolgui, 2020	Presents a notion of a digital supply chain twin through a computerised model that represents network states for any given moment in real time		Production Planning & Control
Robotic technologies for on-site building construction: A systematic review	Gharbia, Chang-Richards, Lu, Zhong , Li, 2020	Provides a systematic review of robotics for on-site building construction	Literature review	Journal of Building Engineering
Towards on-site, modular robotic carbon-fibre winding for an integrated ceiling structure	Reinhardt et al, 2019	Research and development of robotic carbonfibre winding of an integrated ceiling structure for flexible workspaces scenarios	modelling	Construction Robotics
Constructing living buildings: a review of relevant technologies for a novel application of biohybrid robotics	Heinrich et al, 2019	Reviewed relevant technologies within construction automation and structural engineering	Literature review	Journal of Royal Society Interface
Building traits for organisational resilience through balancing organisational structures	Andersson, Cäker,Tengblad, Wickelgren, 2019	Describes and explains how balancing organisational structures can build traits for organisational resilience	Qualitative	Scandinavian Journal of Management
Deep Learning for Critical Infrastructure Resilience	Andersson, Cäker, Engblad and Wickelgren, 2019	Presents deep learning and critical infrastructure protection and illustrates how deep learning can improve resilience	Case Study	Journal of Infrastructure Systems
Digital skin of the construction site Smart sensor technologies towards the future smart construction site	Edirisinghe, 2018	Developed the concept of the digital skin of the future smart construction site.	Systematic and hierarchical literature review	Engineering, Construction and Architectural Management
What Are the Prospects for Robots in The Construction Industry?	Bogue, 2018	The present uses and potential future roles of robots in the construction industry	Literature review	Industrial Robot
Defining resilience for the US building industry	Kurth, Keenan, Sasani & Linkov, 2018	Presents opportunities and limitations for mainstreaming resilience into building industry processes and actors	Literature review	Building Research & Information
Briefing: UK-RAS white paper in robotics and autonomous systems for resilient infrastructure	Fuentes, Chapman, Cook, Scanlan, Li, Richardson, 2017	A briefing of the published UK-Robotics and autonomous systems (RAS) network	Literature review/ white paper	Smart Infrastructure and Construction
Contextualising mainstreaming of disaster resilience concepts in the construction process	Amaratunga, Malalgoda and Keraminiyage, 2017	Presents knowledge base of construction professionals on disaster resilient society	Interviews/Focus Group	International Journal of Disaster Resilience in the Built Environment
Resilient Robots: Concept, Review, and Future Directions	Zhang, Zhang and Gupta, 2017	Review on recent developments in the emerging field of resilient robots and the related robots that share common concerns with them	Literature review	Robotics
Self-Healing and Damage Resilience for Soft Robotics	Bilodeau and Kramer, 2017	Review on the state-of-the-art in damage resilience and self-healing materials and devices as applied to these three pillars.	Literature review	Frontiers in Robotics
Quantifying resilience	Angeler and Allen, 2016	looks at resilience terms, concepts and quantifies resilience	literature review	Journal of Applied Ecology

Survey and Introduction to the Focused Section on Mechatronics for Sustainable and Resilient Civil Infrastructure	Li et al, 2013	looks at research progress on the construction automation in the built environment	Systematic literature review	IEEE/ASME Transactions On Mechatronics

3.3 Theoretical background to resilience in construction robotics and human-robot teams

In industrialised construction (IC), more innovative and integrated techniques link the design of processes and systems (Autodesk, 2019). While the definition of resilience is understood on the surface level, conceptual and mathematical modeling is needed to broaden its applicability (Hoorn, 2018). The OECD outlines resilience as "the capacity for a system to absorb disturbances, recover from disruptions, and adapt to changing circumstances while retaining essentially the same function as before they were disrupted" (OECD, 2019; Chiou & Lee, 2021). Different concepts in resilience have identified it as resilience: rebound, which restores the system to its normal state after disruption, and robustness, which reacts to disruptions effectively. By introducing adaptations and emergence of new solutions within the system of functioning, resilience lies beyond the notion of robustness (Zieba et al., 2009; Li et al., 2013). The ability of construction robotics to be resilient is embedded in that errors of all kinds can be anticipated, reacted to, recovered from, and even learned from (Zieba et al., 2009; Edirisinghe, 2018).

In creating a case for innovation, Adafin et al. (2022) investigated how technological innovations can be enhanced within the New Zealand built sector to improve resilience in productivity. Through collating experiences, the study found that case studies are imperative in advancing the merits of showcasing the benefits of robotics. Further found that government interest is imperative to adoption. As adoption is imperative for improvement in design necessary to achieve resilience, the government must make strategic contributions through incentives and focus on knowledge development. While Edirisinghe (2019) supports this assertion, it also reiterated that heterogeneity of construction workplaces, social complexity of stakeholders, dynamicity of construction activities are factors needed to consider in designing resilient construction robotics. The study further discussed the importance of hardware, communication technologies, and software to support needed digital infrastructure in a collaborative environment. Driverless technologies enhance resilience in robotics as they offer the advantages of remote-controlled workflows vital for high risk and hazardous construction sites. Edwards et al. (2021) affirm this by also stating fusion of technological technical know-how with industry-specific knowledge is important to drive these advancements. Elghaish et al. (2021) assessed the status of adopting UAVs and indicated that while they are innovations, their versatility in applications to achieve resilience is widening. However, licensing and approval to fly are challenges facing the adoption and improvement of these technologies.

3.4 Indicators of Resilience in Construction robotics design for industrialised networks

Resilience is less discussed in construction robotics (Nassereddine et al., 2021). It is, however, imperative to achieving sustainable infrastructure delivery. Resilience in the context of robotics for construction has been defined with indicators as identified by Fiksel (2003), Zieba et al. (2009), and Hollnagel and Woods (2006). They are.

Cooperativeness: Construction robotics for deployment on industrialised construction sites would not operate in silos but in collaborative tasks. In human-robot teaming, cooperativeness is essential in building trust, understanding tasks, and enhancing communication between robotics and humans (Chiou and Lee, 2021). This, therefore, involves the coordination of tasks, ordering of workflows, and choosing an effective team lead. However, the responsiveness of human workers to collaborate in these teams is underpinned by knowledge of the autonomous system, underlying beliefs/perceptions of robotics, assumptions, and socio-cultural implications (Chiou & Lee, 2021). However, resilience for autonomous systems in the built sector is considered how agents within a network cooperate and utilise shared resources when faced with unexpected challenges (Woods, 2015). Research by Friedland (1990) highlights that trust is most likely to flourish when both parties demonstrate genuine responsiveness to each other's needs, not only because trust is reciprocal (trusting because one feels trusted), but also because of the complex interaction among those involved. Enhancing the interaction between a human operator and a robot to optimise the use of their respective competencies is essential for improved cooperativeness

Adjustable Autonomy: Zieba et al. (2009) described this as the ability of robotics to adjust at any time for unplanned events to react to and optimise the distribution of tasks among humans and robots. Nassereddine et al. (2021) highlight that resilience is less about reducing the risk that returns a system to its previous position but more about adaptive capacity, which aids a system in adapting to a world permanently under transformation. For construction robotics to be resilient, they must integrate adjustable autonomy in designs.

Buffering capacity: Hollnagel and Woods (2006) defined this as the quantitative capacity of systems to cope with perturbation without adapting Zieba et al. (2009). Maintenance fears, breakdowns, loss or mechanical intolerance identified as fears associated with the adoption of construction robotics must be designed to withstand stress, strain, and external pressures to offer more effectiveness and justify the cost of procurement.
Margin and tolerance: This describes the behaviour of a system concerning a boundary of operations (Hollnagel and Woods, 2006; Zieba et al., 2009). Tolerance towards tasks and between teams is important. Nassereddine et al. (2021) stated that resilient teams tend to have members who can resolve conflicts. This is also important to avoid destructive tendencies from humans towards robotic teammates.
Flexibility: this describes the capacity of autonomous systems to adapt to new constraints (Hollnagel and Woods, 2006; Zieba et al. 2009). The construction sector is reputable for encountering engineering challenges necessitating flexibility in approach. This further reiterates the importance of integrating human, technical skills with the operational capacity of the robots.
Cross-scale interactions: Due to the importance of communication in collaborative systems, cross-scale interactions examine the communication between the different entities of the system. In examining the challenges to the resilience of robotics, Srinivas Aditya et al. (2021) mentioned this interaction embodies perception, cognition and action. It further explores a robot's sight, speech, thoughts, social awareness, proximity, autonomy and how humans perceive these robots. Understandable interaction in communication between collaborative teams in humans and robots must be driven towards enabling a trustworthy environment (Emaminejad et al., 2021). Courtemanche (2020) demonstrated the importance of this and stated relationships serve as the heartbeat of infrastructure projects and therefore is underpinned by the resilience of project teams members who play a key role in improving the overall resilience of the AEC sector.
Diversity: As Fiksel (2003) identified, diversity illustrates the availability of multiple forms and behaviours in the system (Zieba et al., 2009).
Efficiency is explained as focused on ensuring the system's performance while utilising modest resources (Fiksel,2003; Zieba et al., 2009).
Adaptability: This flexibility allows the system to react to different pressures. Situational awareness is vital to this; Jones et al. (2020) state that perception of the environment by the robot, comprehension of the situation in relation with the construction tasks to be executed, and situational awareness allows the construction robot to capture the state of the environment and act accordingly are essential in achieving resilience.
Cohesion: Describes a set of unifying patterns or links and interactions between the entities of an organisation to manage perturbations. To achieve this, future designs must factor in resilient physical practices, economic-resilient practices, social-resilient practices and environmental-resilient practices (Dhakal et al., 2020).

3.5 Importance of Resilience in Construction Robotics and human-robot teams' design

As stated by Bhattacharya and Chatterjee (2021), with the development of several technologies, the potentials of these systems are lost and not appropriately communicated to stakeholders (Bhattacharya and Chatterjee, 2021)
With deployment in hazardous areas, the incidence of damage is high, and self-regenerating properties are important for it to continue to function despite damages. An example of this is the black star robot (Habibi Rad et al., 2021). The investment cost of adopting robotics would be easily justifiable when robots are resilient and can adequately justify the cost-benefit. This is imperative as stakeholders are looking for investing in systems that last and endure. Maintenance and sustaining costs would be more reduced when resilience is designed into robots as they can repair themselves, sense, identify and remedy damages.
Furthermore, with the need of the built environment to be resilient and responsive in the face of shock events such as pandemics. Consequently, stakeholders' requirement is shifting from adopting and deploying robotics just for productivity and further to integrating resilience into infrastructure delivery (Cheshmehzangi 2021). Achieving sustainable infrastructure delivery depends on the industry's resilience, which cannot be achieved without resilient systems underpinning its execution and transformation (Courtemanche, 2020). Due to the unstructured nature of built environment construction projects and the unpredictability of hazards and topographical challenges in heavy engineering and mining works, robotics systems must be resilient to truly adapt to such environments and function optimally with zero human intervention. This is especially important in disaster management and construction during shock events to help address labour shortages, reduce safety issues, and deliver infrastructure needs (Habibi Rad et al., 2021). Resilience is imperative to how human collaborators perceive collaborative construction robots. Therefore, to build resilience in the AEC, Nassereddine et al.(2021) proposed; decentralisation of the operations of design and construction firms, early involvement of key project participants, industrialised construction, circular business models,

remote working, integrated design management using BIM, resilience in staffing and skills training, reversible building design, AR-enabled applications, the shift to automation and 3D printing and Lean Construction.

4. Conclusion

Recent shock events have revealed the vulnerabilities in the AEC sector exacerbated by the continuous use of traditional construction systems, workflows, and processes with no enhanced productivity benefits. With emerging digital technologies, industry practitioners will be looking to maximise returns on infrastructure investment by adopting resilient robotic systems. In the aftermath of COVID-19, many studies are rethinking approaches to infrastructure to build resilient and sustainable infrastructure (Lauren, 2021). Shock events have demonstrated the importance of resilience in infrastructure in maintaining a continuous supply chain, logistics, and delivery of essential goods and services. This has underlined the need for countries to make their infrastructure more resistant to future disasters and pandemics. Governments can limit their exposure to fiscal risks over the lifetime of infrastructure assets by incorporating sustainability and resilience considerations into their infrastructure planning. Therefore, further studies must be conducted to sustain resilience in the face of shocks, considering how interconnected systems incorporating technologies, systems, and humans within the industry can utilise shared strengths to adapt to shocks. This means anticipating, reacting, recovering, and learning from different kinds of errors. Therefore, this study avails a review of conversations on resilience in construction robotics, its importance, and indicators for the design and development of resilient robotics in industrialised construction.

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Influential Factors Affecting the Diffusion of Building Information Modeling in South African Construction Projects

Alireza Moghayedi[1], Mark Massyn[1], Karen Le Jeune[1] and Kathy Michell[1]

[1] Sustainability + Oriented Cyber Unit for Built Environment, Department of Construction Economics and Management
University of Cape Town, Cape Town, 7700, South Africa
alireza.moghayedi@uct.ac.za

Abstract
Sustainability has become the focus of many clients in construction projects, but conventional construction stakeholders' services do not promote sustainability throughout the construction process. Conversely, Building Information Modeling (BIM) has been identified as a tool that construction stakeholders can use to enhance the sustainability of construction projects. However, the majority of South African construction projects still do not utilize BIM. Therefore, this study aims to understand the influential factors affecting the low adoption of BIM in South African construction projects. To achieve the aim of the study, the research study implemented the qualitative research approach. The data collected from semi-structured interviews with several South African BIM experts produced invaluable qualitative data. The collected data was thematically analyzed to extract key findings and themes concerning the key influential factor and their sub-factors on BIM adoption in construction projects. Four identified influential factors and their sub-factors affecting the diffusion of BIM emerged deriving from the findings discussed in the research study. Based on these findings, it was proven that BIM could improve the sustainability of construction projects. Numerous conclusions and recommendations were proposed in this research study targeted at increasing the adoption of BIM intended to enhance the sustainability of construction projects.

Keywords
BIM, Construction projects, Influential factors, Level of adoption, South Africa.

1. Introduction

Sustainable construction has come under the spotlight in the industry in recent years resulting from an awareness of the need to address the life cycle costing of the building (Moghayedi *et al*., 2021). Furthermore, sustainable construction plays a significant role in impacting the construction project's social, environmental, and economic factors by striking a balance between these factors during the construction project's life cycle (Yilmaz and Bakış, 2015). Traditionally construction projects' focus is on time, cost, and quality. However, in recent years, there is an awareness of the life cycle impact of the building, particularly on the social, environmental, and economic sustainability factors, and this propelled sustainable construction to become a crucial concept in evaluating the overall success of the project (Kamali and Hewage, 2017). Furthermore, the sustainability of the construction project can be positively impacted through the adoption of BIM throughout the various stages of the project by all the construction stakeholders to ensure projects remain within project specifications (Ullah *et al.*, 2019).

However, construction stakeholders in developing countries such as South Africa remain stuck in traditional practices (Moghayedi *et al.,* 2022). They are hesitant to adopt BIM due to their lack of understanding of the potential uses and benefits (Gilchrist *et al*., 2021). Construction stakeholders need to realize the benefits of BIM instead of opposing this technology and rather should adopt and implement it.

Awwad et al., (2020) state that the developed countries such as the UK government strategies for more sustainable construction through the following key factors: a design for minimum waste, applying lean construction principles, minimizing energy in construction and use, pollution reduction, preservation and enhancement of biodiversity, conservation of water resources, respect for people and local environment, setting targets to benchmark performance and that these factors need to be incorporated throughout the lifecycle design of the construction project. Specifically, regarding the pre-construction stages of the construction process, the primary strategies implemented to contribute to the sustainability of the construction project are processes such as site selection, flexible and durable design, and selecting sustainable materials (Yılmaz and Bakış, 2015). Most of a buildings' negative impacts on sustainability are undertaken in the early design stages of construction. Past research has recognized the importance of the early design stages in reducing buildings sustainability (Carvalho *et al*., 2020).

Construction projects have become more complex, and the complexities surrounding big construction projects result from thousands of documents and drawings being processed and used manually (Gilchrist *et al*., 2021). Two-dimensional information management can result in miscommunication amongst the design and construction teams and often times are inadequate for complex projects. Miscommunication can result in mistakes made during construction such as poor design, outdated drawings used, delays, cost overruns, poor quality and design clashes with BIM existing as an innovative technology that can improve the inefficiencies of conventional construction information management (Carvalho *et al*., 2020).

The positive impact that BIM can have on the sustainability of construction projects and the construction industry, in general, is essential (Awwad *et al*., 2020). BIM can shift the construction industry from the 'conventional' paper-based approach to a cloud-based collaborative 3D model process and allows sustainability to be measured throughout a project's life cycle.

Construction stakeholders prefer conventional practices rather than proactive in approaching BIM (Carvalho *et al.,* 2020). There is believed to be a lack of understanding of the potential uses and, more importantly, benefits of BIM (Gilchrist *et al*., 2021). The construction industry remains one of the slowest adopters to new innovative technologies, with the South African construction industry being no different.

BIM has become a central focus amongst construction stakeholders due to the improvement in productivity and efficiency it offers (Gilchrist *et al*., 2021). However, the barriers to adoption are believed to be poor connectivity, high software costs, lack of international certification and lack of understanding of the uses and benefits of BIM in South Africa (Gilchrist *et al*., 2021). These reasons have negatively affected BIM uptake amongst construction stakeholders in South Africa.

Sustainability has become at the forefront of many industries worldwide, and previous research shows the importance of sustainability, especially in the construction industry (Carvalho *et al*., 2020). BIM gives construction stakeholders the ability to become drivers of economic sustainability in the construction industry.

Despite the benefits and potential of using BIM on construction projects to enhance the sustainability of the projects and able construction stakeholders the ability to become drivers of economic sustainability in the construction industry, South African construction professionals prefer using their traditional methods and practices.

Therefore, there is a need to identify the key influential factors associated with BIM diffusion in South African Construction Projects. As its central aim, this study seeks to develop this knowledge base through the establishment of the BIM adoption conceptual framework for the South African construction industry.

2. Research method

Since the influential factors affecting the diffusion of BIM in South African construction projects are still a less explored area, it requires utilizing qualitative techniques to collect data from the experts to investigate this little-understood phenomenon as proposed by Creswell and Creswell (2017).

Deploying semi-structured interviews in the present study aimed to provide a basis for conceptualizing the key influential factors in the adoption of BIM in South African construction projects.

The number of interviewees was considered to be between three and 16, as a reasonable preliminary estimation for defining the sample size (Bazeley, 2013). Thus, an initial list of 10 South African BIM experts was identified. As a result, interviews were reached saturation point after conducting interviews with five interviewees whose profiles are detailed in Table 1

Table. 34. Interviewees' profiles

Code	Professions	Experience in BIM	Organization	Project size
1	Quantity surveyor	5 years	Engineering consulting	Large
2	Construction manager	7 years	Developing	Large

3	Architect	3 years	Local government	Large
4	Quantity surveyor	4 years	Quantity surveying consulting	Large
5	Structural engineer	8 years	Engineering consulting	Large

For this research, an inductive approach has been adopted. The structure of the study was developed through the data that was collected. Following this, a thematic analysis of the data collected was employed as this is a commonly used inductive approach to analyzing data. Common themes (influential factors) and sub-themes were identified in the interview transcripts using NVivo, and these themes were used for developing the conceptual framework.

3. Results

Examining the data extracted from the transcribed interviews, the following common themes (influential factors) and sub-themes emerged throughout:

3. 1 Barriers and challenges concerning BIM adoption

Barriers and challenges relating to BIM adoption is influential factor that emerged throughout the data collection gathered through the research. It is concerned with the issues surrounding the broader adoption of BIM technology in the construction industry. The five sub-factors of that form from the barriers and challenges theme discuss below.

3.1.1 The disconnect between design and costing of 3D models

When applying cost to BIM models, Participants1 stated that a disconnect exists between how modeling software is used in building design contrasted with how costs are applied. Participant 1 noted that the way QSs produce cost reports by following the South African Standard System of measuring differs drastically compared to how architects design buildings.

> *"There is a disconnect between how the modeling software is used and model the information and how they translate to cost".*

This is further corroborated by Participant 3, who suggests that designers need to collaborate when designing the BIM model. This leads to a more comprehensive design and aid in all the components being coded correctly.

Participant 5 further elaborates on the importance of having comprehensive and correct information in the model to allow cost reports to be produced more accurately. Finally, participant 5 explains the need for all the design consultants to work together to achieve more accuracy within the 3D model.

3.1.2 Lack of awareness of BIM capabilities

According to Participant 1, there are varying levels of BIM adoption in the South African construction industry. Thus, affecting the level of awareness by designers concerning the capabilities of BIM. If these capabilities are known, BIM would be used to its full potential.

Participant 5 emphasized the need for the use of BIM to extend past the detailed design stage of construction.

> *"But the problem in South Africa and most countries where it hasn't taken off is that everything stops at this stage in the detailed design. So, at this stage, we complete our designs and prepare tender documentation and print on hard copy and issue to the contractor at the beginning of the construction period, so that is where the model stops and doesn't go any further than that".*

Participant 3 emphasized that the main benefit of using BIM for the lifecycle of a building is not applied currently enough in the South African construction industry. Furthermore, Participant 3 alludes to the fact that many contractors are unaware of BIM completely, which acts as a barrier to its adoption.

3.1.3 Lack of training and experience using BIM

The learning curve associated with measuring from 3D models was steep, according to Participant 3.

> *"Due to time pressure always being a factor, they decided to revert to measuring from 2D drawings as they lacked the prior training and experience."*

Participant 1 further details the current lack of training and experience in the South African construction industry concerning BIM. Furthermore, they state a level of adoption among the larger design firms, but the level of training and experience varies drastically depending on the individual. Many designers use 3D modeling software to draw in a 2D space.

Many consultants simply do not have the necessary time to learn how to use 3D modeling software adequately.

> *"It is a specialist thing and requires a training course about it. I think a lot of people who have worked for 3D measuring software companies have been trained in BIM to sell a specific product."*

3.1.4 Poor quality of BIM models

Participant 2 believes that even in developed countries though the architects that work in the country are advanced and well trained in BIM, the quality of their 3D models is not up to the desired quality. When busy with cost reports, one has to check the 2D drawings to ensure that these align, so no major mistakes are made. The poor quality of these 3D models causes BIM to be inefficient.

> *"In the UAE, we are more advanced in BIM modeling as we use prestigious architects that are trained fully in the system using updated technology but still the quality is still poor. We still have to go back and check specifications to the drawings".*

Participant 4 states that the design consultants do not have enough to code and design BIM models due to time pressures properly. Furthermore, Participant 4 believes that BIM was developed in a perfect world where designers can produce BIM models properly. However, an ideal BIM is yet to be seen by Participant 2, and they believe that it will be a long time until this is achieved more consistently.

3.1.5 Fragmented industry

Collaboration is a difficult task to achieve when working on BIM models, according to Participant 1. The industry is very fragmented due to the current economic climate.

> *"There is a lot of resistance in the industry especially from directors in architecture and quantity surveying firms to adopt new technologies".*

Due to the high cost of adopting BIM, many construction companies and consulting firms do not believe the cost of adoption is worth the investment, according to Participant 3. This has led to a very fragmented industry where only some companies have the capabilities of using BIM in construction projects.

3.2 Benefits of adopting BIM in construction projects

The benefit of adopting BIM in construction projects is another influential factor that emerged throughout the data analysis. It is concerned with the advantages of implementing BIM in construction projects. Five sub-factors of benefits of adoption BIM emergent theme are discussed below.

3.2.1 3D Visualization

Participant 1 emphasized the importance of visualizing the building. This assists the architects and engineers in fully understanding and coordinating their services and equipment effectively to go into the building to limit the number of runs. Similarly, Participant 4 highlighted the most significant advantage of BIM is the 3D visualization, where you can fully understand the more complicated designs when it comes to Mechanical, Electrical, Plumbing services.

> *"Currently, the one advantage would be when you review the drawings so 3D models you can look at that building upside down left and right. You can see every angle of that building".*

Participant 5 noted that the 3D visualization that comes with BIM assists the clients who cannot understand the 2D drawings.

3.2.2 Clash detection

Participant 1 explained that the 3D model had been used for coordinating services in the design, reducing the number of clashes that occur on-site. Consequently, this reduces the cost and number of delays that occur during the project.

> *"Project stakeholders are being more and more used as a coordination tool to coordinate their general arrangements designs with the coordination of the services to minimize the number of clashes that we do experience on-site because that is a very costly and time nightmare for contractors".*

Participant 4 further explained the consequence of reducing the number of clashes on the project. The designs of the MEP engineers are complex, and with the 3D model, there will be a better understanding of the system, which can alleviate the wastage that comes from the project. This can be attributed to not only saving the time and cost of a project but also the effect of not extending the project timeline. If extended, staff will need to come to the site, cars, plants, equipment, use of facilities, all that pollution and waste can be indirectly alleviated through BIM.

3.2.3 Less redundant

Participant 1 emphasized that it may be less measuring being done, but the time now will be spent checking the quantities of the model and making sure that the information is accurate.

Participant 2 highlighted how the company had a team that would conduct measurements for the estimates off 2D drawings. However, most of the measurement team was retrenched due to the COVID-19 pandemic and the economy. Now, they extract quantities off the BIM model, and it is much faster in delivering estimates and cost reports to clients.

> "*That measurement process took long because they would measure off normal 2D plans, so they would take like two weeks to measure. So now we are measuring ourselves, extracting off the BIM models which is much quicker".*

3.2.4 Manage information flow

Participant 1 stated that there needs to be absolute synergy and collaboration for BIM to be successful. Therefore, international markets are set up as turnkey solutions where there is no separation between the professionals.

> *"It does necessarily need to be a turnkey situation. There needs to be better communication between the designer and construction teams."*

Participant 5 stated that with the BIM, any changes that the architects make automatically update their design protocols, and as such, they do not have to start from the beginning from the first principal design, so with BIM it redesigns everything with the updated information, and they just need to check if it is done correctly and resubmitting.

3.2.5 Minimize time and cost

Participant 1 believes there is a benefit for BIM in ensuring that the ongoing maintenance and operational cost of the building are looked after and evaluated.

Participant 3 explained how BIM could be used as a checking tool if there is a dispute with the contractor of the rate of an item and the bill of quantities database that can search for that specific item; no contractor can argue with that amount of data the rate is incorrect.

> *"With BIM, there is much less chance of making errors because you are not taking information from one platform, so there is no room for error".*

3. 3 Drivers of BIM Adoption

Drivers of BIM adoption was a theme that emerged throughout the data collection gathered through the research. It is concerned with the issues surrounding the wider adoption of BIM technology in the construction industry. The drivers of BIM adoption contain three sub-themes.

3.3.1 Owner/Client involvement

Participant 5 believed that more should be done to drive BIM adoption in South Africa in government projects. Participant 5 believes that BIM adoption throughout all new government projects in the UK will allow construction projects in the UK to attain 5D and 6D BIM in the next couple of years. The government played a key role in the sudden surge of BIM adoption in the private sector. Additionally, Participant 5 states that private clients must also drive BIM adoption in construction projects. If clients and government are aware of the benefits of construction and operation of buildings using BIM, they will require the professional team to be adequately capable of using BIM.

Participant 2 outlines a negative associated with clients driving the use of BIM. Participant 2 states that the professional fees of the QS can be linked to the time taken to produce cost reports, especially in the pre-contract phase of construction.

> *"So, when we are producing the bill with 2D drawings in UAE, we take longer and produce more fees, but now they are saying we can give you less fees when you use the BIM model because instead of taking two weeks to measure, we now take two days and useless people, so we get less fees as well".*

Therefore, BIM can make reports more efficient, albeit with the accuracy of BIM models still being unsatisfactory, according to Participant 2.

3.3.2 Utilizing by Contractor

Participant 5 expressed the need for contractors to give the as-built BIM model to the client after they have completed the construction of a new building. Giving the client the most accurate up to date model due to design and construction differences.

> *"A lot of contractors in the UAE have their own BIM specialists, and they will ask for the BIM drawings and measure it out to make sure it is correct. They will do quantity checks as well."*

Participant 4 shares the same opinion as Participant 5 for the need for contractors to be BIM capable. If the contractors have BIM specialists in their companies, this gives them the ability to provide clients with the most accurate 3D models once the building is completed. In addition, it allows the client to utilize the capabilities of BIM better.

3.3.3 *Utilizing by consultants*

Participant 1 explains that in their own experience, the consultants who possess the ability to drive the use of BIM for design on construction projects are either architects or engineers. Therefore, they possess the necessary training and experience in using BIM software for design. Currently, these consultants are primarily being used as coordination to lessen the probability of clashes in design between architects and engineers.

> Participant 1: *"...depends really on the driving consultant, which is typically the architect in many cases, but we do find in certain instances the engineers are somewhat the driving and lead designers".*

Participant 4 and Participant 2 also state that the driving consultants of BIM on construction projects are mainly the architects and engineers in the UAE.

3.4 Guidelines for BIM Models

Guidelines for BIM models was a theme that emerged throughout the data collection gathered through the research. It is concerned with the level of quality the BIM model should have to achieve full 4/5D implementation. The five sub-themes of guidelines for BIM are discussed below.

3.4.1 Standard Model for BIM

Participant 2 explains that they have a BIM team with a system in place and documents that the architect needs to follow when they produce the BIM models. Participant 2 further notes that even the clients have certain guidelines, the BIM model needs to meet particular standards.

Participant 3 believes that it is critical for the future of BIM. The designers and QSs need to collaborate because they think differently. Every component that the designers draw needs to be coded and structured in a certain way.

Participant 5 states that they follow the new ISO standard for their model, where it focuses on not only the 3D design but also the data within the model.

> *"We follow the new ISO standard. It focuses not only on the 3D drawing but also the data model, so we ensure that data is in this 3D model.".*

3.4.2 *Creation of an as-built model*

Participant 5 emphasized the importance of creating an as-built model that does not stop at the design stage but instead gets developed through the other stages and contains data that will make the model useful for the client for the operations and facility management of the building lifecycle.

> *"From construction to the as-built is what we are currently doing now, and this is what makes BIM work is to take it through the construction stage have a proper as-built model with all the data required to take it to the next stages".*

3.4.3 Designing to a standard system

Participant 1 states the importance of the standard system, and to fully have the BIM model automatically produce an estimate, it needs to be designed according to the standard method of measurements.

> *"It separates materials obviously because certain materials are costed differently and if it exceeds certain parameters, the cost of that material increases but it also sets the labor component".*

3.4.4 Trusting accuracy of BIM models

Participant 1 expressed the fallacy around extracting quantities from the model, reducing time in measuring as the model can be inaccurate and the time spent measuring will now be spent checking the model's accuracy. Participant 1 states that as a professional, you need to have confidence in the quantities, and if you blindly rely on the model for the quantities, you are not 100% certain of the quantities.

Participant 4 also emphasized the importance of trusting the BIM model and the impact of doubting the information from the architect.

> *"But once you check and find that 1st error in a BIM model, you will start to doubt the information that you received from the designer."*

The emerging influential factors and sub-factors extracted from the data analysis are conceptualized in Figure 1.

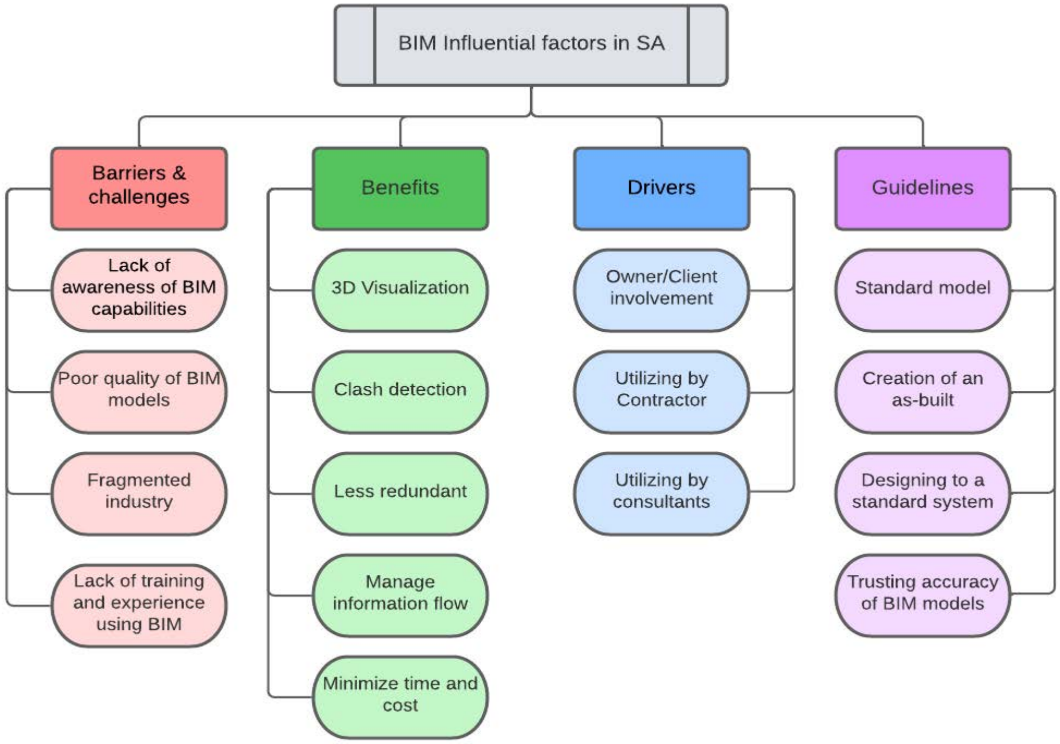

Fig. 35. A figure caption is always placed below the illustration. Short captions are centered, while long ones are justified.

4. Discussion

The research findings show several barriers and challenges in adopting BIM in South Africa.
These findings support the research findings of Akintola *et al.* (2017), who state that industry fragmentation hinders BIM adoption in the construction industry. Therefore, poor collaboration from the project team hinders the ability of the BIM model to be produced accurately.

In addition, Oraee *et al.* (2019) and Akintola *et al.* (2017) assert that a lack of support from the government regarding policies, practices, knowledge, procedures, and drivers concerning BIM acts as a barrier to BIM adoption. Secondly, Oraee *et al*., (2019) note the high costs of implementing BIM technology as significant barriers to adoption. Awwad *et al*., (2020), states that a lack of understanding/training of professionals acts as a barrier to the adoption of BIM in the construction industry as the performance of BIM is not optimized due to the learning curve it requires.
Based on the findings, it is apparent that there are many benefits to utilizing BIM in construction projects. The results suggest that BIM greatly assists with 3D visualization, clash detection, managing information flow and minimizing time and cost. This aligns with the research findings of Ullah *et al.* (2019), Oraee *et al.* (2019), Gilchrist *et al*., (2021), who believe that the improved visualization and modeling capabilities enhance the productivity and coordination of the construction project. The collaboration of the professional team and the coordination of services are further supported by Oraee *et al.* (2019), who notes that BIM reduces errors and clashes, which prevents unnecessary reworks which correlate with the findings which indicate the understanding and coordination of the engineering services reduce the number of clashes before designs go to the site.

The findings relating to the use of BIM to extract quantities are further corroborated with Gilchrist *et al*., (2021), who expresses the efficiency of extracting quantities with BIM to produce budgets and estimates.
The key individuals/organizations which drive the adoption of BIM are vital to the further adoption in the wider construction industry. The findings displayed those clients, i.e., government or private, are the primary drivers of BIM adoption in the construction industry. Additionally, the role that contractors and consultants play in the adoption of BIM on construction projects is also key to further adoption in the industry.

These research findings are supported by the findings presented by Akintola *et al.* (2017). They state that a lack of guidance and drivers from government authorities hinders the construction industry in adopting a standard for BIM models. Implementing policies and standards for BIM models, such as BIM utilising mandatory in public and infrastructure construction projects, will drive BIM adoption throughout the country.

The findings relating to the guidelines for the BIM model suggest that the model needs to follow a standard and contain relevant data in the BIM model. This corresponds to the research done by Akintola *et al.* (2017), who highlighted the importance of government agencies to drive BIM implementation and develop guidelines for construction projects. Akintola *et al.* (2017) further state that the construction industry stakeholders in South Africa need to agree on a standard to adopt and provide guidelines. This is reflected in the findings, which indicate that the participants follow the BIM ISO standard for their BIM model, which enforces a system that the designers follow when producing the BIM models. This finding corresponds with Kuzminykh *et al.* (2022), who states that the quantities extracted from the BIM model need a standardized coding system to be accurate and consistent.

In addition, the findings indicate that the accuracy of the BIM model is important to achieve full integration of 4 and 5D BIM. However, the participants still find themselves doing checks and getting huge errors flagged. The importance of the accuracy of the model is further supported by Kuzminykh *et al.* (2022), who states that the data in the model could contain duplicates and errors if not classified in a relevant coding system; this results in the inaccuracy of the quantities and affects the integrity of the estimates.

5. Conclusions

The adoption rate of BIM in South African construction projects is low, and there are a few South African construction companies are apprehensive about implementing BIM. Therefore, understanding the key influential factors on the diffusion of BIM in South African construction projects is of paramount importance to adopters and policymakers at both construction companies and the industry level.

In conclusion, the results provide strong evidence that BIM impacts the sustainability of construction projects through providing improved visualization of the building for construction stakeholders, clients, and contractors, thus lowering the possibilities for clashes in the design and construction, better management of the flow of construction and design information and minimizing the time and cost of the construction project.

From the conclusion that BIM significantly impacts the efficacy and accuracy of construction projects, it is recommended that South African built environment professionals implement BIM in their construction projects as enhancing the project's sustainability is beneficial to the client and the construction industry.

It can also be inferred from the study's findings that there is a lack of understanding from construction stakeholders regarding the full capabilities of BIM. As a result, the designed model has insufficient data or no standard in place so that it can be effectively used for optimum adoption of BIM. Also, it was discovered that there should be more guidance and influence from South African government authorities to improve the adoption of BIM by enacting a standard/guideline for the BIM model. This improves the quality of the BIM and enhances the accuracy of full BIM implementation.

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BIM and Building Resilience: A Hybrid Mechanism to Integrate Measures Against Flooding

Mohammad Mayouf[1], Ali Sharif[2], Mark Shelbourn[1]

[1] School of Engineering and the Built Environment, Birmingham City University, Birmingham B4 7XG, UK
[2] Pulse Consult Ltd., Birmingham B1 1TT, UK
Mohammad.Mayouf@bcu.ac.uk

Abstract
For over a decade, there has been a rapid progression in applying the use of Building Information Modelling (BIM) across the whole life cycle in a construction project. Despite many of the benefits that BIM offers, there is limited evidence that portrayed the role that BIM plays in improving the resilience of built assets, especially against unprecedented events such as flooding. To date, many flood resilient measures were introduced, however, a hybrid mechanism that integrates these measures collectively integrating stakeholders' needs and requirements is currently lacking. This research aims to portray the role of BIM in facilitating an integrated mechanism toward improving the resilience of built assets against flooding. Data was attained using secondary data from existing studies in the literature and primary data using semi-structured interviews with six experts from one of the city councils in the UK. The findings show that despite the progressiveness of measures against flooding, it is often targeted at an urban level with limited emphasis at a building level. The analysis supported pointed out the role that BIM can play in improving the resilience of built assets through informing design elements, which can support providing more informed decisions. The paper proposed a hybrid mechanism that supports recognizing BIM's role in integrating resilience measures of the built assets against flooding. Future work will examine the effectiveness of the proposed mechanism in a real-life scenario.

Keywords
BIM, Flooding, Resilience, Design, Risk.

1. Introduction

Across the globe, resilience against flooding has been a major area of interest for both academia and industry, and this can simply be reasoned by the longitudinal impact that flooding imposes on the environment, economy and society [1]. The term 'resilience' refers to the capability of a system, community, society or defence to react and recover quickly and easily from the damaging effect of a realised hazard [2]. Although the concept of flood resilience may be associated with scale (e.g. single building, city scale, or regional scale), the common understanding of flood resilience refers to the ability to withstand flood hazards and recovery after the flood hazard takes place [3]. Over the years, flood resilience has recognizable become one of the key aspects of flood risk management. The complexity of flood risk management is context-dependent where, for instance, it is considered more complex in urban areas when compared to rural areas [4]. There are many studies on Flood risk management, for instance, a study by [5] conceptualised risk management as the result of measuring hazard, exposure and vulnerability. [6] proposed a six-step flood risk management process whereas another study [7] outlined a four-step process. In 2020, the Environment Agency outlined four components of resiliency: placemaking, protecting, recovering and responding [8] where these components require integrating the view of different stakeholders. However, with most of the ongoing efforts on flood resilience, the anticipation is often toward visualizing and simulating the impact at an urban scale, and this can potentially narrow the focus at a building level, and more importantly, do not take into account the view property owners and how they perceive flood resilience measures [9]. Another complexity is the fragmented coordination between property owners, operators and also developers, which often lead to limited hazard considerations [10].

With the advent of information technology in construction, Building Information Modelling (BIM) is recognised as one of the robust mechanisms that support the built environment across different aspects by allowing a technologically collaborative process that integrates different stakeholders [11]. Conceptually, BIM allows for projects to be built virtually before they are constructed physically, which supports a more holistic consideration of many inefficiencies and potential issues that occur during the construction process, and an overlook of the whole life cycle of a building [12]. This plays an important role in informing cost-related aspects ([13][14]), improving risk mitigation, and ultimately supporting improved and robust coordination between stakeholders involved in a project [15]. In the context of unprecedented events including natural disasters, the use of BIM is often for visualizing purposes [16] which supported many aspects including emergency evacuation path planning, indoor localization, and fire emergency simulation. Amongst natural disasters, flooding can be recognised as one of the events that are classified as one of the unprecedented natural events and also accounted for as part of infrastructural-related considerations for buildings. To date, some efforts (e.g. [10][17][18]) have elaborated on BIM's role within the context of flooding, however, there are limitations in terms of the integration of different flood resilient measures as part of the BIM process to provide a hybrid mechanism to support a more tangible recognition of flooding-related aspects. This research aims to portray the role of BIM in facilitating an integrated mechanism toward improving the resilience of built assets against flooding.

2. Literature Review

2.1. Flood Resilience: Review of Barriers and Challenges

Flood resilience forms one of the core elements of flood risk management [4], which is seen by many studies [6][7][8] as a complex combination of considerations to ensure that the level of preparedness for flooding is sufficiently efficient. A study by [19] that combined empirical evidence from 22 publications classified flood resilience measures for property into two categories (see table 1): water exclusion ([19][20]) and water entry ([21][22][23][24]). Whilst studies on both water exclusion and water entry were extensive, one of the key challenges with implementing flood resilience measures is the reluctance of homeowners to accept change and responsibility for purchase and installation for flood resilient technologies/measures [26]. Furthermore, a study conducted by [6], in France, Germany, the UK and the Netherlands concluded that participants view flood resilience as a complex and tedious exercise carried out by experts working for local government, combined with other issues such as a lack of guidance, knowledge and capacity. This ultimately has a long-term effect on the property's level of resilience, and research also indicated that even when the key stakeholders were aware of flood resilient technologies/measures, there was not enough information or experience [27] to confidently decide on the type of flood resistance technology to purchase [3][26]. In addition to this, it is imperative to state that, with the recent technological developments, many stakeholders highlighted their lack of confidence in the application of innovative flood resistance measures/technologies such as mobile flood barriers, levees and sustainable urban drainage systems [28]. Imperatively, this highlights the complex issue associated with implementing flood resilience measures and the need to have an integrated approach toward flooding [8][27]. Despite the wide range of resilience measures against flooding, the complexity of improving resilience against flooding can be captured through the need for a hybrid approach to integrate these different measures, and the need to incorporate the views of different parties involved from designers, developers and property owners, and more importantly provide incorporate inputs that improve the design aspects of a building [10][29]. This rationalizes the need for a hybrid mechanism that integrates flood resilience measures while integrating stakeholders' needs and requirements. This can perhaps support an improved optimization of appropriate resilience measures to provide a more informed decision and manage cost implications associated with flooding [27][30].

Table 34. Flood Resilient Measures based on Existing Literature

Resilience Measure	Type of Measures	
Water Exclusion Measures	Wave return wall, rock armor, beach nourishment and coastal cliff stabilization, Planting trees and hedges, covering the ground with plants to reduce water pollution, diverting high water flows, creating leaky barriers to slow water flow and restoring salt marshes.	[19] [20] [21]
Water Entry Measures	Aperture and closing systems, building skins and wall sealants, barriers, automatic flood doors, non-return valves, air bricks and pumps, tiled floors, raised sockets, wall-mounted TV, Closed-cell insulation, plasterboard laid horizontally.	[22] [23] [24] [25]

2.2. BIM role for Flooding

In the context of flooding, research indicates that BIM uses the first two phases to identify a primary BIM data set for flood risk management solution selection and early cost estimation before the installation phase [31]. One of the research studies illustrated that BIM can be used for flood risk management by providing timely information for informed decision making [32]. For refurbishment options for properties, BIM can be used for refurbishment option selection and early cost modelling [31][33]. Once a basic BIM model is built in the BIM system, the flood risk strategy design process is followed to develop and plan a flood protection scheme [17][32]. To make an informed decision about the type of floodproofing design to be deployed, detailed project information is essential during the assessment process in conjunction with physical assessment data. This includes customer design requirements, construction material specification, expected project duration and risk management [31]. Moreover, BIM has also been implemented in Fukuoka, Japan, alongside GIS it was used to simulate underground flooding [34][35] and measure the impact climate change would have on coastal and riverine flooding [36]. The implementation of BIM for infrastructure is nearly 3 years behind its use on buildings, however recent studies have indicated its use on infrastructure projects is increasing [37]. A study conducted by [38] suggested that the use of BIM on infrastructure has brought about financial as well as technical benefits for stakeholders, BIM has enabled accurate cost estimations to be formed which aid in better planning and coordination. In addition to this, BIM supports capturing and storing data which reduces time-consuming tasks [39]. Furthermore, BIM has also helped in bridge infrastructure projects by identifying uncertainties. The use of BIM has enhanced productivity by reducing trial and error within the construction phase, BIM tools have enabled the visualisation of potential risks. Bridges are at risk from flooding, other natural hazards and scouring, these are all risks that can result in collapse; with BIM these risks can be identified before they occur [37]. Research constructed by [40] demonstrated that the use of BIM on infrastructure can reduce risks by increasing collaboration in the construction phase which supports reducing costs for stakeholders. Collaboration can be seen as a major key in informing decisions, especially in complex situations, for instance, a recent study by [10] illustrated the value of incorporating different stakeholders by integrating their requirements within BIM-GIS to improve the resilience of drainage infrastructural systems for hospitals when flooding occurs. Another study by [16] illustrated the value of incorporating the views of different stakeholders to develop a resilient system for hospitals.

Regarding the above efforts, current literature demonstrates the limited role that BIM plays towards flooding as the key benefits highlighted are better collaboration and communication, model-based cost estimation, preconstruction project visualization, improved coordination and clash detection, reduced cost mitigated risk, improved sequencing/scheduling increased productivity and prefabrication, safer construction sites, better build and stronger facilities management and building handover. Such benefits of BIM implementation have been well documented. Existing literature does not identify data/information requirements that support better design decisions for buildings and infrastructure. The type of data/information collected to enhance the value BIM can offer to infrastructure and building projects, and infrastructure and building flood resilience has not been identified. It can be argued that due to this BIM currently plays a limited role in identifying more resilient materials that can be used to make informed design decisions. Current literature demonstrates that the research on flood resilience for buildings and infrastructure has mainly focused on preventive measures such as coastal defences and that other measures proposed by the risk assessment against flooding and BIM research on its role towards flooding is limited and does not identify data/information requirements that support more informed decisions with relation to flood resilience measures. This research will focus on what is required within the BIM environment to allow for the design and construction of more resilient buildings and infrastructure to help protect the UK against flooding.

3. Research Methodology

This research aims to portray the role of BIM in facilitating an integrated mechanism toward improving the resilience of built assets against flooding. This research adopts an inductive approach through using qualitative data to provide a more holistic and exploratory view of the complex phenomenon in this research. Data was attained using secondary data from the literature, and primary data using semi-structured interviews with six experts from one of the city councils in the UK. The secondary data was used to derive the benefits of BIM for buildings, and how it supports facilitating a collaborative process between different stakeholders [41]. The secondary data supported rationalizing the need for a more collaborative mechanism that engages the view of different stakeholders and how this support provides more informed decisions about flood resilience measures. Despite the many benefits for improving different aspects across the whole life cycle, improvements are still required to unlock the full potential BIM can offer to infrastructure and building resilience. As for the primary data, the use of semi-structured interviews was rationalized by the need to gain an in-depth understanding of the needs and requirements of stakeholders. In this study, the views of stakeholders involved were property developers (4 participants), a city planner (1 participant) and a BIM Manager (1 participant) who work at one of the city councils in the UK. Property developers were selected as this would support gaining perceptions on flood measures incorporated for new properties, city planners for their view on risk management and accountancy against flooding, and a BIM Manager to gain a practical insight into how BIM can support incorporating flood-related measures within the BIM process. In this study, the sample size was determined by the accessibility to data, the fact that in the UK city councils heavily inform flood measures [26] and finally that this research does not seek saturation point, hence gaining and interpreting perceptions to gain an understanding of the phenomenon have superseded the need to interview a large sample. Thematic analysis using open coding was used to code the responses from participants in this study, and this would support drawing meaningful outcomes for the research. To illustrate the thematic analysis process followed in this paper, the below figure (figure 1) explains the process of data analysis.

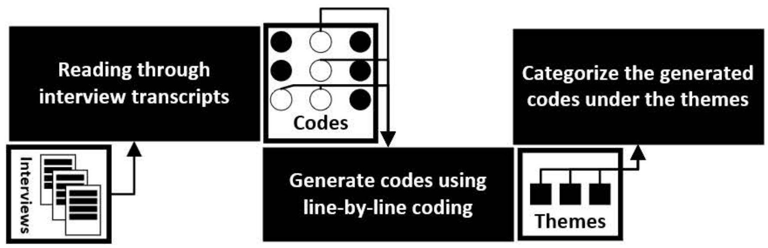

Fig. 36. The Thematic Analysis process followed in this research

4. Results and Analysis

4.1. Perspectives on Flood Resilience Measures

This theme aims to demonstrate and interpret the various perspectives of flood resilience. On flood measures, most property developers had similar perspectives on flood resilience technologies, for instance, participant 1 quoted *"**so in terms of resilience it involves identifying the source of flooding and then tackling the mechanisms that allow flooding get there…..say for instance a local authority trying to protect the town would look at upstream flood storage or conveyance and things like that to try and prevent flooding**"* Another participant quoted "***flooding you look at different kinds of defences, to that whether it be flooding on the coast and it's sea walls or you're looking at trying to stop flash flooding in mountain areas; some of that has happened because of deforestation***". The responses demonstrate that flood resilience/technologies are implemented as mitigation measures in response to the potential source of flooding (e.g. upstream flood storage & conveyance) at a level away from the built asset to prevent floodwater from penetrating the built asset altogether. As for the city planner, it was quoted as "***resilience being you're allowing it in or accepting that it's going to come in and making the recovery quicker***". The city planner's viewpoint indicated that a key part in flood resilience measures/technology is stakeholders accepting that floodwater is going to penetrate the built asset, and flood resilience is about creating an environment in which the built asset can return to normal functionality as quickly as possible. The property developers' perceptions highlighted certain measures that are taken into account, for instance, one of the participants quoted "***include things like raising your electrics to above water level, maybe thinking about replacing more expensively perhaps hollow floors and for maybe some more solid floors***". As for the BIM Manager, he mentioned that "***for flood measures, I think it's about materials and services integrated into the design of the building, and their resiliency in the event of flooding, which certainly is an element that must be adhered to***" this shows that flood resilient technologies/measures should proactively take into account the level of resiliency of building systems when flooding occurs so that risks can be reduced once the building has been affected by a flood event.

3.2 BIM Potential for Flood Risk Management

This theme aims to investigate the role BIM currently undertakes in flood risk management of built assets. According to most property developers, they had limited awareness of BIM, however, some had limited knowledge where one of the participants stated **"*I think our interaction with BIM is limited because we're not specifically in that design space, we're not doing design, we're often at the planning stage - that's where our involvement is most often and there's an element of design in there but it's not you know we're not getting into often not getting drawn into that detailed design which in my view is where BIM seems to be most useful*…"**. The quote above demonstrates that role of property developers is mostly during the planning phase with limited involvement during the design stage, hence their awareness of BIM capabilities is considerably limited. As for the city planner's perspective, it was quoted "***It has, in this domain it has some clear potential I think the idea that we are integrating the different stakeholders involved in that design process through the BIM platform is going to save a lot of wasted effort sharing of information…and this can support informing many aspects about a building especially if information about nearby developments are retrievable***", the response further highlights that BIM currently plays a limited role in flood risk management, and this is considered vital when digital information. As for the BIM Manager's perception, ***"so I think that data is already available and we don't need more data we just need to be able to use the data that already exists better, that's people understanding, not just what data does exist but how it can be used to inform the design and provide more informed decisions"***. The response given by the BIM Manager demonstrated that there is a lack of understanding of how to make use of data available within the BIM environment; the data required for them to work within the BIM environment is available, however as they lack an understanding of how to access, interpret and then make use of that data they cannot gain the full suite of benefits.

3.3 BIM for future of Building Resilience

This theme aims to demonstrate how the implementation of BIM can potentially lead to the design and construction of resilient built assets against flooding. In addition to the previous themes, this theme is recognized as one of the key findings to support understanding the phenomenon investigated in this research. From the responses provided by property developers, two participants indicated that BIM has a role to play in the future design and construction of resilient buildings and infrastructure. They added ***"Most flooding-related considerations often require simulating at an urban scale, but if you aligned the data to the BIM models it can lead to more consistency to work with, within the BIM environment, so essentially if data outside the BIM environment can be aligned with the BIM model, it could lead to a better accountancy of more resilient infrastructure & buildings"***. The above statement demonstrates that there are obstacles currently preventing flood risk specialists importing data into the BIM environment; however, one of the property developers stated, "***In most cases, especially that majority of property development projects data are not produced within a BIM compatible drawings and layers***". This indicates that aligning data to the BIM model is proving to be difficult once property developers can produce data that can be BIM compatible. As for the city planner, the response was "***we are rapidly growing into an era where technology seems to be very domineering, so I think that BIM will be useful, but coordination between BIM data and data outside BIM remains an obstacle …. When we have a development project, there are so many layers of data/information that come from different parties, so we must have a common environment to support better coordination***". This illustrates that managing data/information is complex in a common data environment but seeing how BIM can be a central system remains an obstacle. As from the BIM Manager's perspective, "***Amongst latest technologies, digital twin enables you to simulate different scenarios about whether that be infrastructure or building and you create a digital twin, during the design stage so you will be using predictive analytics to predict how that asset is going to perform in different scenarios and that helps…." and "If you get to a point where you have all the data sorted, you then enable yourself to use machine learning and artificial intelligence…***". The BIM Manager added, "***BIM on its own cannot be enough to mitigate the risk of flooding, so BIM can be the case where information layers can be used to be aligned with a digital twin which then can provide real-time data on change of weather, change of circumstances and this can support provide more informed decisions***". The responses provided by participant 4 demonstrate BIM has a major role in designing and constructing resilient built assets in the future, and to achieve this, the concept of machine learning, artificial intelligence and digital twinning needs to be optimized to ensure the full suite of benefits available are made use of.

Based on the three themes, the first themes showed perceptions on flood often focus on taking mitigation/preventative measures but what lacks is coordination between different perceptions. The second theme showed that BIM currently has a very limited role in flood risk management, but it was also mentioned that data can support informing decisions that will enable the construction of resilient built assets. The final theme showed that for BIM to support resiliency, there is a need to integrate data progressively to support more informed decisions.

5. Discussion

It can be argued that the main flood resilience measures are preventive measures (water exclusion) that focus on either diverting or preventing water from entering the property, for example, participants stated "***so in terms of resilience it involves identifying the source of flooding and then tackling the mechanisms that allow flooding get there…..say***

for instance a local authority trying to protect the town would look at upstream flood storage or conveyance and things like that to try and prevent flooding*"**. When referring to literature, many water exclusion measures were identified such as wave return wall, rock armour, and nature-based resilience measures [19][20][21]. Thus, one of the first complexity identified from the primary data is that majority of the focuses are often upon resistance measures whereas resilience measures at a building level are often focused on avoiding and/or reducing damages to different parts of the property. This can portray the need for collaboration [8][9][10] between property developers, designers, city planners and even building owners so that a more holistic approach is taken toward flood resilience. The second complexity highlighted by participants, is that majority of residential properties are not designed using BIM, which can be reasoned by the limited awareness of many stakeholders, especially property developers. For instance, it was stated, "I think our interaction with BIM is limited because we're not specifically in that design space, we're not doing design, we're often at the planning stage***". This shows the lack of a hybrid mechanism that can support the integration of different data/information needs, which can limit making an informed decision about resilience measures. The third complexity is the fact that there are many layers of data/information that need to be incorporated when designing new properties, which require effective coordination, and more importantly, how it can be accommodated within the BIM environment. On this, the BIM Manager stated, *"**so I think that data is already available and we don't need more data we just need to be able to use the data that already exists better, that's people understanding, not just what data does exist but how it can be used to inform the design and provide more informed decisions**"*. Recent studies (e.g. [10][16]) highlighted the value of collaboration in the context of infrastructure projects, as this supports capturing requirements of different stakeholders, hence it is vital to apply the same principle in the context of flooding. The final complexity is the need to consider how effectively BIM can support a more hybrid mechanism to capture appropriate resilience measures of buildings against flooding. In that respect, it was found that incorporating resilient measures require the use of multiple layers of data/information so that more accurate predictions can be achieved. To support this, one of the responses was "***BIM on its own cannot be enough to mitigate the risk of flooding, so BIM can be the case where information layers can be used to be aligned with a digital twin which then can provide real-time data on change of weather, change of circumstances and this can support provide more informed decisions***". Although former efforts (e.g. [17][18][32]) have proposed BIM-based mechanisms toward flood resiliency, many limitations were highlighted such as generalizing results and lack of contextualizing. Therefore, this research proposes a hybrid mechanism (see figure 2) to support integrating the appropriate floor resilience measures for buildings.

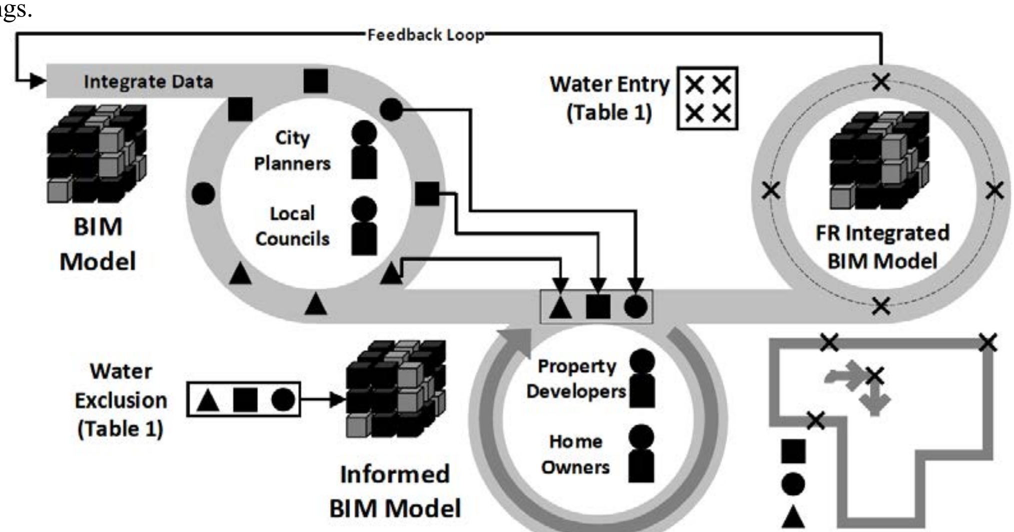

Fig. 2. Proposed BIM-based hybrid mechanism to integrate flood resilience measures.

The proposed framework (figure 2) illustrates the proposed hybrid mechanism toward building resilience against flooding using BIM. The mechanism allows informing water entry measures using in-place water exclusion measures, and this will support informing the appropriate aspects within the property, which supports reducing additional costs, and achieving Flood Risk (FR) integrated BIM Model. The proposed mechanism engages different stakeholders, and support a proactive approach to alert different design parameters (e.g. wall thickness, mechanical services, etc.).

6. Conclusions

To sum up, this research aimed to portray the role of BIM in facilitating an integrated and hybrid mechanism toward improving the resilience of built assets against flooding. The literature showed that there are vastly many ongoing efforts with relation to flood resilience and flood risk management. Although there are many measures including those for water exclusion and water entry, limited efforts illustrated how these measures can support providing an informed decision toward resilience and how it considers different stakeholders' needs and requirements. Literature also highlighted that some complications such as costs can also act as a barrier for implementing resilience measures for properties. Although there are some efforts on BIM for flooding resilience, these efforts are limited, could not be generalised, and more importantly, do not incorporate the views of different stakeholders. To contextualise the research, primary data was attained using one of the city councils in the UK where semi-structured interviews were conducted with property developers, city planners and a BIM Manager. The analysis and discussion identified many complexities that must be acknowledged so that BIM can support the resiliency of properties against flooding, and consequently, the research suggested a BIM-based hybrid mechanism that supports providing informed decisions on resilient measures, especially at water entry-level, so that additional costs can be reduced. This research contributes to knowledge in terms of providing a hybrid mechanism that can facilitate a more informed decision-making system, and more importantly, engage different stakeholders. The research suggests a more robust utilization of parametric data that can be embedded in BIM. Future research will look into validating the proposed approach and identify its practicality in a real-life scenario.

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Earned Value Management with the Use of Building Information Modelling

Yiannis Xenidis and Angelos Koukoulis

Aristotle University of Thessaloniki, Greece
ioxen@civil.auth.gr

Abstract
Building Information Modelling (BIM) is rapidly becoming the prevailing approach for the delivery of construction projects. While, cost monitoring and control is among the main processes supported by BIM, the widely applied Earned Value Management (EVM) method has not yet been adequately introduced in the BIM context. This paper provides a simple walkthrough on how to easily apply a BIM-based EVM. The presented approach is based on the integration of BIM technology and EVM method in a single software platform (AUTODESK's Revit), thus minimizing manual handling and consecutive errors and more importantly facilitating a fast and accurate decision-making process on cost and time control issues. The integration is validated through a case study of a building project that explicitly demonstrates the various implementation steps of the presented three-stages process and provides an example for construction project control practitioners of BIM-based EVM in construction projects.

Keywords
Building Information Modeling, Earned Value Management, Earned Value Analysis, Project Monitoring, Project Control.

1. Introduction

Building Information Modeling (BIM) offers a broad spectrum of services and perspectives to the construction industry covering all life cycle phases from the design of a feasibility study to the monitoring/maintenance during operation. The visualization through a BIM model of a construction project that includes a high volume of multifaceted information provides the interface for timely and fully informed communications between stakeholders that enhance collaboration and efficiency in the project's development and management. One of the most critical support BIM models provide is with regard to cost monitoring and control.

Hakanen (2017) mentions that while an accurate budget is the starting point of a successful project, cost monitoring and control during the project's development is essential for compliance with cost baselines. This process must be holistic, i.e., examine all project's cost items concurrently (Kerzner, 2013) and should be realized by a cost monitoring and control system that (Bennet, 2003; Potts and Ankrah, 2008):

- Enables comparison between actual and planned costs to track deviations in the budget's execution
- Considers time and quality impacts on incurred costs
- Supports a database for productivity assessment at present and future projects
- Documents claims regarding cost overruns and budget deviations, and
- Assists in decision-making on cost related issues

Earned Value Management (EVM) is an established and well-known framework for monitoring and controlling costs that is widely used in the construction industry. EVM is a systematic approach that exploits the evolution in time of the value of the produced work, thus integrating time, quality and cost aspects in a performance baseline, which constitutes an important tool for project management (PMBOK, 2017). Therefore, EVM is a robust framework that fully satisfies the demands of a cost monitoring and control system and could be appropriately modelled as such.

Wang et al. (2014) have reviewed the attempts of incorporating BIM to a cost monitoring and control system for construction projects and have found a limited number of related efforts; moreover, this efforts presented shortages either due to a partial consideration of the project's cost items or due to the orientation to small- and medium-sized projects. Furthermore, the few attempts to combine EVM and BIM were limited to the use of the latter for a more accurate and efficient data management in EVM application, rather than integrating the methodological and technological approaches towards the creation of a single BIM-based tool for the application of EVM.

This paper presents an attempt to integrate BIM and EVM in a single BIM model that facilitates and speeds up cost monitoring and control by using a single software platform instead of a combination of more than one of them. In the next sections, first EVM is briefly summarized and previous attempts to combine EVM and BIM are briefly reviewed to present the context and background of this research. Then a case study of a real project is presented where cost monitoring and control during the construction phase are performed with an integrated BIM-based platform that applies EVM. The proposed model is discussed in terms of the benefits and limitations it presents. Overall, this work aims at providing to the stakeholders in the construction industry a simple, replicable, easy to use and manage BIM-based application of EVM for cost monitoring and control.

2. BIM-based Applications of the Earned Value Management

EVM introduces a set of measures and indicators, which when used in combination allow the cost's monitoring of any project. The basic measures as listed in the Standard for Earned Value Management (PMI, 2019) are: (a) the Budget at Completion (BAC), i.e., the total budget of the project, (b) the Planned Value (PV), i.e., the budgeted cost for the amount of scheduled work up to a given time, (c) the Actual Cost (AC), i.e., the real costs incurred and accounted for the work performed until the time of control, and (d) the Earned Value (EV), i.e. the value of the work performed until the time of control. These basic measures with simple mathematical operations produce several indicators such as the Schedule Variance (SV), the Cost Variance (CV), the Schedule Performance Index (SPI), the Cost Performance Index (CPI), the Estimate at Completion (EAC), etc. The measures and indicators constitute a toolbox for cost monitoring and control, while the estimates are predictors based on the assumption that previous experience may indicate future performance.

Kenley and Hartfield (2015) have recorded EVM and BIM as the main approaches for construction projects control when applied both separately and in combination. Kim et al. (2010) have designed and applied a 5D BIM-based model, where the outputs after running the model were a 3D plan of the structure, a Gantt chart and an EVM graph. Turkan et al. (2013) have used laser scanning to collect data from a structure and compare them to the respective BIM model to evaluate the project's progress. Other researchers have also focused on the use of automated data collection tools and equipment (e.g. GPS, RFID, UWB) to support EVM (Boschè et al. 2013). Foremny, Kluczuk, and Nical (2014) have developed the Mobile Earned Value Management System (MEVMS), an operable system in mobile phones and tablets that uses as an interface the MS Excel and allows for the exchange of EVM assessments and project plans, thus facilitating communication on cost monitoring. Marzouk and Hisham (2014) have attempted to apply EVM on bridges through an application that extracted work volume data from a Bridge Information Modelling (BrIM) tool to MS Excel that was, consequently, used for cost assessments. Elghaish et al. (2019) have integrated EVM and BIM with Activity Based Costing (ABC) to support Integrated Project Delivery (IPD) in terms of enhanced cost structure and risks/rewards allocation.

In all these cases with the exception of the work by Elghaish et al. (2019), which, however, is focused on a broader topic, there is no actual integration of EVM and BIM but rather a combined application of them, which is achieved through the data exchange between different software tools. This process, though, is time consuming due to the manual processing of input data, while it retains the limitations met in platforms of cooperating software tools (e.g. compatibility), thus resulting to an approach which lacks cost efficiency. The presented work in this paper integrates EVM in a BIM software tool, thus allowing more efficient cost monitoring and control.

3. Integration of EVM and BIM: Design and Application

3. 1 Design

The implementation of EVM through a BIM model is designed as a three-stage process:

1. Create the structure's 3D model and the EVM calculation sheets that draw input from the 3D model's plans. The direct connection to the model's plans ensures the dynamic update of the calculations every time there is a change in the model.
2. Select the cost assessment approach between the two main alternatives, which are: (a) assess costs on the basis of structural elements or (b) assess costs on the basis of used material. The first alternative requires a

very accurate and analytic model as the volumes of the structural elements must be precise to assess costs per element based on unit costs. The structural elements may be further grouped based on spatial or other criteria. The second alternative takes into consideration the used volumes of the various materials employed in the project, ignoring, though, the structural element where these materials have been were used for. This option may seem simpler; however, it lacks a direct connection to the model, thus rendering it useless for scenario planning.

3. Insert budget and cost data for the various structural elements and calculate the basic EVM measures and indicators. This step will be repeated periodically based on the model's update with actual costs or at any time during the construction phase when the project's management team tests various risk and performance scenarios.

The described process was applied on a test case that is presented in detail in the following section.

3.2 Application

The described approach was applied to the four-story residential building presented in Fig. 1. The building was constructed in 2010 and its selection was based on the availability from the construction company of sufficient data for the design and implementation of the project in terms of scheduling, budgeting, and materials use. At each floor a 100m^2 apartment was built, while the building had an open parking area (pilotis), and a basement.

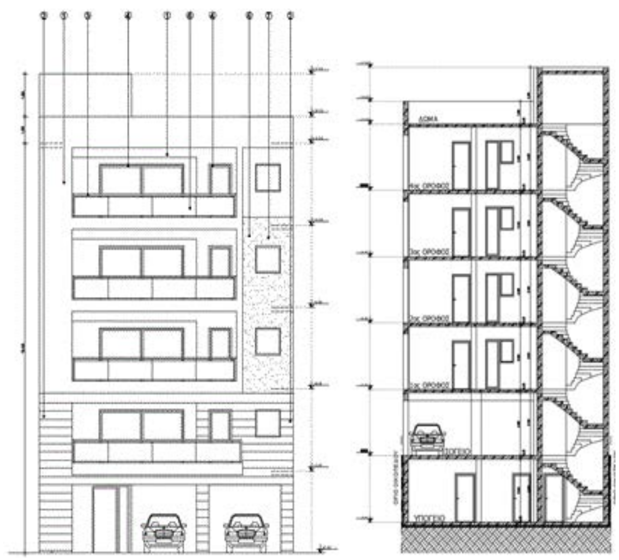

Fig. 37. View and Section of the modelled building figure

The contractor apart from the plans, also, provided the total costs of the used materials, namely steel, concrete, masonry, frames, insulation panels, and floors (marble, wood, and tiles). Based on these data, the building was modeled in AUTODESK's Revit and the result is shown in Fig. 2.

AUTODESK's Revit provides reports in tabular form (called Schedules) that allow customized calculations with the help of parameters selected by the user. The default parameters, while relevant in some cases (e.g., element's cost, element's volume, etc.) are not directly associated to EVM; therefore, the software's option to build new customized parameters oriented to the desired analysis has to be activated. Following a simple line of commands, the parameter's type and properties are set and, consequently, the PV, EV, AC tables are formed. The three tables have a similar form, which is illustrated in Fig. 3. A final table is created to collectively present all the information of the earned value analysis, including all EVM measures and indicators (SV, CV, SPI, CPI). This table is depicted in Fig. 4.

Apart from tables, EVM is mainly presented through the graphical illustration of the evolution in time of the cumulative values of the basic measures. The production of these graphs from any BIM software is impossible; therefore, another solution is required for the full application of EVM. In the context of this work, the pyRevit rapid-prototyping environment was applied. pyRevit is a fully open source software tool that introduces a Python script library in Revit, which allows the programming of several tabs in Revit user interface to facilitate processing of BIM models. In this case, pyRevit was installed and used to program a command that allows the extraction of EVM tables to MS Excel where the creation of the graphs is feasible. The transition from Revit to MS Excel (depicted in Fig. 5) is mandatory since Revit cannot produce EVM graphs; however, the programmed command with the use of pyRevit allows both an easy, automated transition between the two software tools and the update of the graphs after each modification in the BIM model. In this way, a unified software platform is, practically, created that saves the construction manager from manual input of the cost data and, instead, translates any studied or performed changes during construction to EVM indicators, thus allowing the automated BIM-based application of EVM.

Fig. 38. BIM model of the studied building

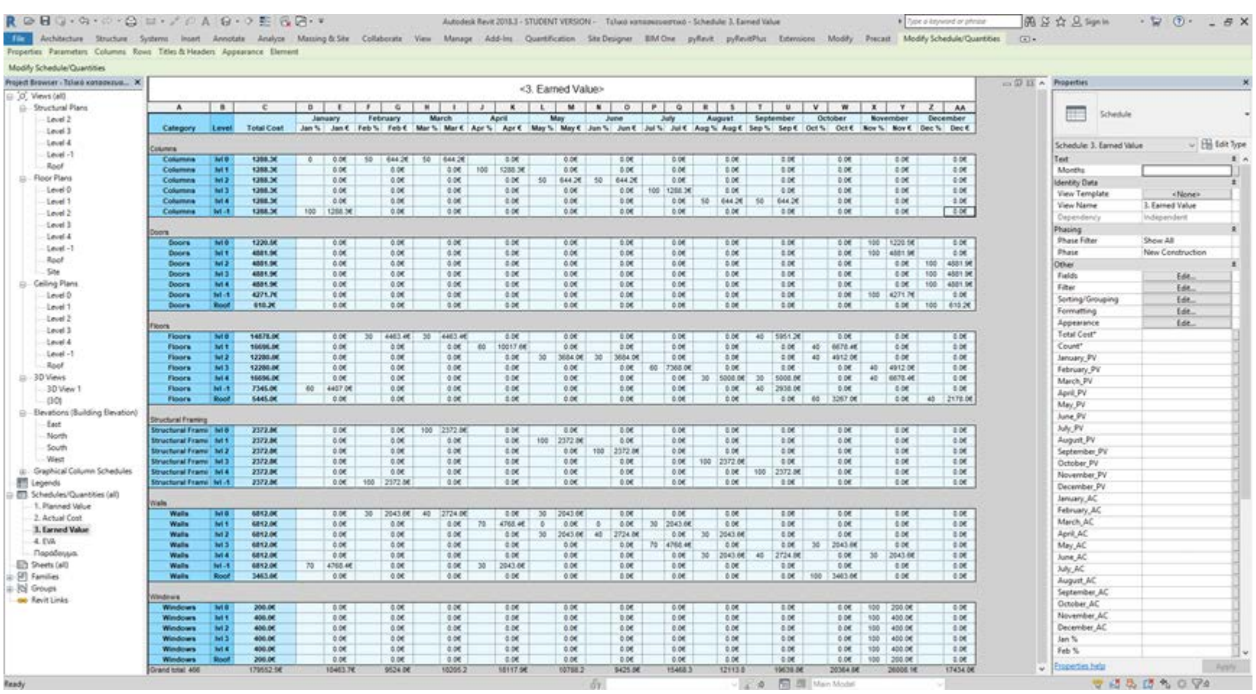

Fig. 39. Basic measures (PV, EV, AC) table form

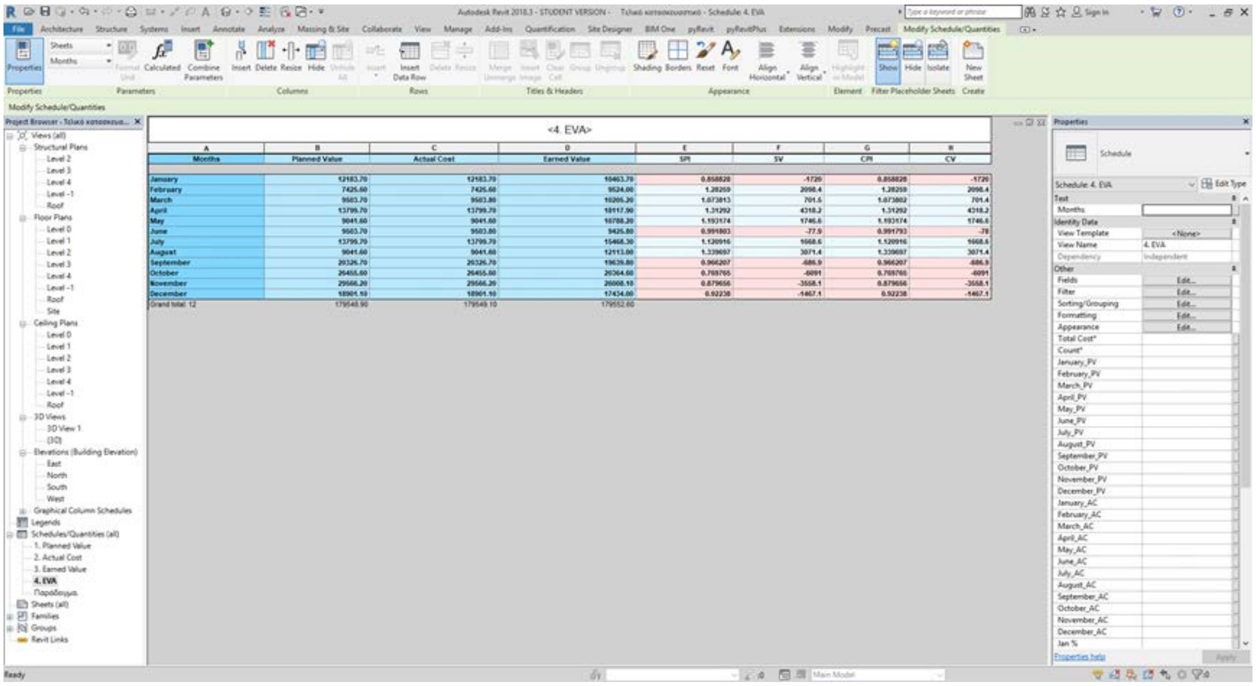

Fig. 40. Earned Value Analysis integrated in BIM software

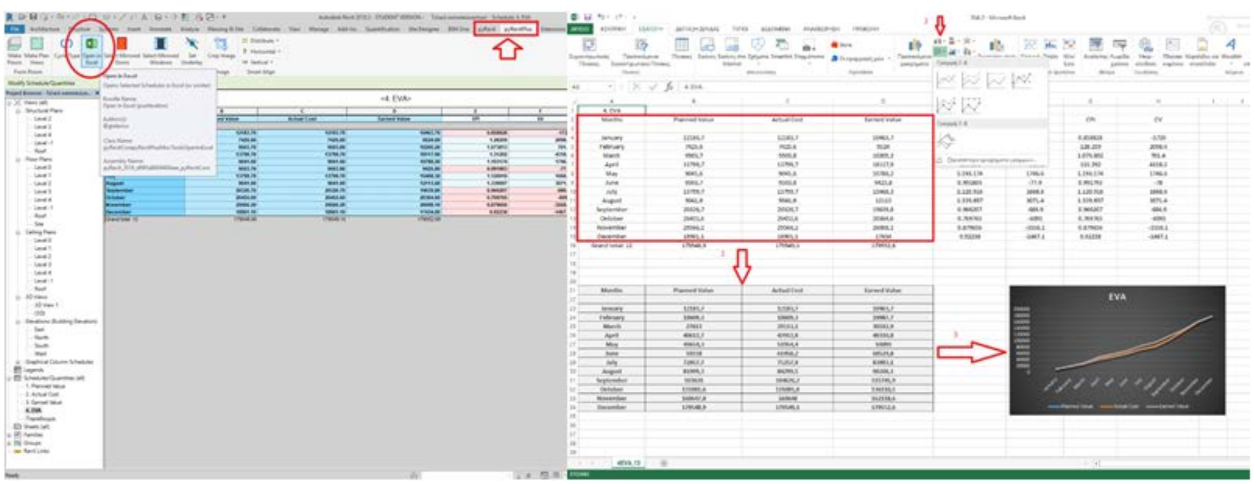

Fig. 41. Transition from AUTODESK's Revit to MS Excel for the creation of Earned Value Analysis graphs

The next stage involves the determination of the cost assessment approach. In this case, it was selected to assess costs based on the structural elements that had to be constructed at different building levels. The reasons for adapting this fragmented cost assessment approach were several. First, the construction company that provided the data had not recorded costs based on the exact composition in terms of material, thus preventing from applying the analysis at the material level. Second, the common professional practice is that contractors assess the costs based on the activities they have to perform, which is usually denoted by the name of the structural elements; therefore, the cost records, in this case also, were directly associated to the work performed for specific structural elements.

Another common practice is that several works related to various structural elements are assigned to different sub-contractors (e.g., there is one sub-contractor for concrete elements, another one for masonry, etc.), thus resulting to cost records associated to sub-contractors and indirectly to their part of the total work that has to be performed. The choice to consider the costs for the structural elements per different level was dictated from the need to better align the model with the construction process and facilitate the recording of the project's actual progress in terms of performance. First, the horizontal structural elements (i.e., beams and slabs) are progressing in iterative steps that are repeated for each different building's level. The same stands also for frames and masonry that according to the plans are following the same pattern in terms of placement per floor. Therefore, it is reasonable for these elements to model them at the floor level and monitor the performance and costs of the related work accordingly. The vertical structural elements (i.e., the columns) could be modeled uniformly for the total building's height; however, this approach would hinder the automatic assessment of the work progress as there would be difficulty to determine the percentage of work performed at intermediate levels between start and finish of their construction. This obstacle would also affect the correct application of EVM; therefore, the appropriate way of modeling the structural elements for the needs of EVM would be to discretize them per floor.

Based on the above-mentioned analysis, the structural elements were grouped at the floor level as slabs, beams, columns, masonry and frames. Each structural element was considered as built only after the conclusion of all construction activities required for rendering it operable in the building. This means, for example, that a slab was considered as concluded work only after the construction of the floor on top of it and, similarly, a wall was considered as concluded work only after its painting, etc.

The final stage of the process involves the model's periodical update with progress data that the construction manager inserts during the project's development. The designation to the model of concluded structural elements either to depict real progress or to test future performance scenarios is a standard iterative process of cost monitoring and control.

For validation reasons, the building model presented so far was tested under a hypothetical scenario of an alleged delay of about two weeks due to unexpected weather conditions that hindered concrete activities at the third floor. Following, according to the scenario, an already poor progress in the project's development that was depicted through low values of EVM indicators (i.e., the scenario considered SPI=CPI=0.6), the new delay would have an adverse effect on schedule and would derail substantially the project with an impact on keeping the budget.

Facing such a scenario in the traditional way would involve several calculations based on alternatives of future performance that could be only verbally described among the project's stakeholders and, finally, involve changes to several plans and reports with the directions for future actions. Having the BIM model, though, the construction manager could investigate rigorously and fast, several future alternatives for increasing future performance by changing the sequence of activities or shortening their duration based on resources re-allocation. The most important is that the examined multiple scenarios (e.g., prioritizing the construction of structural elements as shown in Fig. 6) were immediately reflecting the changes to EVM measures (see Fig. 7) and the overall performance based on EVM indicators (see Fig. 8), thus allowing a clear presentation of the impact of each investigated scenario. This presentation according to the contractors of the construction company that provided all data would definitely reduce the response time to potential risks by facilitating understanding and coordination among the stakeholders and allowing fast and well-informed decision-making.

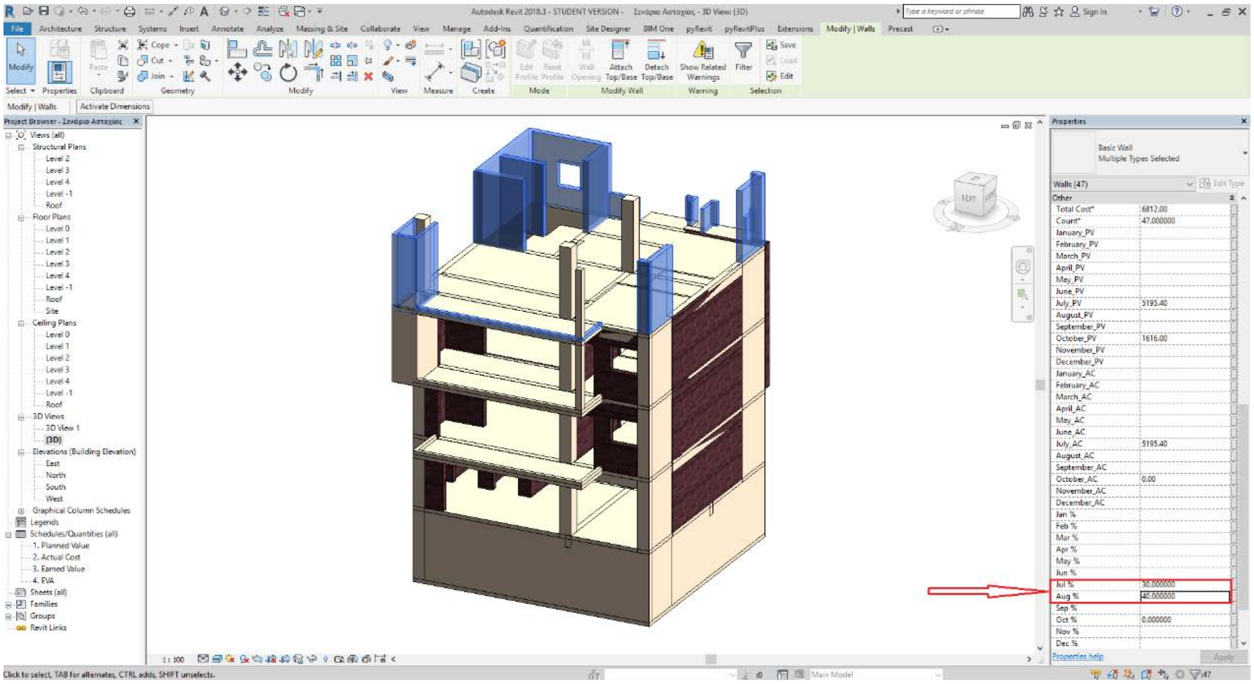

Fig. 42. Testing of response alternatives to scenario threats

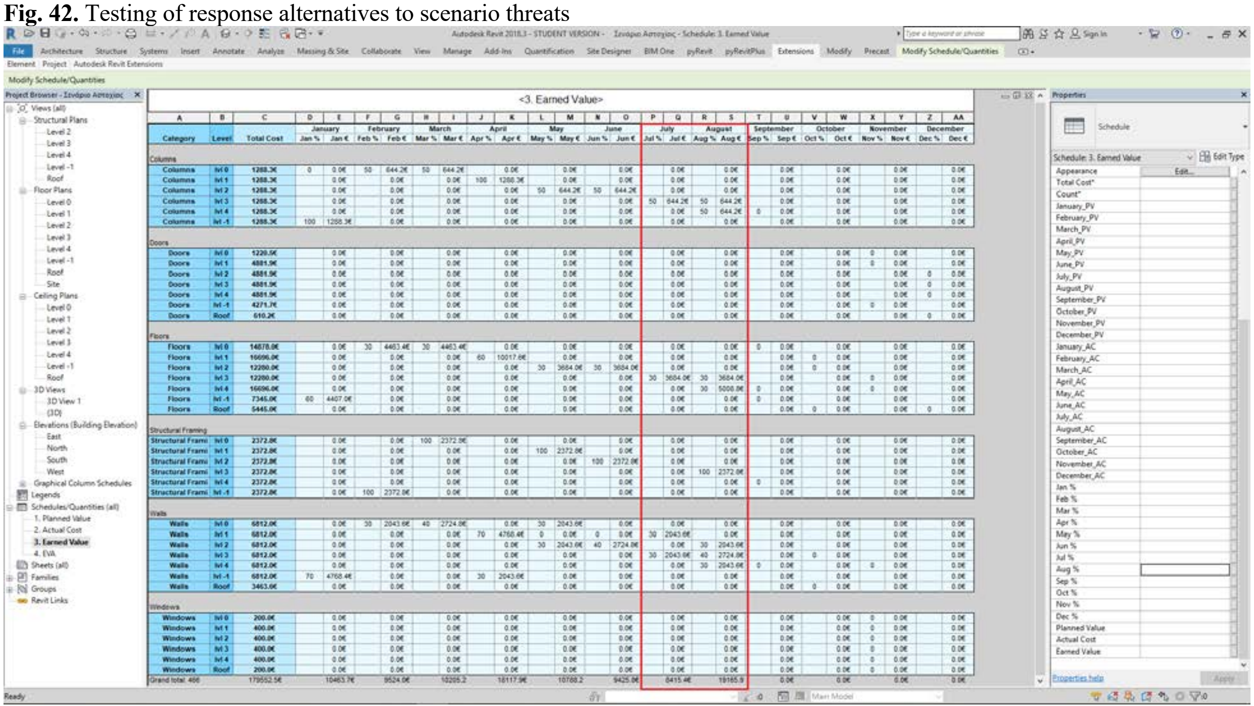

Fig. 43. Reflection of changes to EVM measures

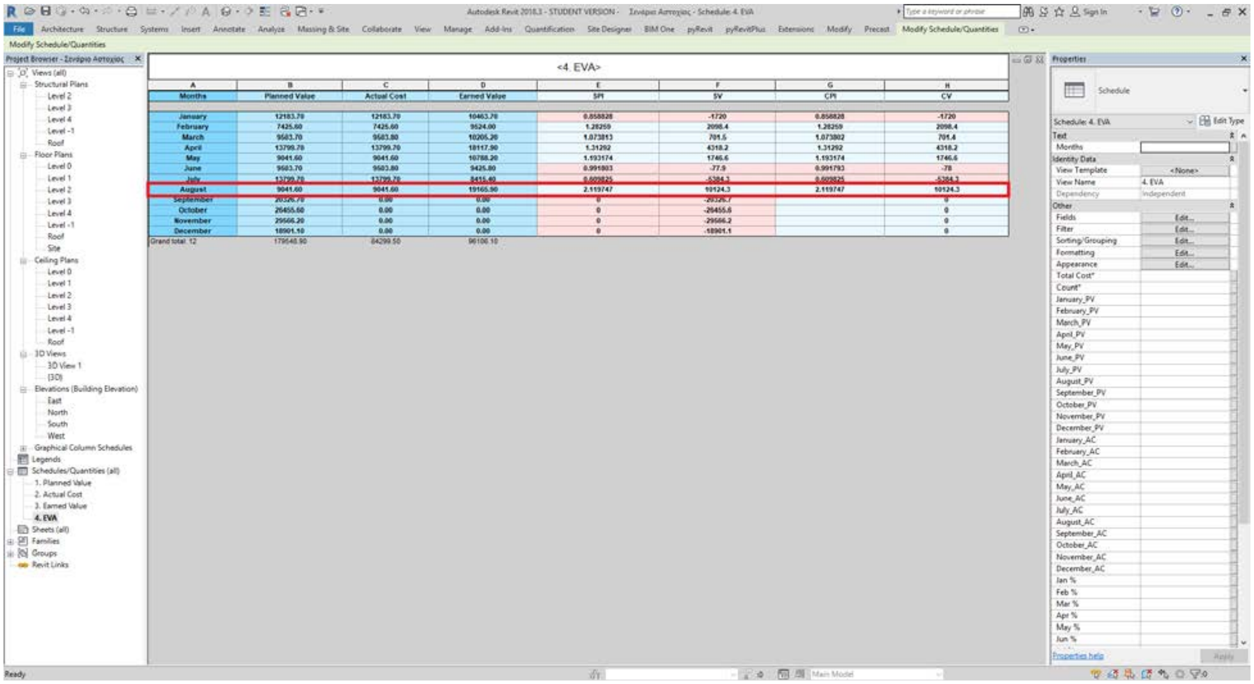

Fig. 44. Reflection of changes to EVM indicators and estimates

4. Discussion and Conclusions

This paper presents a practical and easy way to integrate Building Information Modelling with Earned Value Management for construction projects cost monitoring and control. Despite, the obvious potential and benefits of such integration, there have been only few previous similar efforts, which, moreover, presented limitations with the more important one being the lack of direct and automated connection between software tools used for this reason. The work presented in this paper manages with the help of pyRevit to put together AUTODESK's Revit and MS Excel to perform EVM without the need for manual import of data and with the significantly greater part of the analysis conducted in the BIM software, while MS Excel is used only for producing the graphical outputs of EVM.

Beyond the obvious yet critical benefits of performing an automated BIM-based EVM, such as the accurate and fast decision making regarding responsive actions against potential risks and threats or controlling schedule and cost variances during a project's development, a few more fundamental effects of this integration can be observed.

The first is that the requirements of the cost control and monitoring approach dictate the modelling process of the structure. This tradeoff is essential as the design phase is functionally linked to the execution phase of the project's life cycle, thus enhancing the overall project's constructability. Furthermore, it brings forward at an early design stage, the managerial aspects that govern the project's development, something, which is generally undermined at this phase due to the emphasis given on engineering issues.

The second effect is that the provided transparency to the cost monitoring and control process, substantially enhances the project's stakeholders shared understanding regarding cost issues. Consensus in dealing with the several risks is built thanks to these shared views, but more importantly requests of changes are documented and unnecessary claims, which often raise when the project's deviate from planned performance goals are reduced.

The third, and last noted, effect is that the proposed approach enhances the managerial perspective during the project's development through the creation of a holistic viewpoint that also allows the obtaining of a more complete and more accurate project's knowledge.

All the above-mentioned positive impact fosters the practical and easy integration of BIM and EVM as confirmed in the context of the presented work.

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Electric Vehicle Charging Stations Deployment Optimization using Genetic Algorithms

Vasiliki M. Lazari [1] and Athanasios P. Chassiakos[1]

[1] University of Patras, Patras, 26500, Greece
a.chassiakos@upatras.gr

Abstract

The incorporation of electric vehicles to the transportation system is considered to be imperative in order to mitigate the environmental impact of fossil fuel use and alleviate the current energy crisis. For that reason, it is of critical importance to establish methods for determining the location of the charging infrastructure in an optimal way. This study uses Genetic Algorithms to develop an optimization model that determines the optimal locations to place the charging stations and the number of stations that need to be deployed. This is implemented by combing into a linear objective function the goals of maximizing the electric vehicle user satisfaction (minimum travel distance) and minimizing the construction, operational, and maintenance cost for the charging stations deployment, while considering the user charging demand and the service area. The model has been applied to a simple project consisting of a 200-EV fleet and is tested for various scenarios in order to provide insight regarding the effectiveness of the algorithm by examining the quality of the solution and the required computation time. These scenarios assess the model efficiency in finding either the coordinates of the stations or both the required number of stations and their exact locations, while investigating how different initial solutions, in terms of number and distribution of the charging stations, affect the optimization outcome. Evaluating results indicate that the proposed model can effectively approximate the optimal solution in all cases.

Keywords

Electric vehicles, Electric vehicle charging stations, Charging station placement problem, Genetic algorithms, Multi-objective optimization

1. Introduction

In December 2019, the European Union decided on its Green Deal for Europe, with the aim of becoming carbon neutral by 2050. This target has set turning to e-mobility as one of the EU's top priorities as a way to mitigate the environmental impact of fossil fuel use, achieve future goals to reduce air pollution and alleviate the current energy crisis. Electric vehicles (EVs) promise high efficiency, energy savings, low noises and zero emissions, however, the lack of supporting charging infrastructure is holding back their prompt, widespread adoption. For that reason, it is imperative to deploy an extended network of charging stations for attracting private vehicle drivers to use EVs. This has as a prerequisite to solve efficiently the facility allocation problem, meaning that the number and the location of the charging stations composing the respective network should be firstly optimized, while considering certain constraints (budget limitation, charging station capacity, dispersion of the charging demand etc.).

Existing research has developed a variety of methods and algorithms in order to solve the charging station placement and sizing problem. (Huang & Kockelman, 2020) utilize genetic algorithms to solve the fast-charging station location-and-sizing problem to maximize EV charging stations owner profits across a region for BEV owners who wish to charge en route, taking into consideration elastic demand, station congestion, and network equilibrium. Genetic Algorithms have also been employed by (Akbari et al., 2018), (Efthymiou et al., 2017), (Tao et al., 2018) to calculate the necessary number of charging stations and best positions to locate them to satisfy the clients demand, with (Efthymiou et al., 2017) and (Tao et al., 2018) using origin – destination (OD) data of conventional vehicles in

Thessaloniki (Greece) and real-world driving data of 196 battery electric vehicles in Wuhan (China) respectively, for the purposes of their analyses.

(Yi et al., 2019) develop a model based on artificial immune algorithm to identify the optimal solution considering user's comprehensive satisfaction: charging convenience, charging cost and charging time. (J. He et al., 2018) develop a bi-level mathematical model to optimize the location of charging stations for EVs with the consideration of driving range. The upper-level is to maximize the flows served by charging stations, while the lower-level depicts the route choice behavior given the location of charging station. (Erbaş et al., 2018) apply a geographic information system (GIS)-based Multi Criteria Decision Analysis using the analytical hierarchy process (AHP) to address the electric vehicle charging station site selection in light of 15 environmental, economic and urbanity criteria. A hierarchical optimization model, integrating three levels of analysis, is also chosen by (Kong et al., 2017) to assist city planners for charging station location selection and system design. (Zhang et al., 2019) establish a GIS-based Multi-objective Particle Swarm optimization model aiming to both minimise the total cost of the charging stations investment and maximise the service coverage. (Bai et al., 2021) solve the siting and sizing problem by combining the hybrid particle swarm optimization (HPSO) algorithm with the entropy-based technique for order preference by similarity to ideal solution (ETOPSIS) method. (S. Y. He et al., 2016) present a case study on planning the locations of public electric vehicle charging stations in Beijing, China, where they apply and test the effectiveness of three different classic facility location models (the set covering model, the maximal covering location model, and the p-median model). (Liu et al., 2018) use an intelligent multi-objective optimization method to handle this problem by integrating a multi-objective particle swarm optimization (MOPSO) process to obtain a set of Pareto optimal solutions and an entropy weight method-based evaluation processto select the final solution from Pareto optimal solutions.

Existing studies generally attempt to solve this problem by creating models which use a predefined list of candidate locations for charging stations to be deployed, as well as a predefined number of stations to allocate. The objective of this study is to develop an optimization model that determines freely the optimal locations to place the charging stations within an area of interest and the number of stations that should be allocated, with the goal to maximize the electric vehicle user satisfaction (minimum travel distance), while considering the construction, operational, and maintenance cost for the charging stations deployment.

2. Proposed model

The electric vehicle charging stations deployment problem is a large combinatorial problem based on the optimization model of facility location problem. This analysis is positioned among the approaches of minimizing total charging station network cost and maximizing user satisfaction by reducing travelling distance, as the goals of the main infrastructure placement choice, while considering EV fleet assignment as a second level of the problem. The analysis aims to search for the most efficient locations for positioning the charging stations within the area of interest and provide suggestions on the number of EVs that can make use of the charging station daily, so as to ensure that the solution meets the charging demand per day.

The objective function of the proposed model represents the total cost that needs to be minimized and is formulated as the sum of the costs of all optimization objectives. In the present paper, two objective goals have been proposed and evaluated for their efficiency in approaching the global optimum and in minimizing computational time, which incorporate:

- The cost for deploying a network of charging stations (CSc), representing the sum of costs for land acquisition, construction, operation and maintenance.
- The cost of travelling distance (Dc), representing the sum of units traveled by the users from their charging demand point to the nearest charging station.

The above parameters can be incorporated in a linear objective function of the following form:

$$minF = w1 * CS_C + w2 * Dc \quad (2)$$

where *wi* is the corresponding unit cost value, defined by the user based on the problem characteristics.

The following assumptions and constrains are considered in the development of the optimization model:

- The optimization analysis is performed after the user provides the margins of the area of interest in the form of coordinates.

- The optimization analysis is performed after the user provides the desired number of charging stations that will compile the charging network, and for which the model will provide the optimal placement within a given area. Alternatively, the number of charging stations is considered as part of the optimization problem.
- The potential charging deployment sites are not predefined by the user in the form of candidate locations but are determined through the genetic algorithm employment.

The present analysis has used evolutionary algorithms, and more specifically Genetic Algorithms, to approximate the optimal solution as it is a classical method, suited for this type of optimization problems, where the exact solution is unknown or computationally expensive to obtain. The proposed model has been implemented in an Ms-Excel spreadsheet and the optimization is performed via a commercial optimization software (Palisade Evolver 8.1) which works as an Excel add-in. The Genetic Algorithm that has been employed to search for optimal solutions uses 50 chromosomes to form the initial population with crossover and mutation rate 0.5 and 0.1 respectively. An iterative procedure of 200,000 trials or 60 minutes of runtime is used for all the scenarios that have been tested.

3. Results

A case study with a simple project consisting of a 200-EV fleet is considered in order to illustrate the algorithm application. The number of EVs (charging demand), the number of stations compiling the charging network, the cost per station, the coordinates of the charging station location and the total travel distance covered by users to satisfy their charging needs are shown in Table 1, representing the initial scenario tested in which all stations have initially been placed at coordinates (0, 0). Alternatively, one can start the optimization with either predetermined initial locations for placing the charging stations or randomly allocated stations within the area of interest. Figure 1 graphically presents the respective demand scatter diagram and charging station deployment for the initial solution of the case study.

Based on budget limitations, various scenarios have been tested where a maximum number of deployment sites is defined by the user. More specifically, 25 different scenarios have been examined where the charging station network was composed of 1 to 25 stations respectively, aiming to achieve a balanced trade-off between the two optimization objectives described in Section 2 and depicted in Equation (1). Table 2 presents the optimal solution of each scenario and provides the average improvement of the objective function which was achieved by applying the proposed model. The objective function values are calculated by equation (1) with $w1$=1, $w2$=10, CSc equal to 1000 times the number of stations and Dc=7,157. Fig.2 indicatively presents the charging station allocation for the case of employing 12 such stations. This scenario leads to the overall best solution (lowest total cost after optimization) among all scenarios for the existing demand size and origin.

For attaining a more quantitative assessment of the degree of convergence to the absolutely best value, further specific test cases were designed and implemented. In particular, a couple of scenarios considered the demand concentrated in specific points of the study area with the number of points being equal to or lower than the number of stations. In particular, the demand was allocated in eight points (randomly placed in the search area) and a number of eight or ten charging stations were alternatively assumed (initially all placed at coordinates (0, 0)). In both cases, the model allocated one station exactly at each demand spot (i.e., the transportation cost was zero) leaving the two unnecessary stations in the second case unmoved.

Table 35. Project data for the initial placement of stations in the application example

EVs (charging demand)	Number of stations	Cost per station (in units)	Station coordinates	Travelling distance (in units)
200	i=1,2,...,25	1,000	(0,0)	7,157

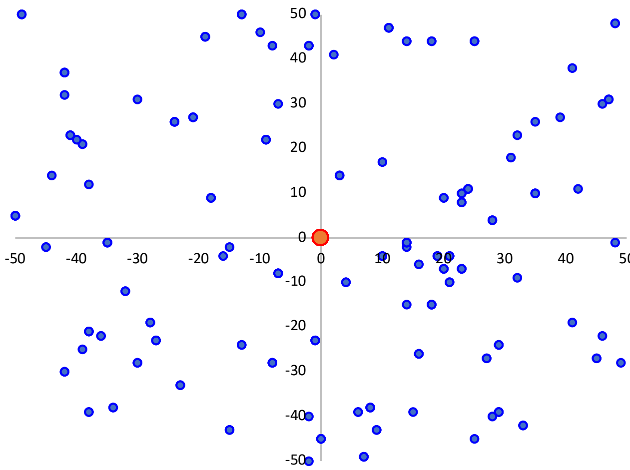

Fig. 1. Demand scatter diagram (blue color) and charging station deployment (orange color) for the initial solution of the case study

Table 2. Optimal results for the application examples

EVs (charging demand)	Number of stations (and scenario number)	Objective function before optimization	Objective function after optimization	Average improvement (%)
200	1	72,569	72,047	0.72
200	2	73,569	55,543	24.50
200	3	74,569	44,265	40.64
200	4	75,569	38,563	48.97
200	5	76,569	34,314	55.19
200	6	77,569	32,690	57.86
200	7	78,569	31,068	60.46
200	8	79,569	30,568	61.58
200	9	80,569	29,614	63.24
200	10	81,569	29,200	64.20
200	11	82,569	28,788	65.13
200	12	83,569	28,341	66.09
200	13	84,569	28,510	66.29
200	14	85,569	28,643	66.53
200	15	86,569	29,016	66.48
200	16	87,569	29,176	66.68
200	17	88,569	29,993	66.14
200	18	89,569	30,254	66.22
200	19	90,569	30,497	66.33
200	20	91,569	30,994	66.22
200	21	92,569	31,574	65.89
200	22	93,569	32,325	65.45
200	23	94,569	32,677	65.45
200	24	95,569	33,221	65.24
200	25	96,569	33,791	65.01

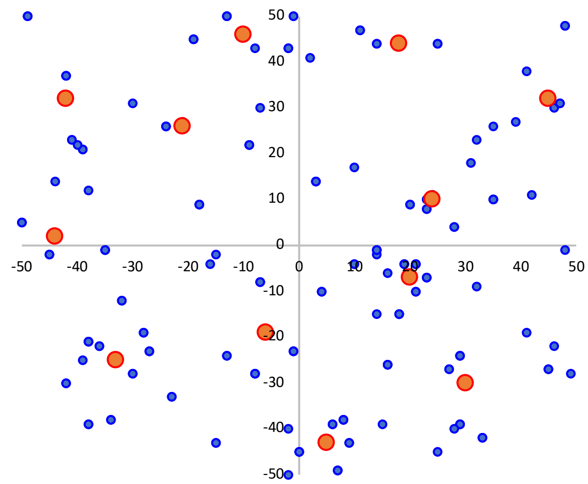

Fig. 2. Demand scatter diagram (blue color) and charging station deployment (orange color) for Scenario 12 of the case study

According to the results presented above, the travel distance decreases with the increase in the number of charging stations being deployed. However, the number of charging stations should be determined and kept under certain limitations based on the charging demand, the size of the area of interest/coverage service as well as the restrictions in budget availability. Figure 3 portrays the classical trade-off diagram between the charging station number and the travelling distance. This diagram shows the impact of a change in each attribute to the other attribute and how this may affect the decision making, minding the special characteristics and constraints of the problem. For example, if the main goal is to keep the travelling distance for the drivers under 2,000, the optimal number of charging stations is 10, providing that the available budget is over 10,000. In case that the budget is limited to 8000 then 8 charging stations may be constructed in order to approximate the initial goal of the travelling distance (2,222). It can be seen in Table 2 that a considerable minimization improvement is being achieved in most of the optimization cases compared to the initial solution. By applying the proposed model, the decrease in the objective function ranges from 0.72% to 66.68% with an average level of 59.83%. An exception to these results is Scenario 1, which has a very limited solution space size and alternatives to search for the optimal placement, as the network comprises of one charging station and therefore has not much room for improvement. Figure 4 portrays the relative convergence function rate indicatively for four indicative scenarios. The function convergence diagram is formed using the following function:

$$C=(F(i)-F_{optimal}) / (F_{initial} - F_{optimal}) \qquad (2)$$

where i is the optimization iteration and $F(i)$ the value of the objective function in i^{th} iteration. Among the presented results in Figure 4, Scenario 10 presents the fastest rate of convergence and is reaching its optimal solution after approximately 110 seconds of runtime, while Scenarios 15, 20 and 25 are developing the optimal solution after 250, 500 and 650 seconds respectively. This is expected since the higher the number of stations, the more computationally difficult to place them in an optimal way.

Additionally, Scenario X - built upon Scenario 12 (representing the case study best solution) - has been used to examine whether a different initial charging station allocation setting could be a parameter that affect the model efficiency. For this optimization, an initial station allocation setting in the form of “X” was selected, as depicted in Figure 5. In this setting, four charging stations have been placed at point (0, 0) while the other eight stations have been distributed symmetrically in the four quadrants. The optimization results (CSc = 12,000, Dc = 1,634, Objective function = 28,341) indicate that the algorithm converges to the same solution of Scenario 12 (see Fig. 2 above) regardless of the initial station placement.

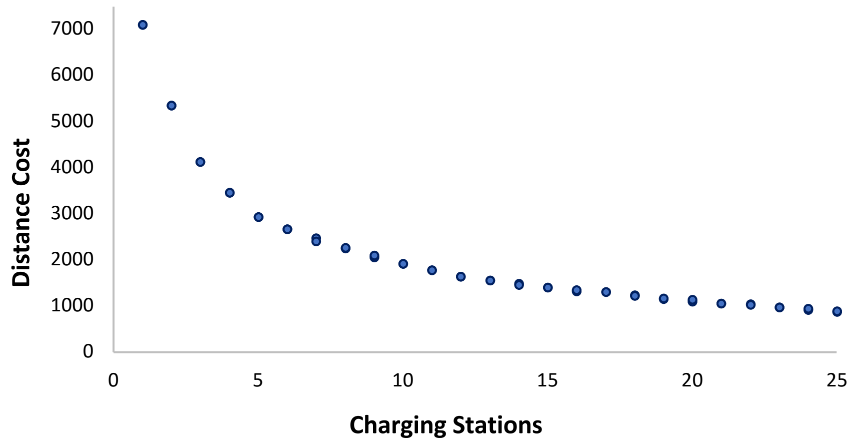

Fig. 3. Trade-off diagram between the distance cost and the number of charging stations

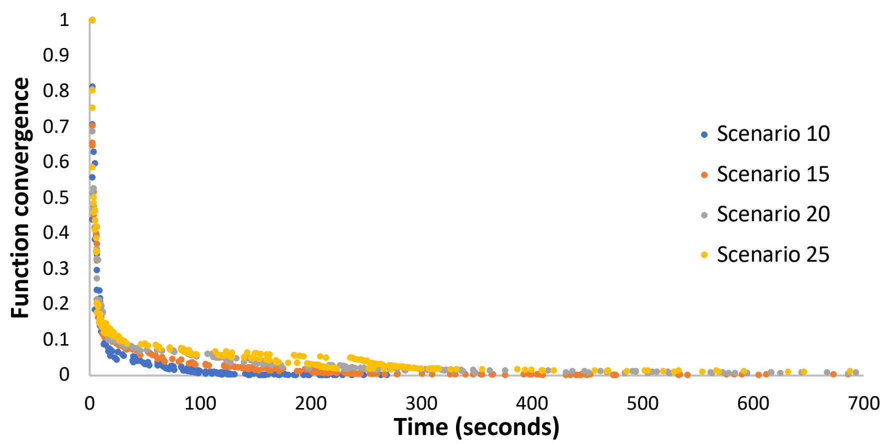

Fig. 4. Optimization convergence curves for different scenarios.

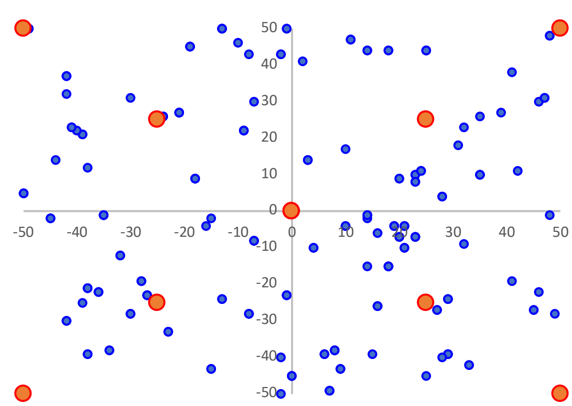

Fig. 5. Demand scatter diagram (blue color) and charging station deployment (orange color) for Scenario X of the case study

In the second direction of analysis, the number of charging stations was considered as a decision parameter in addition to the optimal station placement (Scenario N). More specifically, the algorithm was redeveloped to identify both the number and the location of the charging stations. Several tests were performed considering an initial number of stations ranging from 15 to 25 and being initially placed at coordinates (0, 0). In general, the model presented a convergence to a solution consisting of 12 stations while small deviations in the objective function were observed, ranging from 28,341 to 28,370. The minimum value solution was found to coincide with those of Scenarios 12 and X.

For the case that the demand was considered as concentrated in eight points (randomly placed within the study area) and starting with ten charging stations, the algorithm eliminated the two excessive stations (to avoid the deployment cost) and allocated the remaining eight stations exactly upon the points of the demand existence to fully eliminate the transportation cost.

4. Discussion

This study proposes a model which utilizes Genetic Algorithms to formulate a flexible tool for planning the location of charging stations infrastructure. This analysis can be extended to include additional factors/constraints that could affect the optimization outcome, such as the physical-geographical condition and topography of the area of interest and the difference in charging station capacities, based on the grid tolerance. Also, within the area of interest, different zones could be considered to indicate variations in station deployment costs, either for land acquisition, construction or operation and maintenance.

In regard to the selected algorithm, it should be highlighted that due to meta-heuristic algorithm special characteristics, the obtained solution may not necessarily be the optimal one in every single run (especially as the problem grows up in size). To improve the success rate (i.e., to minimize the degree of error between the obtained and the optimal solution), the algorithm was run repetitively so that, considering the stochastic nature of it, to obtain more viable solutions. Different optimization criteria were tested in order to identify the one that better suits the individual problem objectives, limitations and characteristics. By exploring more alternatives, it is much likely to find a solution with higher generalized impact, than by focusing only on the optimization of a single sub-goal.

5. Conclusions

The electric vehicle charging stations placement problem is one of the most challenging optimization problems in transportation sector and in the field of infrastructure management. In this context, the objective of this research is to propose a solution for optimal EV charging infrastructure deployment, based on Genetic Algorithms which are considered as an effective tool used to handle large combinatorial optimization problems. The present study has delivered a model to optimize the number and the location of charging stations for EVs. The variables composing the objective function were the driving distance required for the fleet of EVs to reach the charging station and the construction, operational and maintenance costs of the charging network deployment. The presented case studies (varying in terms of parameters tested and initial station network allocation) have demonstrated that the proposed method can attain the reasonable planning of the EV charging stations, including both the number and location of the stations, considering the priorities and individual objectives in every tested scenario.

Acknowledgement

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ID 85

Cementitious Paste Defects Correlated to Engineering Properties of Concrete

Achintyamugdha Sharma[1], Todd Sirotiak[2], Xuhao Wang[3], Peter Taylor[4], Priyanka Deka[5], Ravi Kiran[6] Dayakar Naik[7]

[1] JCMS, Inc., Mercerville, NJ 08619, USA
[2] North Dakota State University, Fargo, ND 58105, USA
[3] Chang'an University, Xi'an, China
[4] Iowa State University, IA 50010, USA
[5] JCMS, Inc., Mercerville, NJ 08619, USA
[6] North Dakota State University, Fargo, ND 58105, USA
[6] University of North Dakota, Grand Forks, ND 58202, USA
asharma@jcms.com

Abstract
This study was aimed at investigating potential correlations between microstructure properties of cementitious paste samples and bulk properties of hardened concrete. In this study, defects in paste samples were detected and quantified by using X-Ray Micro-Computed Tomography (μ-CT) technique. These quantified defects in paste samples were correlated with bulk properties of corresponding concrete - electrical resistivity, drying shrinkage and degree of hydration from eight cementitious combinations. The results showed correlations between the degree of hydration in concrete and defects in paste. Additionally, the degree of cracking of paste samples can help predict drying shrinkage of resultant concrete.

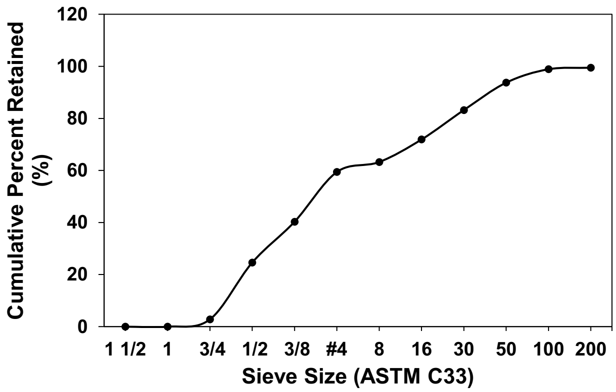
Keywords
Cement paste, microstructures, X-Ray Micro CT.

1. Introduction
The microstructure of cementitious paste and concrete composites has been extensively investigated by several researchers in the past decades (Jan Bisschop & J. G. M. Van Mier, 2002; J. Bisschop & J. G. M. Van Mier, 2002; Bisschop & van Mier, 2008; de Sa et al., 2008; Golewski, 2018; Monteiro, 2006; Sharma et al., 2020; Shi et al., 2011). In concrete, portland cement acts as the glue to hold coarse aggregates and sand together through hydration reactions that result in the formation of crystals like calcium silicate hydrates (CSH) and calcium hydroxide (CH). The characterization of paste microstructure can reveal the extent of formation of such crystals which in turn can provide useful information about hydration. The rate of hydration depends upon physical and chemical characteristics of cementitious materials used in concrete. Portland cement and pozzolans such as fly ash and nanosilica are carefully chosen by engineers to optimize the production of hydration crystals to refine the microstructure of paste.

Cement paste is the most vulnerable component in concrete to micro-cracks and defects caused by tensile forces due to differential evaporation and volume changes (Bentz, 2006; de Sa et al., 2008). These defects lead to disintegration at the paste-aggregate interface, also known interfacial transition zone (ITZ). As a result, larger cracks are formed in concrete. Deleterious ions like chloride and sulfate can ingress through such cracks. A permeable system of interconnected voids can facilitate the movement of such ions dissolved in pore fluids. After reacting with hydration products, these ions lead to the production of expansive compounds like calcium oxychloride (in case of chloride), and thaumasite and ettringite (in case of sulfate) (Ikumi et al., 2016; Peterson et al., 2013; Whittaker & Black, 2015). As a result, the durability of concrete is compromised. Therefore, characterization of defects and voids in cementitious paste can help in the investigation of durability of concrete.

A material used to impart ductility to concrete composites is fiber. The addition of synthetic or natural fibers can help dissipate tensile energies by transferring load through the fiber-matrix interfacial bond (Abbas & Khan, 2016). Randomly dispersed microfibers with

Figure 1: Combined particle size distribution curve for coarse and fine aggregates as per ASTM C33 (ASTM 2018)



monofilaments having diameter in the micrometer range can be used to provide resistance to microcracking in cementitious paste and concrete (Branston et al., 2016; Yousefieh et al., 2017). A relatively recent and more environment friendly fiber with good mechanical properties is chopped basalt fibers (Katkhuda & Shatarat, 2017). It has reportedly better density, tensile strength and elastic modulus compared to glass fibers (Fiore et al., 2015).

In this study, eight different cementitious combinations comprising of three types of cement (coarse ground, Type I Portland cement, Type IL Portland Limestone Cement), fly ash and nanosilica, and basalt microfibers were investigated. The microstructure of paste samples from these mixtures was investigated to derive indications about the durability of their corresponding concrete samples.

2. Materials and Methods

In this study, the microstructure of cementitious paste samples was investigated by using non-destructive technique X-Ray Micro-Computed Tomography (μ-CT). Degree of hydration, electrical resistivity and drying shrinkage of corresponding concrete samples were investigated for comparison.

2.1 Materials

In this study, three cement types were used: Coarse Ground portland cement (CG), Type I portland cement (TI), and Type IL portland limestone cement (TIL). Additionally, Class F fly ash (FF), Class C fly ash (FC) and colloidal nanosilica were used as supplementary cementitious materials (SCM). The chemical and physical properties of the cementitious materials are presented in Tables A1 and A2 in Appendix. Chopped basalt fibers 13µm in diameter, and 24 mm in length, treated with a silane-based coating (0.25% w/w) were used per manufacturers recommendations. The dimensions and dosage rate of basalt fibers was also selected as per recommendations from previous literature for optimum performance (Elshafie & Whittleston, 2015). The silane-based coating is provided to protect the fibers in an alkaline environment. In case of concrete samples, ½" (nominal aggregate size) limestone aggregates and locally available sand were used. Figure 1 shows the combined gradation of the aggregates. The water-to-cementitious materials ratio, binder content, and binder to coarse aggregates to fine aggregates weight ratio were fixed at 0.42, 344 kg/m^3, and 1:3.08:2.23, respectively. An organic acid-based air entraining agent, and a polycarboxylate based Type F high range water reducing agent (WRA) were used. For paste samples, the water-to-cementitious materials ratio was fixed at 0.40. Paste samples were cast at a lower water-to-cementitious materials ratio in order to minimize bleeding.

2.2 Concrete Specimens and Tests

In this study, eight cementitious combinations were investigated: Coarse Ground portland cement (CG-P), Type I ordinary portland cement (TI-P), Type I ordinary portland cement, 30% of which is replaced with Class C fly ash (TI-FC), Type I ordinary portland cement, 20% of which is replaced with Class C fly ash (TI-FF), Type IL Portland Limestone Cement (TIL-P), Type IL Portland Limestone Cement, 30% of which is replaced with Class C fly ash (TIL-FC), Type IL Portland Limestone Cement, 30% of which is replaced with Class C fly ash and 0.25% (v/v) basalt fibers (TIL-FC (B)), and Type I ordinary portland cement, 5% of which is replaced by colloidal nanosilica (TI-NS). The mixture proportions of the concrete used are shown in Table 1. Standard 100 mm x 200 mm cylinders were cast for measuring electrical resistivity (ASTM C1760) and degree of hydration through semi-adiabatic calorimetry (ASTM C1753) (ASTM, 2012, 2015). Shrinkage in the concrete mixtures under restrained conditions was also measured by the standard ring test method specified in ASTM C1581 (ASTM, 2009).

Table 1: Mix proportions

Mix Code	Cement (kg/m³)	Class F Fly Ash (kg/m³)	Class C Fly Ash (kg/m³)	Nano Silica (kg/m³)	ed Basalt Fiber Addition (% v/v)	Water (kg/m³)	WR (ml/m³)	AEA (ml/m³)	Fine Aggregates (kg/m³)	Light Weight Aggregates (kg/m³)	Coarse Aggregates (kg/m³)
CG-P	344	0	0	0	-	145	888	45	1061	0	768
TI-P	344	0	0	0	-	145	721	45	1061	0	768
TI-FC	241	0	103	0	-	145	862	45	1061	0	768
TI-FF	275	69	0	0	-	145	448	45	1061	0	768
TIL-P	344	0	0	0	-	145	1457	45	1061	0	768
TIL-FC	241	0	103	0	-	145	971	45	1061	0	768
TIL-FC (B)	241	0	103	0	0.25	145	971	45	1061	0	768
TI-NS	327	0	0	17	-	145	4280	45	1061	0	768

2.3 Paste Specimens

Cement paste samples were cast for the eight cementitious combinations mentioned in section 2.1.2. For microstructure studies, paste samples were cast in hour-glass shaped 3D printed molds with internal dimensions 0.5”x0.5”x2” (Figure A1). The mold was fabricated using a resin-based 3D printer called Form 2. A 3D CAD model was drafted using Autodesk Fusion 360. The shape of these molds was selected so that stress due to drying shrinkage is maximum along the middle section of the specimens. This would increase the probability of encountering microcracks in this central, thus facilitating the process of imaging. The 3D molds were covered with two plates on the top and bottom, which were fastened using pan-head machine screws (USS #4-40 x ½ in.) the threads were generated using the software. Cement paste was prepared in accordance with ASTM C305 and poured into the molds (ASTM, 2014). All the pieces were also tied together by using rubber bands to provide better water tightness. These samples were then rotated at 10 rotations per minute (Figure A2) for approximately 12 hours to avoid bleeding. Then the samples were wet cured for up to seven days. At the end of seven days from mixing, the top and bottom plates were demolded, and the paste samples allowed to dry under conditions compliant with ASTM C1581 for 28 days (ASTM, 2009).

2.4 Micro Computed Tomography

Dried paste samples inside their molds were subjected to X-ray µ-CT scans with a General Electric V|Tome|x s 240, at the NDSU Electron Microscopy Center Core facility. Scanning was done using the 180 kV x-ray tube running at 110 kV, 350 □A, exposure of 333 ms and 1200 images collected per sample. Reconstructed volumes were analyzed with the commercial software package Volume Graphics Studio Max version 3.0. Initially, the Surface Determination mode of the software was used to distinguish between material and background (voids or pores in this case). The surface fit function was applied using the threshold value as the central value between the peaks of material and background in the data histogram. Additionally, an iterative surface determination mode was applied for enhanced precision. This default histogram generated by the software can be used to have an approximate idea of defects within the system. Although the surface determination histogram can be manually fit for detailed detection and quantification of voids as small as 30 µ, for a quick comparison of porosity for voids of size 75 µ and larger, among different cementitious combinations the default method is deemed adequate (Du Plessis et al., 2016). Surface determination was followed by measurement of void sizes by the default Porosity/Inclusions/Defects determination mode of VG Studio Max 3.2. Minimum voxel size was maintained at 8 voxels, and minimum probability of voids was maintained at 0. Figure A3a and A3b show typical examples of 3D reconstruction of paste samples and pores/defects as observed through µ-CT.

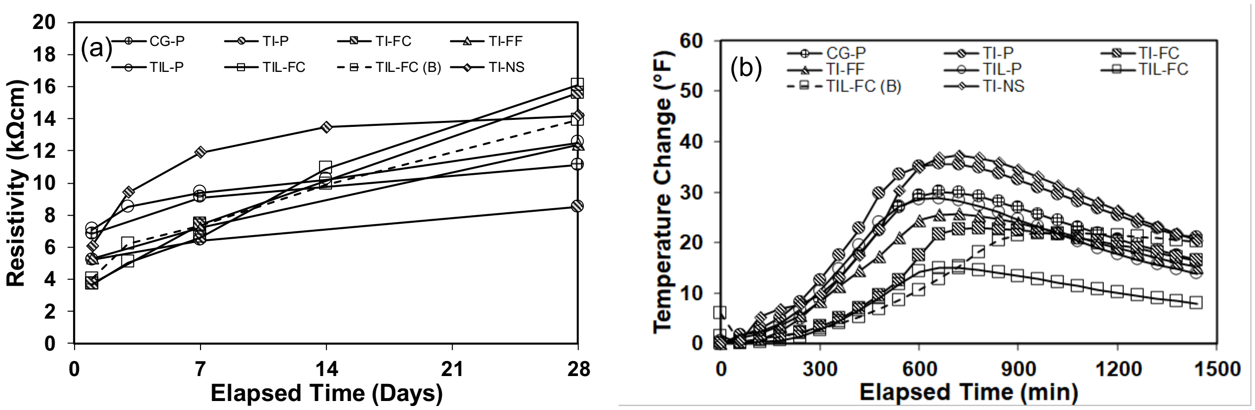


Figure 2: (a) Electrical resistivity of concrete, (b) Rate of hydration as measured through semi-adiabatic calorimetry

3. Results and Discussions

3.1 Paste Microstructure (μ-CT) and Concrete Durability

Figure 2a shows the electrical resistivity results of samples from the concrete mixtures over time elapsed. It is an indirect determination of the durability of the concrete mixtures. The durability of concrete is determined by the ability of the microstructure to resist the passage of deleterious ions like chloride and sulfate through pore fluid. Pore fluid is a better conductor of electricity as compared to cementitious products and aggregates. Therefore, to ensure high durability in concrete an interconnected system of voids capable of transporting pore fluids with dissolved ions should be avoided (Mohr et al., 2000). CG-P is observed to have one of the lowest resistivity results among the eight mixtures. On the other hand, TI-NS appears to have the highest resistivity results through 14 days from mixing. Due to lower fineness of coarse ground cement and a consequently lower surface area compared to other cement types used in this study, the availability of hydration sites should be lower (Bentz, 2010). As a result, the rate of hydration should be slower and consequently, the microstructure of the cementitious system is not as refined when compared to faster reactive systems, like TI-NS, as demonstrated by the peak of temperature change plot obtained through semi-adiabatic calorimetry test (Figure 2b). Due to the presence of nanosilica, the pozzolanic hydration of calcium hydroxide (CH), a by-product of primary hydration reaction, to calcium silicate hydrate (CSH) is driven at a high rate. As a result, a refined microstructure is produced. Nanosilica particles also physically fill interfacial transition zone (ITZ) between cement paste and aggregates (Khaloo et al., 2016; Singh et al., 2013).

Figure 3a and 3b show total defects and average paste diameter of the eight mixtures, respectively. When considering the paste samples of this study, the defects detected and measured through μ-CT could be a combination of voids and cracks. Based on the settings of μ-CT used in this study, the voids detected are roughly more than 100 μm in diameter (assuming the voids to be spherical in shape). Voids of such a size range typically form when free water evaporates without causing any significant tensile stresses (Taylor & Wang, 2014). The availability of free water in turn is dependent on the reactivity of cement and pozzolanicity of supplementary cementitious materials (SCMs). Microcracks can form due to a gradient in relative humidity between subsequent layers of paste resulting in tensile stresses (J. Bisschop & J. G. M. Van Mier, 2002; de Sa et al., 2008). This is mainly because outer layers are drier than the inner ones. From Figure 8a, it is evident that the total number of defects (voids + cracks) observed through μ-CT is the lowest for paste samples from CG-P. In contrast, the paste samples for TI-NS have the highest number of defects. The average pore diameter, however, does not appear to be significantly different between the two mixtures (Figure 3b). As resistivity of the concrete for TI-NS is higher than that of CG-P (Figure 2a), it is likely that the former has a discontinuous system of voids compared to the latter. This trend should also be reflected in their corresponding paste samples. Figures 4a-4h show the void size distribution of the mixtures as observed through μ-CT. From Figure 4h, it is evident that the paste samples of TI-NS have voids distribution with a wide range of sizes. This may be indicative of a discontinuous microstructure with hydration products like CSH crystals filling otherwise larger voids through a rapid hydration process. As a result, the movement of pore water and dissolved ions will be impeded, leading to high electrical resistivity. This is however, not reflected in case of CG-P (Figure 4a).

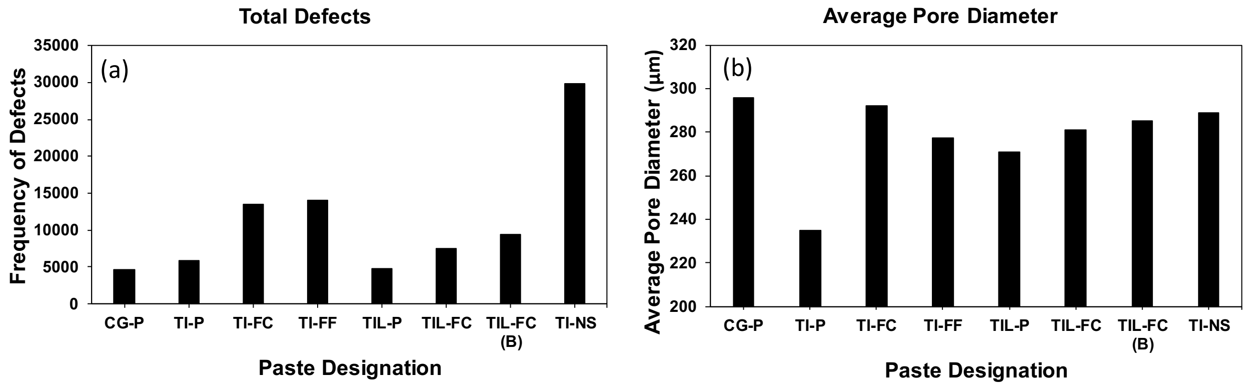


Figure 3: µ-CT results for (a) Total defects, (b) Average pore diameter

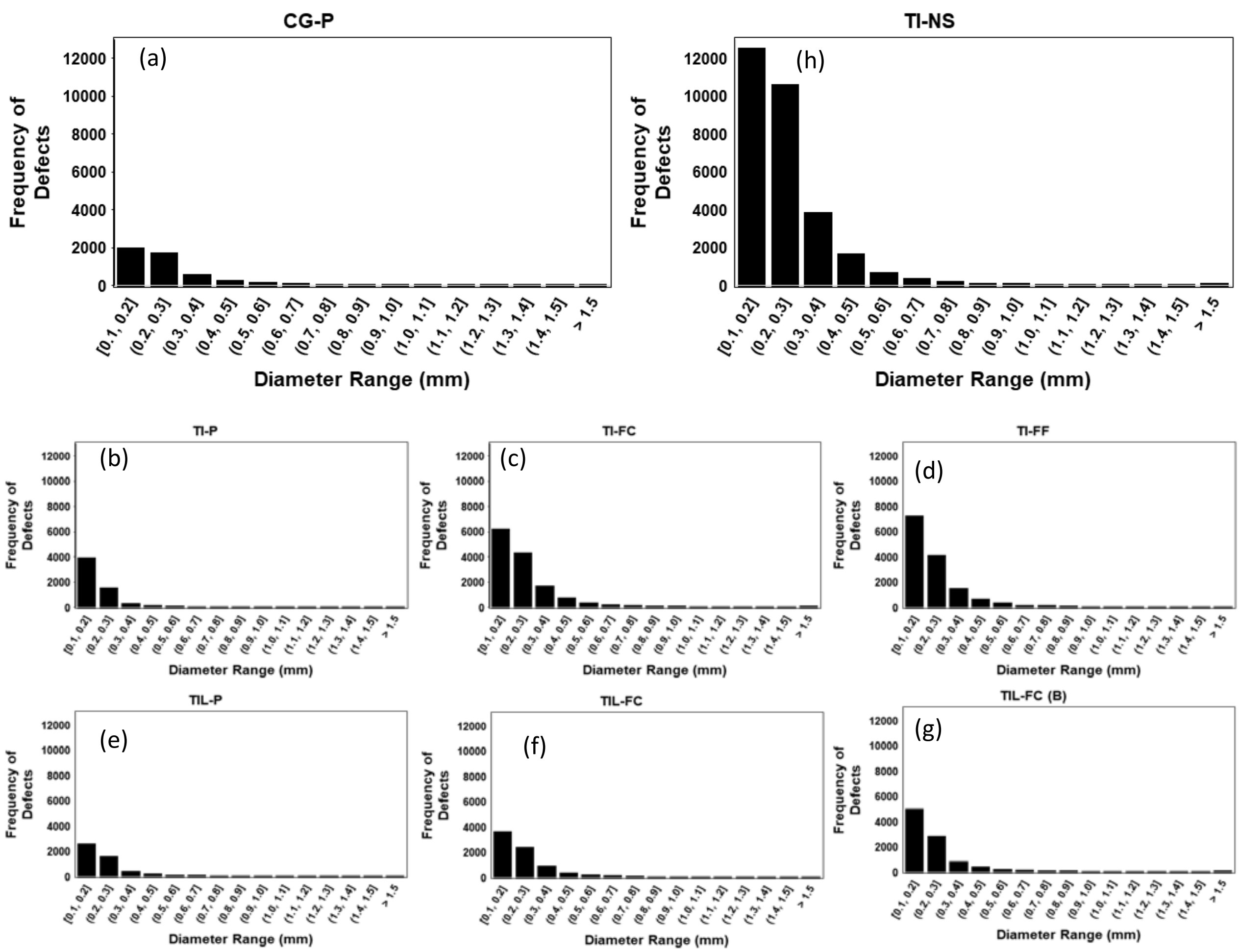


Figure 4: Frequency of defects for paste samples of (a) CG-P, (b) TI-P, (c) TI-FC. (d) TI-FF, (e) TIL-P, (f) TIL-FC, (g) TIL-FC (B), (h) TI-NS

The resistivity results of the concrete mixtures containing fly ash (TI-FC, TI-FF, TIL-FC, TIL-FC (B)) are seen to be higher than their control counterparts (TI-P, TIL-P), especially at the later ages (Figure 2a). Mixtures containing fly ash usually have a slower rate of hydration initially (Figure 2b). Fly ash being a pozzolan, helps in refining the microstructure of concrete over time, thereby increasing durability (Celik et al., 2015). Paste samples of TI-FC (Figure 4c), TI-FF (Figure 4d), TIL-FC (Figure 4f) and TIL-FC (B) (Figure 4g) are also seen to have higher frequency of defects and a wider range of void size distribution compared to TI-P (Figure 4b) and TIL-P (Figure 4e). This likely means that due to a refined microstructure created by fly ash, the likelihood of a continuous system of voids is reduced (Chindaprasirt et al., 2004; De Weerdt et al., 2011).

3.2 Paste Defects and Degree of Hydration of Concrete

The microstructure of a cement paste is formed by crystals like calcium silicate hydrate (CSH) and calcium hydroxide (CH) which are formed through the process of hydration (Wilson & Kosmatka, 2011). The rate of these hydration reactions determines the rate of formation of such crystals which in turn determines how refined the hardened paste microstructure is (Cheung et al., 2011). From Figure 5a and 5b, a correlation can be seen between total defects found in paste and the slope of the peak of the rate hydration-time curve as measured through semi-adiabatic calorimetry technique. An example of the method of calculating the slope of the peak of hydration is shown in Figure 5c. The relationship between total defects in paste and peak rate of hydration of concrete appear to manifest differently in case of mixtures with and without supplementary cementitious materials (SCMs) (Figures 5a and 5b). The presence of pozzolans (fly ash and nanosilica in this study) help with additional formation of CSH gel through hydration of CH, a by-product of primary hydration of cement (Wilson & Kosmatka, 2011). These additional crystals likely partially fill voids, thus converting a system of a smaller number of larger voids/defects into that of larger number of relatively smaller voids/defects (Figure A4) (Golewski, 2018). As the dissolution of cement minerals like alite (tricalcium silicate) is anisotropic, the orientation and nucleation of CSH crystals in three dimensions may explain the differences in the number of defects vs. slope of peak rate of hydration curves in case of mixtures with and without SCMs (Figures 10a, 10b) (Robin et al., 2018).

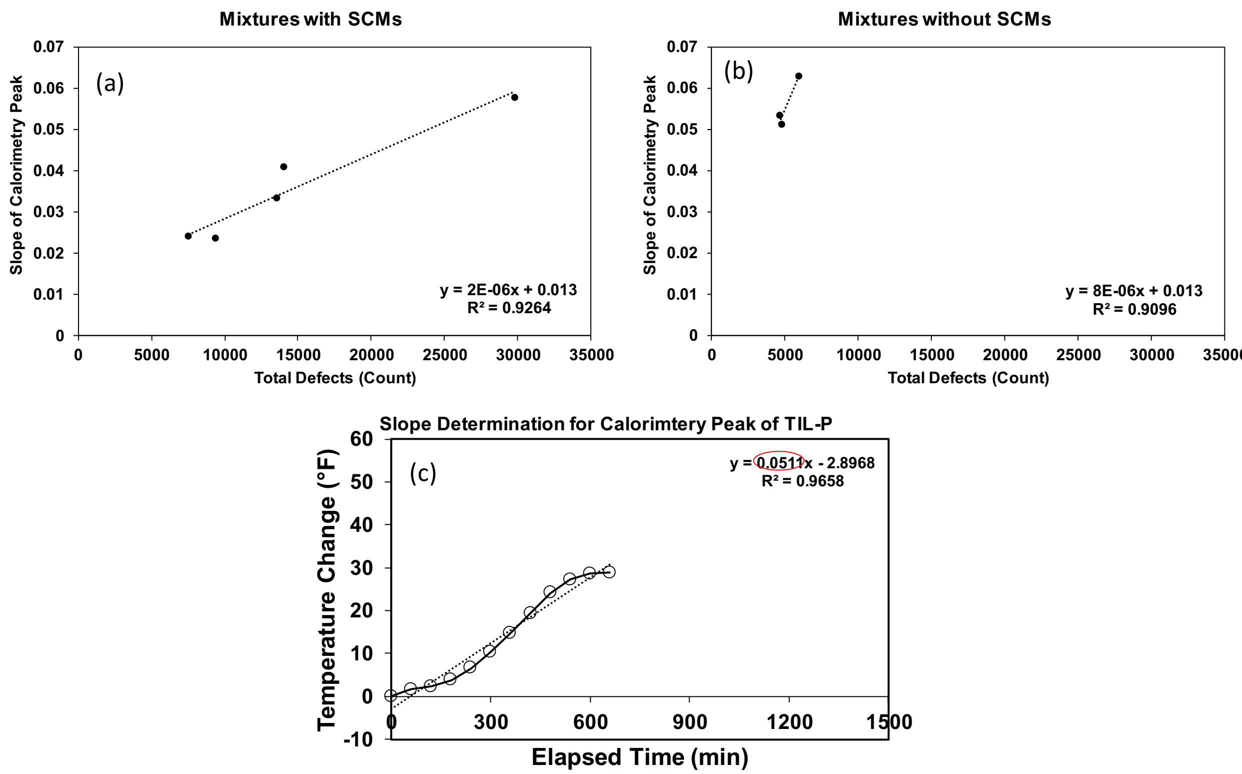


Figure 5: Total defects in paste vs. slope of peak of calorimetry curve of concrete for (a) mixtures without SCMs, (b) mixtures with SCMs, (c) slope of peak of calorimetry curve in TIL-P

3.3 Paste Microstructure (μ-CT) and Concrete Shrinkage

From Figure 6a, the average stress rate, derived from drying shrinkage strain under restrained conditions, appears to be a function of the total defects in paste as observed through μ-CT. When free water evaporates from paste, it leaves voids behind. When tensile forces are formed due to gradients in relative humidity between subsequent layers of cement paste, such materials may have a tendency to collapse into these voids (Jan Bisschop & J. G. M. Van Mier, 2002; de Sa et al., 2008). Therefore, a higher number of voids in paste may indicate a high shrinkage strain in concrete.

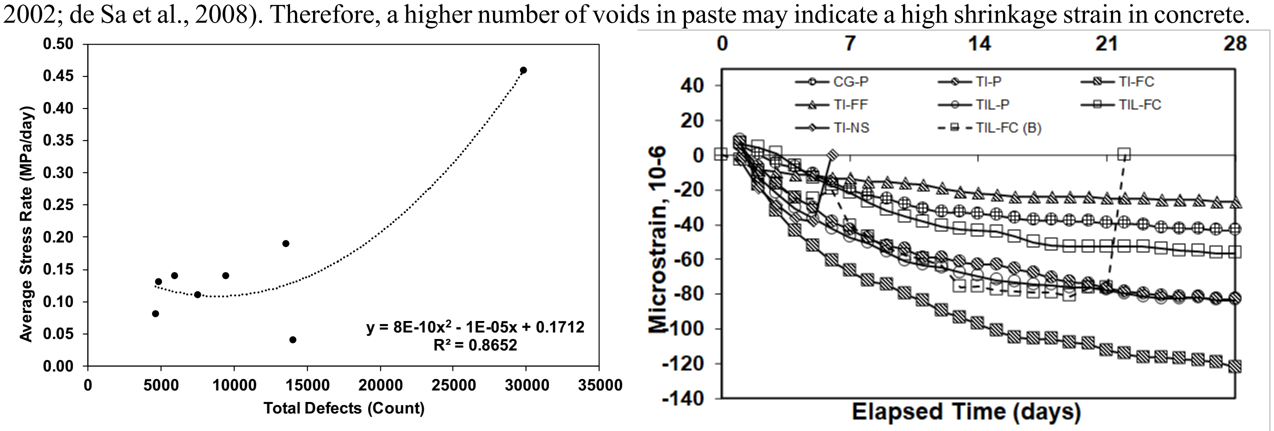


Figure 6: (a) Total defects in paste from μ-CT vs. average stress rate from restrained drying shrinkage in concrete, (b) Drying shrinkage strain for concrete mixtures

Figure 6b shows the drying shrinkage strain for the eight mixtures plotted against elapsed time. Among the mixtures with no supplementary cementitious materials (SCMs), CG-P appears to have the lowest shrinkage strain. Prior researchers have also reported lower shrinkage strain for concrete containing coarser cementitious systems (Deshpande, 2007; Mehta & Burrows, 2001; Sharma et al., 2019; Tritsch et al., 2005). TI-FC is seen to have higher shrinkage strain than TI-P. This is consistent with prior literature (Munday et al.). Higher drying shrinkage strain was reported by prior researchers in case of concrete containing fly ash with an unaltered water/binder ratio as compared to control (Nath & Sarker, 2013). This is likely because of a higher availability of free water in case of mixtures containing fly ash as it can help maintain workability with lower amounts of water due to the presence of spherical glassy particles (Jiang & Malhotra, 2000). The curves for TI-NS and TIL-FC (B) appear to abruptly drop to zero indicating cracks in the concrete ring (ASTM C1581).

Conclusions

Based on the findings of this study, it is seen that the electrical resistivity results for TI-NS is the highest among all mixtures, while that for CG-P appears to be the lowest. The degree of hydration (as observed through temperature change plot over elapsed time from semi-adiabatic calorimetry test) appears to influence electrical resistivity results of the mixtures. Total defects (voids + cracks) observed through μ-CT is the lowest for CG-P and highest for TI-NS. Additionally, TI-NS shows voids of a wide range of sizes likely indicating a growth of hydration products like CSH to develop a discontinuous microstructure. The mixtures containing fly ash have higher electrical resistivity results compared to their control counterparts. Moreover, the paste samples containing fly ash have higher number of total defects with void sizes distributed on a wide range of sizes likely indicating a discontinuous microstructure. In this study, total defects in paste appear to have a correlation with degree of hydration of concrete. The relationship between degree of hydration of concrete and total defects in paste shows different trends in case of mixtures with and without SCMs, likely due to anisotropic dissolution of cement minerals. Finally, drying shrinkage of concrete appears to be related to quantification of defects in paste.

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Appendix

Table A1: Chemical and physical properties of cements used

Item	**Coarse Ground Cement***	**Type I Cement***	**Type IL Cement****	**Class C Fly Ash*****	**Class F Fly Ash*****
SiO_2 (%)	21.07	19.80	-	39.01	51.65
Al_2O_3 (%)	4.25	4.90	-	21.23	16.29
Fe_2O_3 (%)	3.13	2.40	-	5.72	5.63
CaO (%)	65.00	63.40	-	24.31	13.00
MgO (%)	0.97	2.80	0.90	5.31	4.26
SO_3 (%)	2.88	3.00	3.10	0.81	0.67
$SiO_2+Al_2O_3+Fe_2O_3$	-	-	-	65.96	73.57
Loss on ignition (%)	0.75	2.60	4.80	0.16	0.10
Na_2O (%)	0.14	0.04	-	1.58	3.23
K_2O (%)	0.58	0.73	-	0.53	2.45
Insoluble Residue (%)	0.21	0.34	0.40		
CO_2 (%)	-	1.50	-		
Limestone (%)	-	3.7	10.0		

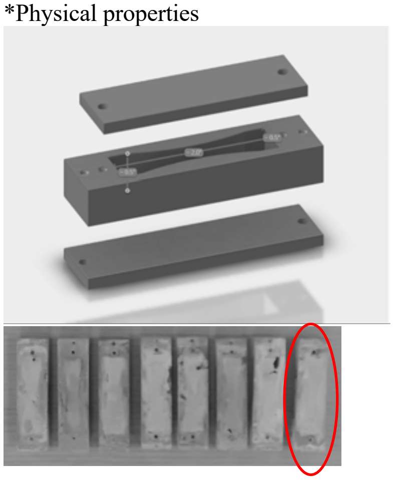
$CaCO_3$ in limestone (%)	-	93.00	96.20		
C_3S (%)	61.62	60.00	-		
C_2S (%)	12.44	9.00	-		
C_3A (%)	5.83	9.00	7.00		
C_4AF (%)	9.3	7.00	-		
Equivalent alkalies (%)	0.52	0.52	-	1.15	1.63
Blaine Fineness (m^2/kg)****	316.94	397.00	382.00		
Fineness (+325 Mesh) (%)****	-	-	-	16.90	21.29

*Limits specified in ASTM C150
**Limits specified in ASTM C595
***Limits specified in ASTM C618
****Physical property

Table A2: Chemical and physical properties of nanosilica used

Item	**Colloidal Nanosilica**
SiO_2 (%)	49.0-51.0
$SiO_2:Na_2O$ Ratio	200-250
Na_2SO_4 (%)	≤0.135
pH	8.5-9.5
Viscosity (at 25°C) (cps)*	≤55
Specific Gravity (at 60°F)*	1.388-1.407
Surface Area (m^2/g)*	110-150

*Physical properties



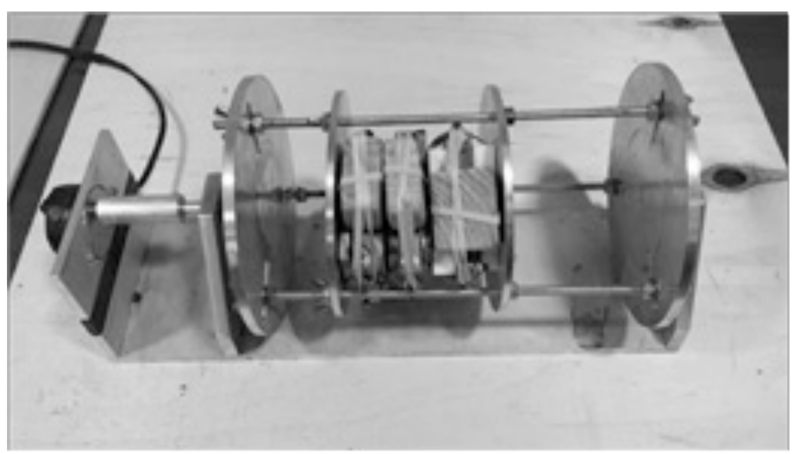


Figure A1: 3D Printed Resin Based Mold for Paste Sample, A2: End-to-end rotating device setup for paste samples

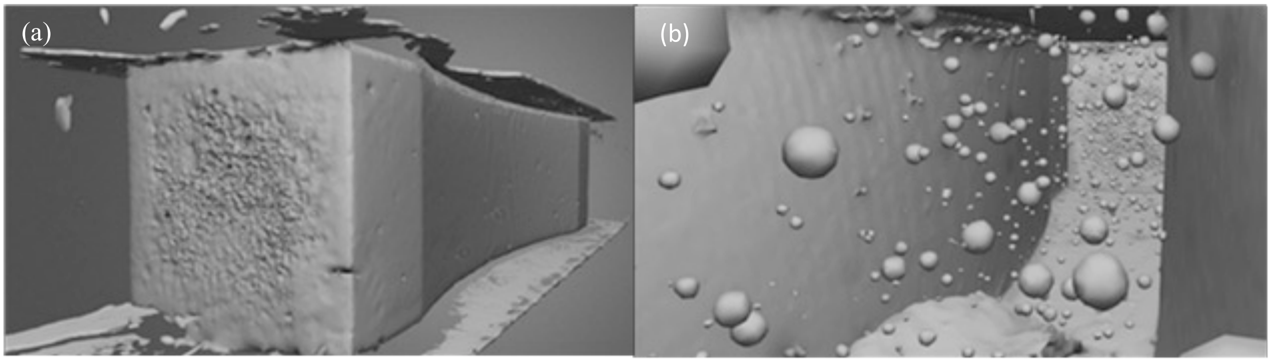


Figure A3: μ-CT Results for (a) 3D reconstruction of a paste sample (b) 3D reconstruction of pore distribution inside a paste sample

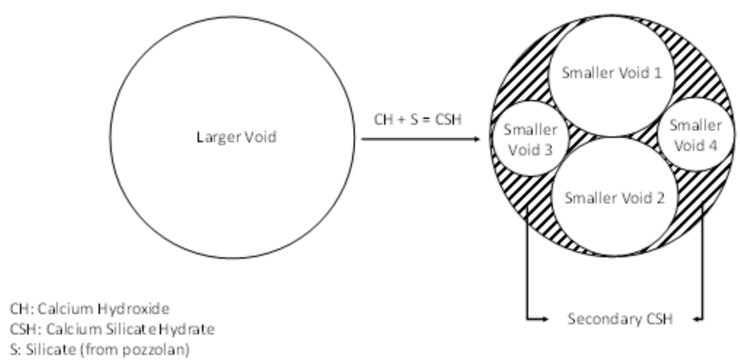


Figure A4: Conversion of larger voids into multiple smaller voids by pozzolan

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Problem-Based Learning (PBL) for a Construction Capstone Course: Assessment Through Competing Values Skill Surveys (CVSS)

Achintyamugdha Sharma[1], Todd Sirotiak[2], Rajender Chada[3]

[1] JCMS, Inc., Mercerville, NJ 08619, USA
[2] North Dakota State University, Fargo, ND 58105, USA
[3] Fairstead, New York, NY 10019, USA
asharma@jcms.com

Abstract

It has been widely recognized that traditional lecture teaching techniques in higher education may leave gaps in the skill development of students, especially soft skills. This gap can prove to be detrimental to graduating construction engineering and construction management students, as well as to their potential employers. But essential skills required to function effectively in the industry such as leadership, communication, mentoring, collaboration, and stress coping can be inculcated in students by implementing alternative teaching techniques such as Problem-Based Learning (PBL). It is therefore important to assess and quantify changes in soft skill development among students due to PBL. In this study, PBL was administered in a course titled "Construction Management Capstone" during the spring of 2015 by the Department of Construction Management and Engineering at North Dakota State University. By using an assessment tool called Competing Values Skill Surveys (CVSS), it was concluded that PBL can have positive impacts on certain soft skills, predominantly in collaborative and control-focused competencies, with some improvements in creative and competitive-focused competencies.

Keywords

Problem Based Learning (PBL), engineering education, capstone, soft skills, CVSS

Introduction

Engineering is the problem-solving application of basic science principles with mathematics. Instructor-centered teaching approaches have been traditionally used for higher level engineering education in the United States (El-adaway et al., 2014). But past studies have criticized such approaches for their inability to provide students sufficient context to comprehend and apply information in the real world (Schmidt, 1993). When students are passive receptors, teachers struggle to raise their interest based on theoretical and practical/laboratory sessions (Zeng & Xu, 2010) and, under such conditions, students do not typically get a chance to work in collaborative environments and therefore lack opportunity to hone their people skills. Considering construction, the industry demands faster and more cost-effective delivery of projects that are essentially achieved through fast-tracked, team-based approaches, such as design-build. Such situations will require collaborative teamwork from professionals to lead, innovate, communicate, manage time under tight deadlines, and cope with stress (Zeng & Xu, 2010). However, some of the traditional teaching pedagogy for civil and construction engineering and management programs are not much focused on the development of the above-mentioned "soft skills" in students (Walters & Sirotiak, 2011). There is therefore a need to explore alternative teaching philosophies in construction engineering and management programs.

In engineering education, capstone courses are intended to create a much-needed link between academic learning and professional experience (Jones et al., 2013). After the Second World War, capstone courses were designed to translate theory-based coursework into practices required by industry (Dutson et al., 1997). Prior survey instruments among teachers of such engineering capstone courses have revealed that the most important goal of a capstone project was to help students apply prior knowledge of courses in simulated environments of realistic, open-ended projects (Pembridge & Paretti, 2010). However, traditional lecture-based teaching techniques may not be able to translate such applicability of previously acquired knowledge (Sirotiak & Walters, 2012). It is therefore critical to think beyond traditional teaching techniques for engineering capstone courses.

Several alternative teaching approaches have been explored in the past to improve the effectiveness of the learning process, such as Discovery-Based Learning (Behzadan & Kamat, 2013), service leaning (El-adaway et al., 2014), and Problem-Based Learning (McIntyre, 2002; McLoughlin et al., 2015; Sirotiak & Walters, 2012). Also known as PBL, Problem-Based Learning is a widely studied and effective learning technique (Hung et al., 2008; Jones et al., 2013). However, while it is critical to assess and quantify potential changes in students' development of soft skills as a result of PBL in higher level classes, there is little published work assessing these changes to the best knowledge of the authors.

In this work, PBL was administered in a course titled "Construction Management Capstone" by the Department of Construction Management and Engineering of North Dakota State University. It was hypothesized that construction engineering and construction management students will show improvements in their collaborative qualities through implementing PBL techniques for a capstone course. One way to assess these improvements may be by the use of Competing Values Skill Surveys (CVSS), which are otherwise used in business-related disciplines.

Methodology

Participants

The participants of this study were undergraduate students of Construction Management and Construction Engineering programs in North Dakota State University, enrolled for the course CME 488 *Construction Management Capstone*. A total of 20 participants learned through a critical system administered with an underlying PBL philosophy. Subsequently, qualitative responses were provided by 19 students, based on which possible patterns were identified. The instructor of the course served as the facilitator.

Class Assignments

The students were provided with loosely structured open-ended tasks as assignments for the course CME 488. One of the projects titled *Napkin Sketch Project* required students to develop complete ideas of their own when divided into groups of four or five. Conceptualized ideas of a structure, based on the initial napkin sketch, were then transformed into CAD drawings, electrical, mechanical, and structural load calculations, schedules, and estimates by the group to form complete bid packages and turned in to the instructor under strictly enforced deadlines. The instructor played the role of the client and the different groups represented contractors who were competing for a bid. Existing building codes and cost schedules from North Dakota, Minnesota, and Iowa were used as guidelines while developing the bid packages and the groups presented their work to the class at semester's end.

Survey Instruments

The students were given the option to voluntarily fill out pre- and post-assessment surveys during the semester. The survey instrument used was CVF's model CVSS. According to Quinn, 6th edition (Quinn et al., 2014), different personality traits and complex actions can be categorized into four quadrant-based categories: *Collaborate, Control, Compete, and Create* (Figure 1a).

The upper left quadrant of the competing values framework marked as *Collaborate* reveals personality traits that lead people toward making connections and collaborations with others. Those excelling in this quadrant can maintain open and respectful communications because they tend to have better understanding of both themselves and others. These individuals are also effective conflict resolvers (Quinn et al., 2014).

The bottom left quadrant of the competing values framework marked as *Control* reveals the personality traits of maintaining stability and continuity. Those excelling in this quadrant can potentially become managers and effectively track whether colleagues are complying with rules and regulations. They are capable of managing varied tasks such as planning, coordinating data from various departments, and keeping up with minute details (Quinn et al., 2014).

The lower right quadrant of the competing values framework marked as *Compete* represents improvements in productivity and profitability. Those excelling in this quadrant understand an organization's vision as well as the environmental and external conditions under which tasks need to be fulfilled. Such individuals are task-oriented and work-focused, accept responsibility, and complete assignments in a timely manner (Quinn et al., 2014).

The upper right quadrant of the competing values framework marked as *Create* represents the ability to adapt to changes and acquire external support. Those excelling in this quadrant are mindful of changes in their surroundings and, moreover, can innovate and excel within existing trends (Quinn et al., 2014).

A person's inclination to exhibit traits of flexibility or control may influence the functionality of an organization, and improvement in performance sometimes depends upon organizational flexibility. Some organizations therefore engage in non-routine projects (Anantatmula, 2008) while, on the other hand, projects are often assigned with specific objectives and schedules to balance flexibility (Quinn, 2004). This quadrant-based assessment system can therefore reveal one's inclination towards flexibility or stability, but also one's inclination towards external or internal functions. Some individuals are more inclined towards internal tasks (accounting, operations management, and supply chain management) while others are conversely better at managing external activities (resources and funding) (Quinn, 2004).

The questionnaires consisted of 36 questions for self-assessment and another 100 questions for assessment by others. Students completed these questionnaires before and after PBL assignments and some open-ended questions were subsequently asked, with qualitative responses.

The four quadrants include five competencies each. A score was assigned to each competency, which in turn was calculated from average scores of five questions as answered by the respondents. These scores could range from 1 (Never) to 7 (Almost Always). Quadrant-based competencies have been shown in Table 1.

Statistical Analysis

Paired t-tests have been performed on the results from pre-test and post-test scores as prepared by the CVSS method. Analysis have been made by using SAS statistical software. A paired t-test is a statistical method, used to compare two population means. Assuming that the difference between the paired values is normally distributed, Student's t test is used to test the null hypothesis that the difference between population means is zero (Hsu & Lachenbruch, 2008).

Table 1: Competencies of Different Quadrants of CVSS (Quinn et al., 2014)

Collaborate *Creating and Sustaining Commitment and Cohesion*	**Create** *Promoting Change and Encouraging Adaptability*
Understanding Self and Others (USO)	Using Power Ethically and Effectively (UPEE)
Communicating Honestly and Effectively (CHE)	Championing and Selling New Ideas (CSNE)
Mentoring and Developing Others (MDO)	Fueling and Fostering Innovation (FFI)
Managing Groups and Leading Teams (MGLT)	Negotiating Agreement and Commitment (NAC)
Managing and Encouraging Constructive Conflict (MECC)	Implementing and Sustaining Change (ISC)
Control *Establishing and Maintaining Stability and Continuity*	**Compete** *Promoting Change and Encouraging Adaptability*
Organizing Information Flows (OIF)	Developing and Communicating a Vision (DCV)
Working and Managing Across Functions (WMAF)	Setting Goals and Objectives (SGO)
Planning and Coordinating Projects (PCP)	Motivating Self and Others (MSO)
Measuring and Monitoring Performance and Quality (MMPQ)	Designing and Organizing (DO)
Encouraging and Enabling Compliance (EEC)	Managing Execution and Driving for Results (MEDR)

Table 2: Competencies having Significant Improvements due to PBL and their P-values

Competency	p-value (α = 0.05)	Quadrant
Managing and Encouraging Constructive Conflict	0.0052	Collaborate
Mentoring and Developing Others	0.0170	Collaborate
Organizing Information Flows	0.0165	Control
Planning and Coordinating Projects	0.0129	Control
Designing and Organizing	0.0436	Compete
Fueling and Fostering Innovation	0.0390	Create

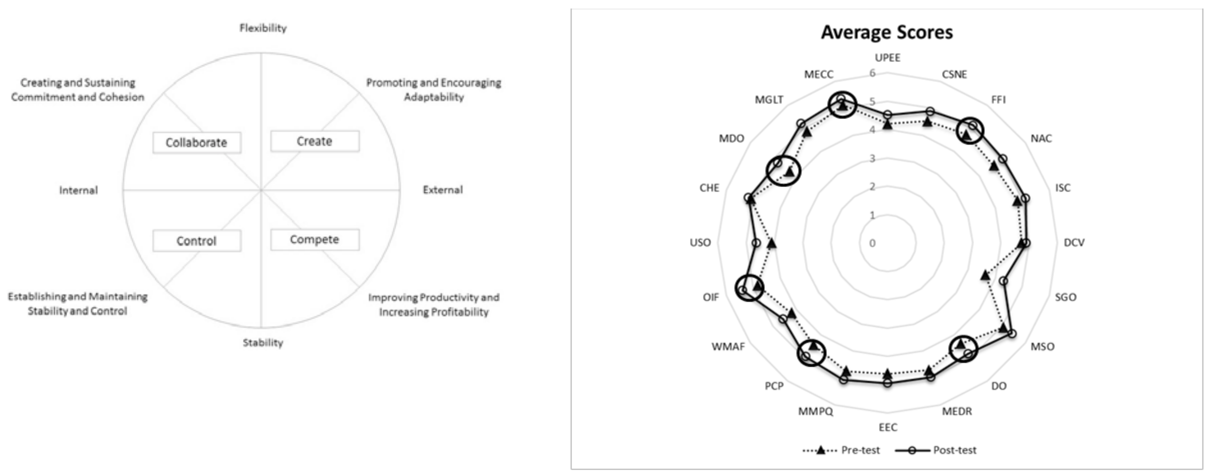

Figure 1: (a) Quadrant-based assessment system of CVSS (Quinn et al., 2014), (b) Pre-test and post-test average scores

Results and Discussion

As can be seen from Figure 1b, out of 20 competencies spread over four quadrants significant improvements were observed for six competencies when compared between pre-assessment and post assessment scores (marked by black circles). These improvements were statistically significant, as confirmed from the paired *t* test, with a 95% confidence interval (Table 2). A p-value lower than the α value (0.05) indicates statistical significance.

The initial hypothesis of improvements in collaborative skills was proved to be correct by the results (MECC and MDO from Figure 1b). However, the research also showed added soft skill growth in several quadrants. Out of six competencies two each were listed in *Collaborate* and *Control* quadrants, and one each was listed in *Compete* and *Create* quadrants of the CVSS profile. This PBL process appealed more towards internal rather than external competencies when the class is considered as a work unit. Students of the class may therefore be assumed to be best-trained toward critical functions of internal operation, teamwork, leadership, communication, and organizational skills as a result of PBL. On the other hand, overall inclinations of the class towards stability or control seemed to be well balanced.

Collaborate Quadrant

Significant improvements in two of the five competencies of this quadrant reveal that students in the capstone course become better collaborators because of PBL, developing traits enable them to work more cohesively with others and be better communicators. Open communication becomes possible because a state of mutual respect is developed among individuals. Mutual understanding, clear communication, and effective conflict resolution are indispensable for success in construction and other industries, and construction engineers and managers are expected to be leaders.

The development of mentoring relationships among groups is also very important in this industry, where a good leader is often a good mentor who in turn is often mentored by a more experienced individual. PBL in this study has evidently promoted at least conflict management and mentoring capabilities skills among students, and this effect is detected and quantified by CVSS.

3.1.1. Managing and Encouraging Constructive Conflict

The first significant competency in the Collaborate quadrant is Managing and Encouraging Constructive Conflict. Conflict is an inevitable reality among the ranks of the workforce in an organization (Tjosvold et al., 2014), may be destructive or constructive (Deutsch et al., 2011), and can be important in organizations to break the stagnancy and monotony of work groups. But while constructive conflicts can promote critical thinking and innovation (Rolih, 2013), destructive conflicts may potentially be devastating to individual team members.

One of the key factors for managing conflicts as discussed by past researchers is the definition of conflict itself (Rolih, 2013; Tjosvold et al., 2014). Conflict has often been confused with confrontations under conditions of opposing interests, or a lack of common goals among team members (Pondy, 1967), or with competition (Deutsch, 1973). However, conflicts can arise among team members with common interests and goals. For example, in a construction engineering setting, team members can interpret plans and specifications of a project differently and therefore may have different approaches to completing tasks. There may also be conflicts between team leaders and team members about such matters as work volume. Conflict management skills are therefore important for construction engineering and construction management graduates, and there is a consensus among past researchers that the path to conflict management is through open or open-minded communication (Rolih, 2013; Tjosvold et al., 2014). There needs to be a certain level of mutual benefit in decision-making for open communication to flourish among team members (Tjosvold et al., 2014), who also need some level of emotional intelligence to be effective conflict managers and promoters of constructive conflict (Schlaerth et al., 2013).

Since significant improvements in the competency pertaining to managing and encouraging constructive conflict were observed in the present study, it is evident that PBL is an effective promoter of such skills among students. Further, such changes in the personality of students could be well-quantified by CVSS analysis. In other words, the positive effect of PBL in managing and encouraging constructive conflict among construction engineering/management students could be detected, quantified, and analyzed in this work through CVSS.

3.1.2. Mentoring and Developing Others

The second competency in the Collaborate quadrant of CVSS that displayed significant improvement of post assessment over pre-assessment is Mentoring and Developing Others. Mentoring in classical terms can be defined as the relationship between a typically older, more experienced person and an inexperienced, typically younger person, where the mentor helps the mentee learn ways of navigating the world at work (Kram, 1985).

Recruitments in organizations may be made with different expectations: some recruits are expected to know basic theories related to the scope of work, while others are expected to have intricate experience in a specialized area (Quinn et al., 2014). This factor can be illustrated with an example from the construction industry. When a graduate construction professional is recruited into a firm, they will be expected to understand concepts such as plan reading, principles of estimating, and scheduling, while more experienced employees of the firm will help the recruit orient towards specific job responsibilities such as construction inspection and client relationships.

This process of providing help to the recruit to fulfill the overall goals of the organization will be termed “mentoring.” In this case, the mentor-mentee relationship will be very important to the firm’s future in maintaining client relations, ensuring quality construction, and bringing in more revenue, and this relationship depends solely upon the effectiveness of the transition of *knowledge* from the mentor to the mentee. However, if a position is being filled for a more specialized job position (e.g., project manager for a project), then the potential recruit will be expected to have years of experience in the specific field and even serve as a mentor to other members of the team. Researchers have identified mentoring abilities of employees as an important aspect of career development (Allen, 2003; Dreher & Ash, 1990), and attempts have also been made to understand the propensity to mentor others, and the relationship between prosocial personality characteristics and personal motives for mentoring others (Allen, 2003). Serving as a mentor was described as a key activity associated with the third stage of a four stage model of professional career development (Dalton et al., 1977), and this inclination to serve as a mentor has also been shown to depend on age (Allen et al., 1997).

Moreover, one’s empathy (the ability to relate to the concerns of others) also influences one’s inclination towards being a good mentor (Allen, 2003). In one study, greater psychological well-being was reported among more than half the study group due to natural mentoring relationships (Hurd & Zimmerman, 2014), and this psychological well-being among employees can potentially lead to greater developments of an organization’s productivity

(Masalimova & Nigmatov, 2015). It is therefore important that graduates from construction programs possess the personality traits to become effective mentors, and incline toward the development of others. It has been shown in this PBL study, the overall inclination of the students towards mentoring and developing others was significantly improved.

Control Quadrant

The results from this study have also shown significant improvements in the Control quadrant. Based on the paired *t* test results of the pre- and-post assessment of CVSS competencies, it is evident that PBL has caused a positive impact on those personality traits of students which are inclined toward maintaining stability and control in a work environment. These improvements will potentially help students organize and manage critical information, operations, and coordinate activities across multiple projects. These skills are expected from construction engineers and managers for effective functioning in the industry (Odusami, 2002).

3.2.1. Organizing Information Flows

Organizing Information Flows is one of two competencies showing significant improvement due to PBL in the Control quadrant. A huge amount of information is constantly produced in this era of digital technology, and it is estimated that in one year alone there is more data created than in all the books ever written and published (Quinn et al., 2014). As a result, there is a sudden, great need to manage this huge data overload. Effective employees are expected to screen useful information from the rest and there is a need to acquire data, organize it, and draw conclusions which can in turn be implemented to solve important problems within an organization.

From the perspective of a construction engineer or manager, one example of the need to organize information flow is when construction firms submit job bids. Employees are expected to create estimates based on quantity take off, find alternative materials and methods for serving the goals of the contract better, and to review designs. To take care of the above, one needs to collect information on existing construction techniques, find the cost of alternative materials, and consider environmental implications. This process requires one to collect information, organize it in a logical order and classification, and draw conclusions. Putting it into perspective, there are many small pieces of information that need to be collected and correlated to deliver a finished product. Therefore, it is important that construction professionals are equipped with skills for organizing information flow. Technical skills such as statistical analysis, scheduling, and estimating techniques may also play a key role in determining whether an individual is capable of managing and organizing information. While higher education stresses technical skillsets, the much-needed soft skills are sometimes lacking. PBL appears to address such areas related to people skills.

3.2.2. Planning and Coordinating Projects

Planning is one of the most essential elements in the smooth execution of a construction project. By its nature the construction industry requires engineers and managers to coordinate between different personnel who may belong to different departments, companies, agencies, and, in some cases, even countries. Several parties—contractors, sub-contractors, architect-engineers, and construction project managers—collaboratively work to fulfill the requirements of a construction project as required by the owner. The success of a construction project then depends upon the effective synchronization, alignment, and adjustment of contributions from the different parties involved (Bygballe et al., 2016). There are moreover different contractual relationships among these different parties that can complicate matters very quickly in case of disputes, if proper planning and coordinating is not done. The interdependent complexity of different parties involved in construction dictates specific methods of coordination (Bresnen, 1990), and much of the planning of tasks and delegating responsibilities to others and/or coordinating with other parties is dependent upon the people skills of those in construction and management. In this work, statistically significant improvements in the skills of the overall class to plan and coordinate projects have been observed (Table 2), and these improvements due to PBL could be effectively quantified by CVSS.

Compete Quadrant

PBL has also improved the competence and productivity-oriented personality traits of the class. These competencies focus a person's ability to complete their activities on time and clarify the understanding of the goals and visions of an organization. Moreover, competent people have a better understanding of their environment and resources. Typically, they are also aware of any constraints that can lead to the failure of the organization's goals. This study shows enhancement in this section.

3.3.1. Designing and Organizing

Significant improvement has been observed for the competency identified as Designing and Organizing (Table 2). A critical skill expected by professionals is the ability to clearly set expectations from team members and then designing and organizing the work accordingly (Quinn et al., 2014). This is an effort to ensure that overall productivity increases and this constant motivation of fellow team members may be achieved in part through the Plan, Do, Check, and Act (PDCA) cycle (Lincoln & Syed, 2011). Construction engineering and management students can often be trained in these technical aspects of productivity. However, the overall clarity of thought, instinctive understanding of surroundings, assessment of resources, and motivation of fellow employees through soft skills can be lost in an academic setting. The results of this study indicate that this can be instilled through PBL. The improvement of this competency among the students due to PBL has been quantified in this study through CVSS.

Create Quadrant

The Create quadrant of the CVSS instrument represents competencies that cause individuals to adapt to changes in their surroundings, possibly through innovating new ways of accomplishing tasks. Because of the dynamic nature of the construction industry, construction engineers and managers should have competencies that enable them to overcome them and adapt. This study has proven that PBL can further induce innovation-oriented competencies in students.

3.4.1. Fueling and Fostering Innovation

In the construction field, innovation affects the potential for economic growth (Blayse & Manley, 2004). Innovation can be defined as a novel change and improvement in a process, product, or system (Bygballe & Ingemansson, 2014) and, in the construction industry, novel changes may result from modifying certain technical aspects of the processes or management strategies (Slaughter, 1998). To bring about innovative management techniques, some level of outside-the-box thinking will be required of the employee and this spirit of promoting innovative change can be applicable to clients, construction managers, and designers. However, alternative construction methods may not be commonly anticipated by contractors or sub-contractors, who may be obligated to follow a set of specifications mainly compiled by the architect-engineer, client, or construction manager. Therefore, fostering an attitude geared towards such innovative practices among construction engineering and management graduates is important. The results show significant improvement in Fueling and Fostering Innovation competency due to PBL.

Conclusion

In this study, the Problem-Based Learning (PBL) technique was used in the capstone course CME 488 in the Construction Management and Construction Engineering program of North Dakota State University. The effects of PBL were assessed by the Competing Values Framework's (CVF) model and with the Competing Values Skill Surveys (CVSS). Out of the 20 competencies spread over four quadrants, significant improvements were observed for six competencies when compared between pre-assessment and post assessment scores. These improvements were statistically significant, as confirmed from paired *t* test (Table 2). The improvements in the six competencies were spread across two each in the Collaborate and Control quadrants, and one each in the Compete and Create quadrants of the CVSS instrument. This study has quantified the positive effects of PBL on the development of certain soft skills of students in the capstone course. The following are the specific conclusions from this study:

- Out of the twenty competencies, the students experienced significant improvements in six competencies. This improvement was assessed through self-assessment surveys administered before and after the semester's work involving problem-based learning (PBL)
- In the Collaborate quadrant, significant improvements were observed in two out of the five competencies. These were, Managing and Encouraging Constructive Conflict and Mentoring and Developing Others.
- Significant improvements in Managing and Encouraging Constructive Conflict competency signifies the ability of the subjects to effectively utilize professional differences of opinion among co-workers in a constructive manner to achieve the desired goals of the concerned project.
- Significant improvements in Mentoring and Developing Others competency indicates that the students can be better equipped to train, motivate, and empathize with junior co-workers and new recruits to ultimately influence retention capabilities of the concerned organization.
- In the Control quadrant, significant improvements were observed in two out of the five competencies. These were, Organizing Information Flows and Planning and Coordinating Projects.
- Significant improvements in Organizing Information Flows competency indicates PBL can help the students efficiently manage the flow of data and information, e.g., preparing bids, making schedules and estimates, projects control etc. in a logical order for successful completion of a construction project.
- Significant improvements in Planning and Coordinating Projects competency indicates PBL can help the students plan things in a logical and optimized order, multi-task between activities, and coordinate among personnel for successful implementation of a construction project.

- In the Compete quadrant, significant improvement was observed in Designing and Organizing competency.
- Significant improvement in the Designing and Organizing competency indicates that PBL can help the students organize tasks effectively. This can be achieved through overall clarity of thought, instinctive understanding of surroundings, assessment of resources, and motivation of fellow employees through soft skills.
- In the Create quadrant, significant improvement was observed in Fueling and Fostering Innovation competency.
- Fueling and Fostering Innovation competency drives the tendencies of a student to be involved in spearheading or participating and promoting in disruptive technologies which can improve the productivity of the construction process.
- One of the limitations of this approach is the long duration it takes to test a hypothesis.
- For future work, PBL can be used to teach other instructional and laboratory-based courses in engineering and other disciplines. Additionally, the impacts of this style of teaching can be assessed on technical skills specific to the discipline, in addition to soft skills.

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Mapping the Dynamics of Emerging Technologies Research Trends in Africa vis-à-vis Built Environment-Related Studies

Olusegun Aanuoluwapo Oguntona[1]

[1] Department of Built Environment, Walter Sisulu University, Butterworth, South Africa
architectoguntona12@gmail.com ooguntona@wsu.ac.za

Abstract
Compared to the conventional ones, emerging technologies (ETs) offer numerous benefits and potentials in the health and safety, digitalization, and sustainability of the construction industry (CI). To mitigate the adverse impacts of conventional materials and technologies on the human and natural environment, ETs are perceived as a panacea, especially in this fourth industrial revolution (4IR) era. However, the global research and development (R&D) focus and discourse on the subject of ETs is pioneered and is continually dominated by the developed or western countries. On the African continent, the uptake, implementation, and utilization of ETs remain in their infancy despite their potential in aiding the transition of the CI to a sustainable and 4IR-compliant sector. Hence, this study is aimed at analyzing and visualizing ET research publication outputs in Africa. A quantitative method was used to analyze the 60 bibliometric datasets extracted from the Scopus database. The datasets are ET research publication outputs from 1990 to 2022. The findings presented the trend, citations, document sources, co-occurring keywords, and most-cited ET research in Africa. The study recommends that African research and higher education (HE) institutions should embrace and commit to research, teaching, and learning on ETs to bridge the knowledge gap between Africa and the rest of the world.

Keywords
Construction Industry, Emerging Technology, Fourth Industrial Revolution (4IR), Africa, Sustainability.

1. Introduction

As indicated by Beach et al. (2013), the construction industry (CI) involves multiple professions and stakeholders making it data-intensive and highly fragmented. The complex nature of the sector and stakeholders' resistance to change is also responsible for its slow-paced transition from conventional construction practices to sustainable and innovative ones. In this present era of the fourth industrial revolution (4IR), it is believed that the infusion and implementation of innovative/emerging technologies (ETs) into the CI should top global priority. However, these technologies are characterized by some impediments and complexities. As indicated by Abdirad and Dossick (2016), these technologies are potentially costly, evolving, complex, and require extensive managerial and technical skills for their effective implementation. The study of Aghimien et al. (2020) also noted lack of training, high cost of training, high cost of technologies, and lack of digital culture as other impediments. Despite the obvious and numerous drawbacks of ETs, Day and Shoemaker (2000) posited their potential to create market opportunities and remake entirely the CI remains too attractive to discard. With the domineering and widespread influence of the 4IR on all sectors of the economy, the CI is left with no choice but to align with the trend.

The previous three industrial revolutions are instrumental and fundamental to the economic productivity and technological advances of the current 4IR (Oke & Fernandes, 2020). Despite the emergence of numerous technologies in the third revolution era, the 4IR give rise to an era of disruptive and high-level automation. Globally, the 4IR promises immensurable benefits and potential for the architecture, engineering, and construction (AEC) sector among others (Aghimien et al., 2020). The era has seen improvements in the efficiency and effectiveness of ETs and the birth of new ones. The area of application of these ETs now cut across all sectors ranging from education, defense, medical sciences, and most especially the AEC industry. To therefore maximize the potential of ETs to transform the CI, creating awareness and their integration into the built environment (BE) education and training are imperative (Keogh & Smallwood, 2021).

According to Veletsianos (2011), the utilization of ETs in any field provides opportunities for meaningful and relevant transformation. However, it is important to note that the realization of new/ETs evolves from existing technologies (Gupta & Jha, 2015). While these ETs dominate the face of the 4IR era, it is important to note that they will likewise define the influence and nature of the coming industry 5.0 on all sectors of the economy. Notable ETs defining the 4IR era include virtual reality (VR), augmented reality (AR), robotics, internet of things (IoT), artificial intelligence (AI), blockchain/distributed ledger technology, 5th generation (5G) networks, serverless computing, biometrics, vactrain, hoverbike, jetpack, personal rapid transit, autonomous rail rapid transit, self-driving car, genetic engineering, cryonics, quantum computing, mobile collaboration, 3-dimensional printing, unmanned aerial vehicles, artificial photosynthesis, wireless energy transfer, powered exoskeleton, sonic weapon, and concentrated solar power amongst numerous others (Maull et al., 2017; Wohlgenannt et al., 2020; Abdi et al., 2021; Ahmad et al., 2021; Dein, 2021; Xiong et al., 2021). The application of these ETs can be found in entertainment, energy, electronics, materials, textile science, optoelectronics, finance, agriculture, aerospace, medical sciences, space, transport, robotics, information technology (IT) and communications, and most especially the AEC industry (Kirkwood & Price, 2013; Gros, 2016; Kumar et al., 2019). Despite the disadvantages and ills associated with the use and implementation of some of these ETs, numerous research has established that their potentials are far-reaching while calling for massive R&D into ways of effectively and efficiently optimizing the ETs in circulation.

While there has been a massive drive and trend in the adoption, and utilization of ETs in developed countries, the continent of Africa and most developing nations lag due to numerous reasons. Hence, the need for a study that presents the present state and trend of ET awareness, adoption, and application in Africa, focusing on the AEC niche. The present study sought to ascertain the trend and development of research studies on ETs in Africa covering the period from 1990 to 2022. The literature search was conducted on February 28, 2022. To better characterize and grasp the pattern of Africa's research contributions and outputs on ETs with a focus on the built environment, a bibliometric analysis was conducted.

2. Research Methodology

The objective of this study is to ascertain the trend and cogent areas of concentration in research publications on ETs within the BE-related fields. Science mapping, which is a quantitative method was used in the study. According to Moral-Muñoz et al. (2019), science mapping is a bibliometric instrument for mining and analysis of scientific and scholarly outputs, productivity, and quality. Science mapping can help in presenting scientific and scholarly works in a format that can be used to aid the description, interpretation, or evaluation of the development and state of scientific and scholarly knowledge and practices (Chen et al., 2014). The cardinal composition of science mapping consists of scientific literature, scientometric, and visual analytic instruments and indicators for identifying cogent patterns for piloting the exploration of visualized intellectual structures (Chen et al., 2017). The terms "Emerging Technology" OR "Emerging Technologies" were used to search and retrieve the bibliometric dataset from the Scopus database. Scopus database was used due to its popularity, richness, and description as a top choice for literature search globally (Aghimien et al., 2019). It is also important to know that the Scopus database by Elsevier is highly subscribed to by most research and higher education institutions across Africa. Due to its simplicity and ease of use, the VOSviewer was used to visualize and present the bibliometric networks for this study. Depending on the choice and proficiency level of the user or researcher, there are other tools such as SciMAT, BibExcel, CiteSpace II, and CitNetExplorer which can perform the same function as VOSviewer.

The search for relevant research publications was focused on published conference proceedings, journal articles, book chapters, and books within the BE-related fields. The key search words adopted were "Emerging Technology" OR "Emerging Technologies". The subject area for the search was limited to engineering, energy, materials science, environmental science, and chemical engineering. The English language was adopted as the language selection because it is the predominant language for disseminating research publications in Africa. Search countries were limited only to the continent of Africa thereby excluding other continents/countries. The time component for this study was the period from 1990 to 2022. The decision to focus on this timeframe was to understand the historical trajectory and trend of ETs in Africa and the built environment. With the key search words used, an initial search result of 37,272 (consisting of results from every continent of the world) results was obtained for the search conducted on 28 February 2022. However, based on the refinements, exclusions, and limitations adopted in the search, a total of 60 publications were exported and adopted as the dataset for this study. The refinements, exclusions, and limitations include the following: the choice of English language as the language selection, subject area limited to BE-related fields, and most importantly the exclusion of countries from other continents except for Africa. Results are presented based on the number of publications per year, the number of publications and citations per country, publications per document source title, most cited publications, and research focuses based on co-occurring keywords. A pictorial representation of the research framework employed in this study is shown in Figure 1.

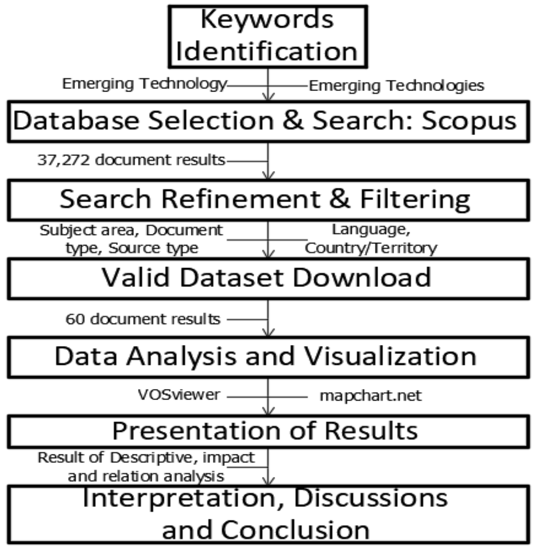

Fig. 45. Pictorial chart of the research framework

3. Results and Discussions

Trend in BE-related research publications on ETs from 1990 to 2022

A total of 60 research publications were extracted after the refinement and filtering process of the database search. Out of the 60 research publications extracted, seven (7) are book chapters, 21 are journal articles and 32 are conference articles. The number of yearly research publications on ETs in Africa from 1990 to 2022 (as of 28 February) is presented in Figure 2. Based on the result, there is no record that Africa produced any research publication on ET that is BE-related in 1990 while the period 1991 to 1994 and 1999 to 2004 recorded zero publication output as well. Compared to the rest of the world, especially the developed nations, the extremely low ET research publication output that is BE-related across Africa is a clear indication that Africa is far behind in the awareness, R&D, adoption, and implementation of ETs. According to Kissi et al. (2022), stakeholders in the BE face numerous challenges that prevent the adoption and implementation of ETs. A few of these barriers hindering the uptake of ETs are lack of awareness, paucity of ETs, lack of technical capacity on ETs, and most especially resistance to change on the part of stakeholders. It is therefore indicative that as the wave of digitalization sweeps across the global BE, Africa will be left with little or no choice but to embrace and align with the trend.

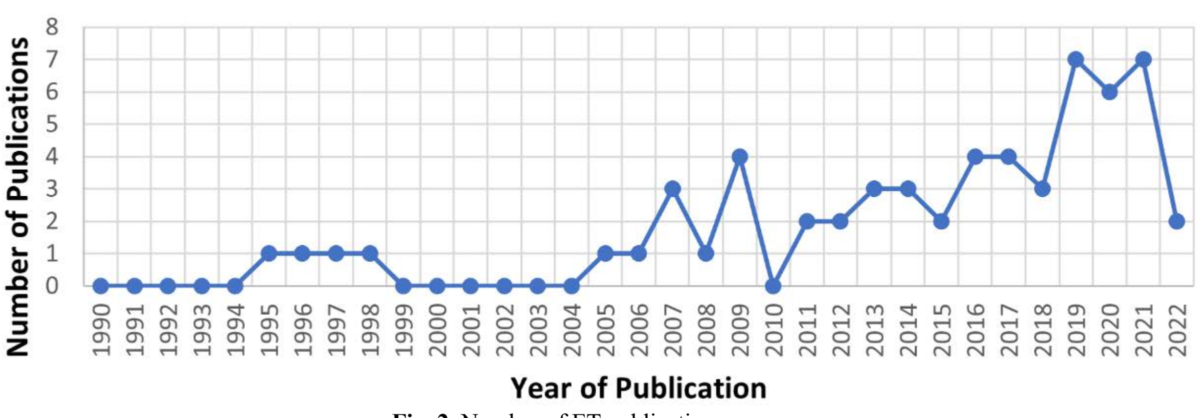

Fig. 2. Number of ET publications per year

Trend in BE-related research publications and citations on ETs per country

A total of 12 countries are found to have contributed to ET research publications that are BE-related across the continent of Africa. This result is based on the search criteria specifying only countries (owing to the low number of countries revealed in the result) with at least one ET research publication from 1990 to 2022. While most of these publications originated from one country, there are some affiliated with research and higher education institutions from other African countries and the rest of the world. Figure 3 presents the trend in research publications and citations on ETs that are BE-related per country. Based on the result, South Africa tops the chart (23 publications and 105 citations). This is followed by Egypt (9 publications and 153 citations), Tunisia (7 publications and 86 citations), Morocco (7 publications and 23 citations), Algeria (3 publications and 18 citations), Nigeria (3 publications and 1 citation), Mozambique (2 publications and 5 citations), Ethiopia (1 publication and 12 citations), and Zambia (1 publication and 2 citations). Benin, Sudan, and Zimbabwe all contribute one ET research publication with zero citations within the years in review. However, it is not surprising to see South Africa and Egypt topping the chart as both countries are at the forefront concerning R&D while they are also home to the top 10 best higher education institutions in Africa according to world university rankings.

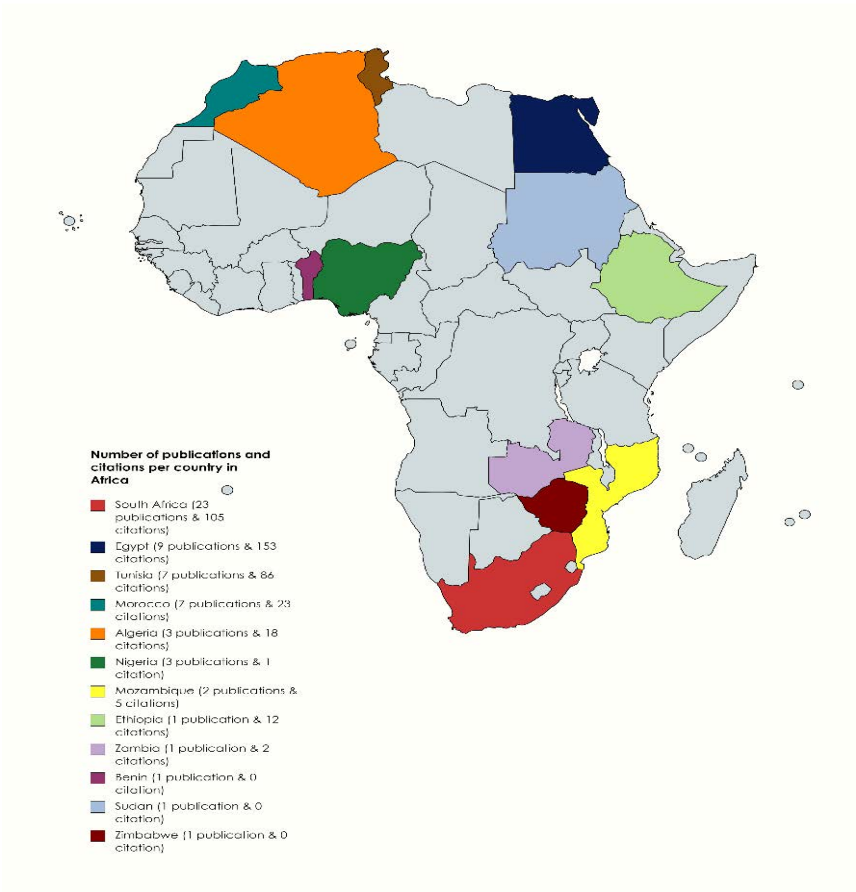

Fig. 3. Number of ET publications and citations per country

Trend in BE-related research publications on ETs per document source

This section presents the trend in BE-related research publications on ETs per document source. The dataset used in the study contains 60 research publications that are published in 54 different books, journals, and conference proceeding sources. Table 1 presents the result based on the search with document sources with at least two (2) BE-related research publications on ETs. Based on this criterion, three (3) document sources were revealed. Lecture Notes in Electrical Engineering topped the list with four (4) publications and six (6) citations. This result is not surprising as the subject area of this document source is industrial and manufacturing engineering published by Springer Nature.

Second on the chart is Materials Today: Proceedings (3 publications and 10 citations), and lastly Journal of Communications (2 publications and 11 citations).

Table 36. Number of ET publications per document source

Source title	Documents	Citations
Lecture notes in Electrical Engineering	4	6
Materials Today: Proceedings	3	10
Journal of Communications	2	11

Most cited BE-related research publications on ET

According to Zhao et al. (2020), the number of times a manuscript is cited is one of the yardsticks for judging its impact. Hence, the imperativeness of analyzing the dataset to identify the most cited BE-research publication output on ET. Table 2 presents the result showing the titles and authors of ET research publications with at least 10 citations. Out of the 60 publications that make up the dataset, only 12 have been cited for a minimum of 10 times as seen in Table 2. The publication titled "The living walls as an approach for a healthy urban environment" and authored by Sheweka and Magdy (2011) is the most cited BE-related research publication on ETs in Africa. The open-access article has 56 citations and is published in Energy Procedia by Elsevier. The study indicated that green vertical surfaces as one of the ETs have the potential to benefit the BE sustainably by directly addressing energy and climate change challenges. The study further states that the adoption and implementation of ETs can offer sustainable strategies for greening the urban environment. With the global call for sustainability especially in the AEC industry, ETs must be maximally embraced and implemented for a speedy transition of the industry to a sustainable one.

Table 2. Number of ET publications per document source

Title	Source	Citations
The living walls as an approach for an approach for a healthy urban environment	Sheweka and Magdy (2011)	56
Adsorption of a textiledye "indanthrene Blue RS (CI Vat Blue 4)" from aqueous solutions onto smectite-rich clayey rock	Chaari et al. (2009)	52
Translocation and accumulation of Cr, Hg, As, Pb, Cu and Ni by Amaranthus dubius (Amaranthaceae) from contaminated sites	Mellem et al. (2009)	52
RASID: Robust WLAN device-free passive motion detection	Kosba et al. (2012)	35
Performance of cement-slag-titanate nanofibers composite immobilized radioactive waste solution through frost and flooding events	Saleh et al. (2019)	23
Chromium and nickel removal from industrial wastewater using Tunisian clay	Ghrab et al. (2014)	18
Ripple reduction in DTC drives by using a three-level NPC VSI	Messaïf et al. (2007)	16
Recent trends in the cleaning of diesel fuels via desulfurization processes	Hanafi and Mohamed (2011)	16
Studies of lead retention from aqueous solutions using iron-oxide-coated sorbents	Boujelben et al. (2009)	13
Phytoremediation of chromium from tannery wastewater using local plant species	Kassaye et al. (2017)	12
Sustainable development: a conceptual framework for the technology management field of knowledge and a departure for further research	Brent and Pretorious (2008)	12
An overview of smart grid cyber-security state of the art study	Dari and Essaaidi (2016)	11

Trend in BE-related research publications on ET per co-occurring keywords

Keywords and relations among sets of keywords constitute the networks of co-occurring keywords (Darko et al., 2020). Co-occurrence of keywords creates an understanding of the instances where two or more keywords occur together. According to Wuni et al. (2019), keywords are necessary for indexing articles in databases because they reflect the theme of such publications. The study of Aghimien et al. (2019) stated that a proper clustering of keywords into themes can help in explaining focus areas of previous studies on the subject. With the aid of VOSviewer software, a keywords co-occurrence network was developed. The unit of analysis is set to all keywords, the type of analysis is set to co-occurrence, the counting method is set to full counting, and a value of three (3) is set which is the minimum number of occurrences of a keyword accepted based on the dataset loaded into VOSviewer. The analysis showed a total of 785 keywords for all 60 research publications that make up the dataset. Out of these keywords, 17 met the threshold of three (3) co-occurrences which were further categorized into four (4) themes/clusters. Based on the number of occurrences, total link strength, and tabulated in descending order, the 17 co-occurring keywords are presented in Table 3. According to Wuni et al. (2019), computing the Pearson product-moment correlation coefficient (r) between the number of occurrences and total link strength is an indication of a strong correlation between the indices. Therefore, the higher the occurrence of a keyword, the higher its chances of co-occurring with other frequently used keywords in ET research. The study of Zhang et al. (2020) amongst numerous other studies also subscribe and align with the same approach as used in this study.

Table 3. Number of co-occurring ET publications keywords

Keywords	Occurrences	Total link strength
Emerging technologies	26	28
Adsorption	3	17
Isotherm	3	17
Water treatment	3	17
Article	3	16
Chemicals removal (water treatment)	3	16
Solutions	3	15
Chromium	3	12
Wastewater	3	12
Wastewater treatment	3	9
Wireless sensor networks	4	6
Energy efficiency	3	5
Electric power transmission networks	3	3
Mobile telecommunication systems	3	3
Research	3	3
Wireless telecommunication system	3	3
Artificial intelligence	3	2

The network visualization map for co-occurring ET keywords is presented in Figure 4 as generated from VOSviewer. At the center of the map is the "emerging technologies" keyword to which all other keywords are linked. Cluster 1 (the green network of the map) contains 6 keywords namely artificial intelligence, electric power transmission networks, emerging technologies, energy efficiency, research, and wireless sensor networks. Cluster 2 (the red network of the map) also contains 6 keywords namely adsorption, article, chemicals removal (water treatment), isotherm, solutions, and water treatment. Cluster 3 (the blue network of the map) contains 3 keywords namely chromium, wastewater, and wastewater treatment. Cluster 4 (the yellow network of the map) contains 2 keywords namely mobile telecommunication systems and wireless telecommunication systems.

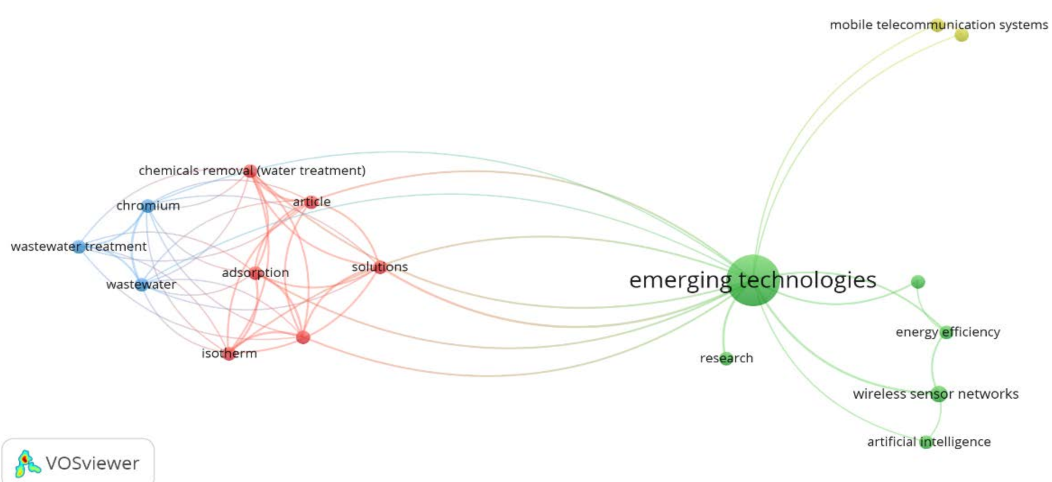

Fig. 4. Network visualization map for co-occurring ET keywords

4. Conclusion and Recommendations

This study sets out to identify the trend and research focus in BE-related ET research publication outputs using a bibliometric approach and with a focus on Africa. Based on the extracted dataset which are ET research publications indexed in the Scopus database between 1990 and 2022 (as of 28 February), the study has been able to understand the trend and key areas of concentration in ET-related research within the BE in Africa. Based on the findings, it can be concluded that the continent of Africa lags compared to the rest of the world with the R&D, adoption, and implementation of ETs. This is evident in the very low research publications on ET that are BE-related which emanated from Africa between 1990 and 2022. However, the highest number of publications of seven (7) recorded in 2019 and 2021 shows steady growth in the awareness level of ETs leading to the research output. With the current coronavirus (COVID-19) ravaging the world thereby forcing everyone to embrace technology and digitalization, it is believed that the AEC industry will be left with no choice but to massively embrace ETs for survival and to stay afloat. Out of the 54 countries that made up the continent of Africa, only 12 countries contributed to BE-related research publications on ET, namely South Africa, Egypt, Nigeria, Zambia, Zimbabwe, Mozambique, Tunisia, Morocco, Algeria, Ethiopia, Benin, and Sudan, representing 22.22%. This is extremely low if the African continent decisively intends to develop and thrive in this era of the 4IR.

While this study has been able to identify the state of ET adoption in the African BE, it is important and recommended that stakeholders in the industry alongside the African Union (AU), non-governmental organizations (NGOs), and other relevant governmental and inter-governmental agencies partner together to drive the digitalization of Africa. It is also recommended that further study is conducted to collect more data from other databases through web-scraping using text mining tools. This will ensure that BE-related ET research publications indexed in databases apart from Scopus are captured, extracted, and analyzed. Finally, it is recommended that massive investment should be directed towards the ET market, R&D, education and training, capacity development, awareness, and technology and knowledge transfer.

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Evaluating the relationship between Socio-Cultural Diversity and Collaboration among Project Teams in Johannesburg, South Africa

Adelegan Adeyeri Adewumi[1], Innocent Musonda[2], Chioma Okoro[3]

[1]Postgraduate School of Engineering Management, University of Johannesburg, Johannesburg, South Africa.
[2]School of Civil Engineering and the Built Environment, Department of Construction Management and Quantity Surveying, University of Johannesburg, Johannesburg, South Africa.
[3]School of Management, College of Business and Economics, Department of Finance and Investment Management, University of Johannesburg, South Africa.
adeyarey@gmail.com

Abstract
The built environment sector is characterised by collaborative working relationships, which are traditionally adversarial, fragmented and incapable of delivering for its customers. The diversity of teams partly contributes to projects not being initiated, executed, and completed within a specific scope of time, budget, and quality, since collaboration between individual and alliance members could be affected. There is limited literature evincing this relationship, which could contribute to improving project success. Therefore, the objective of the study was to establish the relationship between team members' attributes (including socio-cultural diversity, level of association, social interaction) and collaboration. A quantitative approach was adopted to conduct the study. The study amassed data using a questionnaire distributed among eighty respondents, comprising engineers, supervisors, foremen, contractors, project managers, and other decision-makers in engineering, construction, and consulting companies in Midrand, Sandton, and Johannesburg in South Africa. Inferential statistical analysis was undertaken using Pearson's correlation to examine the relationship between team attributes and collaboration. Findings revealed positive and medium to relatively high significant relationships between the variables, indicating that the more the level of association, diversity, and social interaction among team members, the more collaboration among them. The findings from the study are envisaged to be beneficial to construction and project managers in managing teams with diverse social backgrounds and orientations. It was concluded that team collaboration could be maintained even though high social and cultural diversity exists.

Keywords
Collaboration, construction industry, diversity, socio-culture, South Africa

1.0 Introduction

The construction industry, like many others, falls among the most critical sectors of the South African economy. However, it is also faced with decreased productivity due to poor technology and a shortage of skilled experts, among others (Valentine and Voster, 2012). In addition, the construction industry does not always hand over completed projects within the stipulated period, within the planned budget, and to the desired quality (Valentine and Voster, 2012). This is partly due to the level of collaboration among project participants. In recent years, advances in technology have underlined the need for project team members to effectively relate and collaborate amongst themselves (Rahman et al., 2013).

Effective collaboration between project teams and other stakeholders within the construction industry has many advantages: focusing on and achieving core competencies, sharing scarce knowledge and human resources, significant reductions in capital requirements, and high customer satisfaction (Akintoye and Main, 2008). Hence, the way forward towards improving the construction industry's efficiency is not limited to on-site teamwork alone; it also includes efficient collaboration and alliances among construction companies, suppliers, and clients through effective supply-chain management, Public-Private Partnership (PPP) and organisational joint ventures (Akintoye and Main, 2008). However, not all forms of construction project collaboration may be as productive or successful as expected, and clients still have a deep-rooted cost-driven agenda (Akintoye and Main, 2008). However, collaborative practices have been adopted in the manufacturing and service sectors and are increasingly advocated in the construction industry. Collaboration is found to be a suitable means of nurturing relationships among contracting parties, achieving better project performance and greater end-user satisfaction, optimum quality and service delivery (Ayegba et al., 2018).

Hence, ways to improve collaboration in the construction industry warrant consideration. Unsuccessful collaboration among project stakeholders may be caused by various factors such as weaknesses related to social and cultural diversity in the workforce. Human effort greatly determines the construction industry's productivity and success rates (Douma et al., 2000). With this in mind, in the context of South Africa, which encompasses a wide range of ethnicities and a significant number of skilled foreign contractors, all of whom bring their distinct cultural differences, ways of working and communicating to bring progress to the table is of paramount importance. How aspects of social and cultural diversity correlate to team collaboration within the construction sector in terms of the quality of interpersonal relationships and association among diversified staff at all levels and alliance organisations is an area that has been ignored in the literature.

1.1 The research problem

Based on the above, it is evident that the construction industry suffers from poor project delivery in terms of meeting specified time frames and budgets and construction-quality issues. Although many factors contribute to this issue, one of the critical determinants of construction project success is the extent to which individual project team members collaborate effectively, which, to a large extent, is based on social and cultural factors. Consequently, construction projects are likely to continue failing if poor collaboration among project team members remains an issue.

1.2 Research question

Therefore, the present study specifically examined how social and cultural factors affect team collaboration within South Africa's diverse construction industry workforce. This study sought to address the question: "Within the context of South Africa's construction industry, to what extent does its workforce's diversified social and cultural nature relate to work-based collaboration?" The gap in the literature is addressed by focusing on the strength and direction that social and cultural diversity takes in the quality of interactions among actors involved. The study was carried out in Johannesburg, South Africa, quantitatively.

2.0 Literature Review

Collaboration among project teams maximises efficiency, improves profitability, reduces waste, and thus contributes to more valuable relationships and enables benchmarking of current levels of practice against best-in-class performers (Ayegba et al., 2018). Collaboration is driven by top management commitment and mutual and shared understanding of the goals of cooperation and coordination (Gulati et al., 2012). Other factors are mutual trust, willingness to learn from and support others, clear definition of responsibilities, effective communication, complete integration, and risk and reward sharing (Ayegba et al., 2018). A higher degree of collaboration nurtures relationships among parties, achieving mutual benefits from set goals, thus leading to better project performance and greater end-user satisfaction (Wu et al., 2008; Ayegba et al., 2018).

Effectively managing people from different backgrounds and proclivities on construction projects is a difficult task, and in recent years, the construction/development sector has evolved by emphasising partnership between the public and private sectors, joint ventures and strategic alliances (Akintoye and Main, 2007). In reality, for any construction project team, one is likely to find individuals from many different backgrounds; inevitably, this has a significant impact on the project performance. One cannot underestimate the role that the labour force plays in determining the success of any organisation. Therefore, the construction management team must understand the importance of effectively running such cultural differences in their team members. Naturally, how well any group of people performs is highly dependent on the team's ability to effectively work together to achieve a common goal

(Akintoye and Main, 2007). Difficulties in managing people are especially prominent in the construction project environment because such projects bring together people from different organisations, either face-to-face or increasingly online, to complete critical tasks requiring them to be highly interdependent. A project team relates with external boundaries other than its immediate organisation, such as suppliers, clients, sub-contractors and other stakeholders involved (Sundstrom et al., 1990). The factors determining the effectiveness of a team are not limited to saddled responsibilities and tasks nor the overall objective for which the team is constituted, for example, individual abilities, leadership and decision-making strategies, interrelationships, interdependencies, individual satisfaction and fulfilment (Mbohwa and Edward, 2013).

Managing social and cultural diversity effectively within the construction industry can promote economic and political stability and success and boost employee and client satisfaction. In particular, the advantages of implementing effective socio-cultural diversity management include improved innovative creativity, better cooperation and attitudes towards work and colleagues, a more substantial commitment to work, better insights into the marketplace, more significant competitive advantage, and greater productivity (Wambui et al., 2013).

3.0 Research Methodology

3.1 Research strategy

The strategy to investigate the research questions was through quantitative research design, guided by the research gap and contribution (Trochim, 2006). Then, in-depth and critical analysis of the literature review to familiarise with the field of study and understand what other researchers have done concerning the topic of study (Trochim, 2006). The research process had to involve identifying the essential variables needed to gauge this effect. Diversity status was chosen as the independent variable and the level of collaboration as the dependent variable.

The approach involved compiling the questions from the literature in a structured survey questionnaire and using numerically ranked questions, where the participants' response to a statement asked in the questionnaire was indicated. The questionnaire was developed in sections containing the input and output variables. Input variables include the level of association as friends where questions such as having meals together (at least once a month) if one-third of them are friends, if they have worked on the same project in the past, and if they communicate informally after work non-project matters. The diversity variable includes the team's demographic composition within the organisations sampled. Questions in this group include consultation by project managers before decisions are taken, differences in age (less than 10 years), educational level, gender balance (more than 50% are male) and racial profiles. Lastly, on input variable groups is the level of social interaction among team members, with questions such as whether team members meet for social functions after working hours or at weekends and regularly communicate on instant messaging applications like WhatsApp, Facebook, and Twitter. The output variable includes communication media in use (site instruction book, verbal discussion, phone calls, E-mail, Instant messaging applications and written formal letters). In addition, interactions between alliance partners were grouped, that is, time taken to undertake request for inspections (within 24 hours), payment request, request for information; if a resolution of disagreement is made without invoking contractual provisions, if they normally reach consensus on-site problems such as cost or other claims and if the atmosphere in site meetings are cordial. The developed framework is presented in Figure 1. This guided the research and yielded an understanding of the participants' perceptions that were then analysed. With this in mind, two measures were used to check the accuracy of the data collected and analysed; the margin of error and confidence level (Ankrah, 2007; How to analyse questionnaire responses, 2017). Scaling of responses was done using Likert-type scale with weights ranging from 1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree and 5 = Strongly Agree.

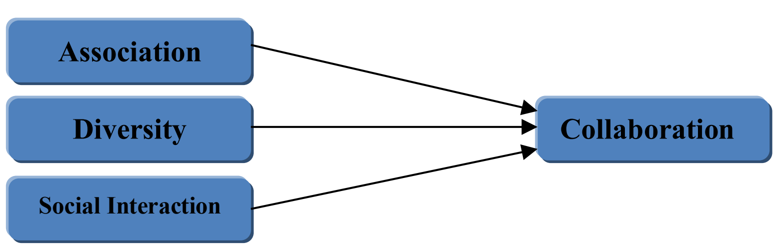

Fig. 1: Diagrammatic representation of input and output scales (Research model)

3.2 Population and sample

Sample selection for this research was made by searching for engineering, consulting and construction companies in selected Johannesburg suburbs. This heterogeneity research sampling was made around Midrand, Sandton and Johannesburg CBD, where construction work was ongoing to enhance variation in the perspective of respondents (Trochim, 2006). The researcher ensured that relevant respondents could give meaningful feedback on the topic under investigation within all organisations responsible for a successful construction project. The sample encompasses a range of people of different levels educationally, ethnicities, and ages to ensure internal validity and cover the social class and cultural background differences. It was also imperative to choose a representative sample size that accurately reflects the construction-sector workforce.

In this research, 254 questionnaires were sent out, to get 119 (sample size) questionnaires filled. However, 92 responses were recorded in total, out of which three (3) were not completely filled, rendering it void and 89 accurately completed responses were received, equating to a response rate of 35.04%. This response rate is considered positive when compared to other researchers' work, recording 27% and 13.5%, respectively (Ankrah, 2007; Idrus and Sodangi, 2010). In this research, the exercise schedule was crucial to increase the response rate.

3.3 Data analysis

The inputs were association, diversity and social interaction among team members, while the output was collaboration, as shown in figure 1. Data analysis was performed by correlation to determine the extent of the relationship between the input factors and collaboration. Information collected was gathered and populated in a spreadsheet, making it easier to get a tabular representation of all the responses. With the aid of filters, it was then possible to look at the response of each question or category of questions to draw up logical conclusions. After collection, the data were quantitatively analysed using SPSS (version 25). The survey questionnaire used was synthesised from the literature. It was tailored to obtain respondents' opinions, structured carefully to avoid leading questions, and reviewed to avoid irritating questions. The final questionnaire was distributed to relevant construction project team members in selected areas around Johannesburg, South Africa. Cronbach's Alpha test was performed to determine the reliability and validity of the variables (to ensure every question in each of the identified groups collects relevant information). A value of 0.8 validity is better, values range of 0.6 - 0.7 is considered acceptable (Pallant, 2013). In cases where the Cronbach's Alpha value was lower than the acceptable values, a report could be given on the mean inter-item correlation values, (recommended to be between 0.2 – 0.4) (Pallant, 2013). Further, the internal validity and reliability report shows consistency in the questions in each group on the input and output scales, ranging from 0.73 to 0.8 for the association in the collaboration scale. Mean inter-item correlation values were used for diversity and social interaction scales with 0.22 and 0.23 values, respectively, indicating good consistency.

Pearson correlation was then used to examine the relationships between the input and output variables. Pearson's correlation coefficient is expected to be between -1 to +1 (Pallant, 2013). This means that a correlation coefficient value of 0 depicts no linear relationship between the tested variables, while a -1 value means as one of the variables decreases, the other increases. Also, +1 correlation values depict that the relationship between the variables is that one variable increases as the other increases. In addition, the significance value (p) of less than 5% implies a relationship between the variables (Pallant, 2013).

4.0 Results

4.1 Relationship between socio-cultural diversity and collaboration

This part of the study presents the results of the questionnaire. The main areas focused on were the team members' interrelationships in construction site projects, how their association with one another is achieved, how their diverse social and cultural characteristics alongside social interaction relate to collaboration among individuals and other participating collaborators. The result of the correlation analysis performed was also tabled below.

4.2 Findings on the relationship between diversity and collaboration

The team members' association as friends, diversity and social interaction was considered, as this would help determine if differences in the demographic structure of the organisation allow individual members to relate better on the project and non-project matters. From table 1 below, the relationship between team members' diversity on collaboration had a medium positive 0.323 (p=0.002) relationship with the level of association as friends (Tassoc). A positive and relatively strong value of 0.574 was found between their demography and collaboration (Tdiverse) (p= 0.000), and a medium strength of 0.318 (p= 0.002) between collaboration and team members social interaction (Tsocialint). These positive and medium to relatively high relationships indicated that the more diversified the team members are, the more collaboration exists among them. These results indicate a significant relationship between the variables, giving the direction and strength of such relationships.

Table 1: Relationship between team members' association, diversity, social interaction and collaboration

		Tassoc	Tdiverse	Tsocialint	Tcollab
Tassoc	Pearson Correlation	1	.200	.370**	.323**
	Sig. (2-tailed)		.060	.000	.002
	N	89	89	89	89
Tdiverse	Pearson Correlation	.200	1	.194	.574**
	Sig. (2-tailed)	.060		.068	.000
	N	89	89	89	89
Tsocialint	Pearson Correlation	.370**	.194	1	.318**
	Sig. (2-tailed)	.000	.068		.002
	N	89	89	89	89
Tcollab	Pearson Correlation	.323**	.574**	.318**	1
	Sig. (2-tailed)	.002	.000	.002	
	N	89	89	89	89

** Correlation is significant at the 0.01 level (2-tailed).

5.0 Discussion

The project team members' diversity was assessed through various aspects including the demographical (socio-cultural) differences within the organisation that could impact the behaviour of individuals. Team members' diversity was measured through consultation by managers with subordinates before decision-making, the age difference of team members participating in projects, gender profile, education level and racial profile of team members. Diversity reflects the multiplicity of demographic features present in an organisational workforce, especially race, age, sex, origin, culture, religion and capability or disability (Dessler, 2011; Jones and George, 2011).

First, the assessment of whether project manager consults before making a decision revealed significant consultation by managers before decision-making. This is in line with previous research that every member within the team has unique skills and values, which differs; consultation improves leader-subordinate relationships in the workplace (Wambui et al., 2013). Individuals' contribution to the organisation's objectives or project's success brings satisfaction. Consultation could also be in the form of allocation of responsibility and project managers' interactions with project team members, resulting in improved communication (Wambui et al., 2013).

Concerning the age difference, the data acquired confirmed that the age difference among the members was small, below 10 years. This age gap has no impact on the level of relationships when it comes to projects. This aligns with the literature that age has no impact on official responsibility (Chileshe and Haupt, 2010). Although team members might not relate well outside work due to age differences; they relate better with colleagues within their age bracket (Chileshe and Haupt, 2010).

Further, the results showed that a high percentage believes there are wide educational differences in terms of educational differences. The graduate category represents the majority, while other educational categories are the minority, such as those with certificate training and informal educational certificates. This is expected in the engineering, consulting and construction industries.

Further, considering gender as an essential dimension relating to organisational culture, a wide gender balance was evident from the result of the survey conducted as participants supported that males dominate the construction industry. This is in line with findings that men account for 99% of the construction industry personnel over their female counterparts (Williams, 2015). It is also in tune with findings of previous researchers saying women have a lower percentage in the construction industry, accounting for only (if not less than) 3% of the construction and extraction workforce as of 2015 (Stephenson, 2017). This could be because tasks in construction are mostly physical, and this requires younger, active males.

The racial profile showed that every race was fairly represented on construction projects. Therefore, the racial profile was proportionally balanced, as most participants believed that blacks are more than other races and most blacks are from South Africa, the highest racial population in the Republic (Statistics South Africa, 2012). However, many other races are involved in construction projects, and many are from abroad, such as expatriates or online support members (Green, 2002). This connotes that team members are from different races and ethnicity and are dedicated to achieving common construction project objectives.

The result presented above shows that team members collaborate well despite their diversity in cultural characteristics and social class or level. This is in line with the literature that there is a need for team members to collaborate and manage workplace diversity as this helps develop higher competitive advantages, and managers must acknowledge this.

6.0 Conclusion and Recommendations

The study aimed to determine how social and cultural diversity relates to collaboration within South Africa's socially and culturally diversified construction-sector workforce. It was concluded that a significant relationship exists between the project team members and alliance partners. There is a good association between friends and social interaction among team members in the construction industry. The findings reveal that people can relate well in construction projects regardless of their social class, status or cultural background. The medium to high strength of the results demonstrated the quality of collaboration among alliance partners. In other words, social and cultural diversity is not a significant hindrance to establishing a close relationship or collaboration among the project team members and partnering firms in Johannesburg.

From the results and analysis conducted, several recommendations could be made in connection to the objective of the study:

1. Even though individuals on projects within the construction industry relate well and collaborate to achieve their common goals, it is imperative to educate individuals on identifying and appreciating different aspects of cultural diversity. People must learn to respect others and their cultural beliefs.
2. In order to attain project delivery efficiency, it is necessary to promote factors of collaboration, which include trust and communication. Collaborating parties also need to assess the extent to which they are willing to participate in the alliance. Other participating members must be strategically weighed/assessed and trusted to become part of the alliance regarding the expected benefits and the risks involved.
3. Further studies on improving collaboration in the construction industry can be conducted using a larger sample.

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Variation Orders Add or Non Value Add- A Case of South Africa

Ulunji Msiska[1], Nokulunga X Mashwama[2], Didibhuku Thwala[3]

[1] Department of construction management and quantity surveying, University of Johannesburg, Johannesburg, South Africa.
[2] SARChI in Sustainable construction management and Leadership in the built environment, Faculty of Engineering and the built environment, University of Johannesburg, South Africa
admin@umconsultants.co.za, schwalicious@gmail.com

Abstract
Construction project rarely reach completion stage without variation orders being issued by the client's representative, and variation orders can be good and bad for the project. Moreover, variation orders cannot be avoided completely, they can be minimised or prevented if their origin and causes are clearly known. The greater the knowledge and awareness of non-value adding activities associated with variation orders, the greater the prospect of their avoidance and consequent reduction of overall construction delivery costs. This paper focuses on variation as a value add or wastage. Quantitative approach was adopted for this study, structured questionnaires were distributed online and 159 were received and analysed. The questionnaire was distributed to various construction professionals and contractors. Factor analyses was conducted, correlation matrix, coefficients has also been conducted to ensure visibility of co-effincients greater than 0.3 and Kaiser- Meyer- Oklim (KMO) and Bartletts were conducted. From the study it transpired that waste of time, which resultant more labour charges, waste due to wrong use of material or wrongly specified, time and cost reduction, waste of material after demolition of a portion of work, compensation waste of resources such as unnecessary increased project budget, waste due to uneconomic use of machinery or lying idle on site due to change orders were the non value add of the variation orders. This non value add variation orders affect the productivity of construction projects. Therefore, proper channels of communication and planning should be in place, to reduce the occurrence of variation orders in construction projects.

Keywords
Demolition, Idle, labour, Materials.

2. 1. Introduction
Variation orders are any modification to the contractual guidance that are issued to the contractor by the client or clients representative (Arai & Pheng, 2005, Alhilli & Rezoqi, 2021). Variation orders often involve additional cost and disruption to work under way, leading to cost and time overruns (Bower, 2000). According to a study conducted in Kuwait by Koushki, Al-Rashi & Kartam, (2005), revealed that a number of variation orders issued during the construction phase has led to both delays and cost increases. In their study they further confirmed that, the project under investigation incurred more than 58% time delay and cost increases due to variation orders (Koushki et al. 2005). There are some unusual circumstances where variations costs accounted for as much as 100 percent more than the budgeted funds, the industry norm has been determined to be 10 percent (Arain & Pheng , 2005). According to a study done by Oladapo, (2007) regarding variation orders in construction projects, they found that variation orders contributed to the average cost escalation of 7% and 30% time extension more than the original project duration. Moreover, the ocurrence of variation orders seems inevitable in developing countries, where infrastructure and buildings are being upgraded with newly built ones including the constant change in the market. In-addition, Love , et al, (2019), noted that a degree of change should always be expected as it is difficult for clients to visualise the end product they procure. Although, it is likely that variations orders cannot be avoided completely, they can be minimised or prevented if their origin and causes are clearly known (Mohamed, 2001, Khalifa & Mahamid, 2019). The greater the knowledge and awareness of non-value adding activities associated with variation orders, the greater the prospect

of their avoidance and consequent reduction of overall construction delivery costs. There are variation orders which may be seen as counter to the likelihood that they become time consuming and costly elements on construction projects (Mohamed, 2001 and Khalifa & Mahamid, 2019). Therefore, success in managing variation orders results in uninterrupted construction operations and agreed project costs as well as durations (Khalifa & Mahamid, 2019).

2. Variation contributing to wastage

Wastage has various meaning in the construction space, very often wastage has been referred to as a physical loss of material occurring during the construction process (Osman, Omran & Foo, 2009). Some authors defined waste beyond physical losses of materials. Memon, Rahman & Hasan, (2014), defined waste as anything that adds no value to producing the required services.

2.1 Waste associated with variation orders

The paradigm of waste in construction has various meanings depending on one's point of view. Very often, waste has been referred to as physical losses of material occurring during the construction process.Osman, Omran & Foo, (2009), argued that most studies on waste are based on the conversion model in which material losses are considered to be synonymous to waste. According to Osman, Omran & Foo, (2009), waste is defined as any inefficiency that results in the use of equipment, materials, labour, or capital in larger quantities than those considered as necessary in the production of the building. However, it should be understood that the contractor recognises allowable waste as the percentage for losses of material allocated to bill rate components by the estimator at tender stage and it varies from one material to another. For example, stockpile material such as sand and gravel may be allocated a higher percentage while countable material such doorframe, may be allocated null waste Memon, Rahman & Hasan, (2014). Unfortunately variation orders contribute to the occurrence of wastage of material such as cement that hardens in the stores following an instruction to suspend work. This item is mostly overlooked and not allocated to the variation order account and the contractor suffer the loss. Waste of materials resulting from variation orders may occur in the following circumstances:

1. Compensating waste arising when material ordered for one specific purpose is used for another. For example, face bricks ordered for external wall erection may be used for internal plastered walls when there is a shortage of common bricks, or change of specification like installing shopfront instead of bricks.
2. Waste due to the uneconomic use of plant arising when the plant lies idle on site as a result of a variation order. Memon, Rahman & Hasan, (2014), estimated the waste for non-productive use of resources at more than 10% of a project's production cost.
3. Waste of materials due to incorrect decision, inconsistence inspection of works by the project consultant.
4. Waste of materials after demolition of a portion of work caused by the variation order to change a trade. For example, waste for breaking a wall to accommodate a window.
5. Waste due to wrong use of material or waste stemming from materials wrongly specified.

2.2 Non value add variation orders

According to Koushki et al. (2005) a significant cost and time reduction can result if a complete design is presented to the client before commencement of construction work. Whenever a variation order is issued, whether leading to additions, alterations, omissions or substitution, unnecessary costs are likely to be incurred. Construction professionals should be able to determine and quantify non value adding cost associated with variation orders. The realistic quantification of such costs is problematic due to lack of appropriate techniques for their measurement. In practice, non value adding cost which arises from variation orders are then transferred to the client and most of the time are underestimated. For example, one may be able to calculate the costs of aborted works, but non value adding cost arising from non-productive time, redesign and overheads are not attributed to such an activity (Koushki et al. 2005).

Furthermore, Alhilli & Rezoqi, (2021), indicated that every time a task is divided into two subtasks executed by different specialist, non value-adding activities increase. By uncovering non value adding activities arising from variation orders it is possible to take proactive measures to reduce them. A clear understanding of variation orders and subsequent waste is possible if they are categorised by their origin and identification of possible waste zones. Alhilli & Rezoqi, 2021suggested a framework formation of waste and value loss that takes into account the following:

- Waste and value loss
- Factors causing loss and
- Root causes

Similarly, when a variation order is issued, numerous non value adding activities/ costs are likely to arise. These include unplanned site meetings, travelling and communication expenses, idle plant and labour during the waiting time, demolitions, time taken by the designer to understand the required change and redesign, cost and time for litigation in case misunderstanding arises between the contractor and the client or his/her consultant. These represent a waste of resources and are typical paid for by the client. Variations orders do not only affect project performance in terms of time and cost, they also adversely affect the quality, health and safety and professional relations (Arain & Pheng, 2005). Factors influencing the occurrence of variation orders and their adverse impact on project performance vary from one project to another. Factors include the nature of works, the complexity of the project and the procurement method. The integration and implementation of the new trend technology may reduce the occurrence of variation orders on construction project. Digital technology will reduce the occurrence of variation orders, improve productivity, improve safety, improve professional relations among stakeholders and will encourage the usage of limited resources wisely.

3. Methodology

Quantitative approach was adopted for this study. The data was collected through primary and secondary sources, 159 structured questionnaire were received from the construction stakeholders which were then analysed. A five point Likert scale was used to determine the impacts of variation orders on construction projects. The adopted scale was as follows: 1= To no extent, 2= Small extent, 3= Moderate extent, 4=Large extent, 5= Very large extent. The computation of the mean item score (MIS) was calculated from the total of all weighted responses and then relating it to the total responses on an aspect. After mathematical computations, the criteria were then ranked in descending order of their mean item score (from the highest to the lowest). The test of hypothesis was conducted through the factor analysis. These include the assessment of the suitability of data for analysis; Correlation matrix coefficients to ensure visibility of coefficients greater than 0.3, Kaiser-Meyer- Olkim (KMO) and Bartlett 's test was conducted. Kaiser's criterion used as it applies the eigenvalue rule to eliminate and extract factors. Any factor with eigenvalue which was less than one (1) was eliminated and greater than one (1) was retained.

4. Results

4. 1 Descriptive analyses

Table 1 present the variation order factors that contribute to wastage on construction performance in South Africa. The factors were tested for validity and internal reliability. A five point Likert scale was used where: 1= To no extent, 2= Small extent, 3= Moderate extent, 4=Large extent, 5= Very large extent. Certain abbreviations and number of range were established to present results outcomes accordingly. Table 1 below indicate the variation orders that contribute to wastage on construction performance: Waste of time, which results in more labour charges was ranked first with (mean (M)=4.81; Standard deviation (SD)= 0.493; Cronbach alpha (α)= 0.945; Rank (R)=1); Waste due to wrong use of material or wrongly specified with (M=4.74; SD=0.705; α=0.939; R=2); Time reduction with (M=4.73 ; SD=0.752; α=0.940; R=3); Reduction in cost with (M=4.72; SD=0.737; α=0.939; R=4); Waste of material after demolition of a portion of work with (M=4.72; SD= 0.684; α=0.942; R=4). Compensating waste of resources such as unnecessary increased project budget with (M=4.72; SD= 0.657; α=0.949; R=4); Waste due to uneconomic use of machines (machines lying idle on site) with M=4.70; SD=0.612; α=0.942; R=5); Material wastage due to incorrect decisions with (M=4.67; SD=0.689; α=0.937; R=6); Waste reduction with (M=4.67 SD= 0.743; α=0.944; R= 6).

Table 1. Variation order contributing to wastage

Item	Description	N	Mean	Std. Deviation	crobach's alpha	Rank
E18.6	Waste of time, which results in more labour charges	159	4.81	0.493	0.945	1
E18.5	Waste due to wrong use of material or wrongly specified	159	4.74	0.705	0.939	2
E19.3	Time reduction	159	4.73	0.752	0.940	3
E19.1	Reduction in cost	159	4.72	0.737	0.939	4
E18.4	Waste of material after demolition of a portion of work	159	4.72	0.684	0.942	4
E18.1	Compensating waste of resources such as unnecessary increased project budget	159	4.72	0.657	0.949	4
E18.2	Waste due to uneconomic use of machines (machines lying idle on site)	159	4.70	0.612	0.942	5
E18.3	Material wastage due to incorrect decisions	159	4.67	0.689	0.937	6
E19.2	Waste reduction	159	4.67	0.743	0.944	6

4. 2 Exploratory Factor Analyses

Nine variation orders factors that contribute to wastage were subjected to exploratory factor analyses (EFA). Table 2 revealed the presence of correlation matrix of nine variables. All nine factors were less than one (<1) and were considered to be strong variables. Correlation co-efficient have been conducted to ensure visibility of co-efficient greater than 0.3 and there were quite a number of correlations greater than 0.3 tentatively suggests that the factor analysis was appropriate (Hooper, 2012).

Table 2. Variation order contributing to wastage

Correlation Matrix										
		E18.1	E18.2	E18.3	E18.4	E18.5	E18.6	E19.1	E19.2	E19.3
Corre	E18.1	1.000	0.735	0.703	0.529	0.538	0.557	0.504	0.492	0.561
	E18.2	0.735	1.000	0.896	0.666	0.689	0.612	0.618	0.561	0.637
	E18.3	0.703	0.896	1.000	0.788	0.790	0.712	0.718	0.651	0.695
	E18.4	0.529	0.666	0.788	1.000	0.929	0.765	0.639	0.552	0.592

l a t i o n	E18.5	0.538	0.689	0.790	0.929	1.000	0.825	0.691	0.620	0.656
	E18.6	0.557	0.612	0.712	0.765	0.825	1.000	0.622	0.518	0.579
	E19.1	0.504	0.618	0.718	0.639	0.691	0.622	1.000	0.893	0.926
	E19.2	0.492	0.561	0.651	0.552	0.620	0.518	0.893	1.000	0.879
	E19.3	0.561	0.637	0.695	0.592	0.656	0.579	0.926	0.879	1.000

Table 3 below represents the Kaiser-Meyer-Olkin (KMO) with the value of 0.867, which was beyond the anticipated value of 0.6 (Kaiser, 1960), and the Bartlett's test of sphericity (Bartlett,1954) reached statistical significance of 0.000 ($p<0.05$), supporting the factorability of the correlation matrix with a degree of freedom of 36.

Table 3. Variation order contributing to wastage-KMO and Bartlett's test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.867
Bartlett's Test of Sphericity	Approx. Chi-Square	1751.526
	df	36
	Sig.	0.000

Table 4 shows the anti-image matrix of correlation as a measure of sampling adequacy (MSA) which was beyond 0.5 as the indication of the factorability of the data set.

Table 4. Variation order contributing to wastage-anti image correlation

Anti-image Matrices									
Anti-image Correlation									
	E18.1	E18.2	E18.3	E18.4	E18.5	E18.6	E19.1	E19.2	E19.3
E18.1	.905[a]	-0.316	-0.092	-0.061	0.149	-0.233	0.214	-0.097	-0.203
E18.2	-0.316	.844[a]	-0.702	0.157	-0.144	0.125	0.073	0.116	-0.137
E18.3	-0.092	-0.702	.874[a]	-0.283	0.050	-0.116	-0.169	-0.093	0.110
E18.4	-0.061	0.157	-0.283	.842[a]	-0.761	0.089	-0.088	0.132	0.074
E18.5	0.149	-0.144	0.050	-0.761	.829[a]	-0.456	0.068	-0.163	-0.079
E18.6	-0.233	0.125	-0.116	0.089	-0.456	.903[a]	-0.183	0.182	0.053
E19.1	0.214	0.073	-0.169	-0.088	0.068	-0.183	.853[a]	-0.431	-0.626
E19.2	-0.097	0.116	-0.093	0.132	-0.163	0.182	-0.431	.905[a]	-0.269

E19.3	-0.203	-0.137	0.110	0.074	-0.079	0.053	-0.626	-0.269	.878[a]
a. Measures of Sampling Adequacy(MSA)									

Table 5 shows the communalities of the variables after extraction and were above the acceptable 0.3 value (Field, 2000).

Table 5. Variation order contributing to wastage- communalities

Communalities		
	Initial	Extraction
E18.1	0.598	0.473
E18.2	0.837	0.673
E18.3	0.887	0.838
E18.4	0.879	0.695
E18.5	0.908	0.775
E18.6	0.719	0.617
E19.1	0.905	0.734
E19.2	0.827	0.612
E19.3	0.885	0.706
Extraction Method: Principal Axis Factoring.		

Table 6 shows the total variance explained of the variation order factors that contribute to wastage on construction performance and it revealed one components which had eigenvalue of above 1 namely: (6.430). The components eigenvalues defined 71.448% of the total variance before the rotation and 68.045% after the rotation. The Kaiser eigen value which is greater than 1 was retained for interpretation (Fabrigar, et al. 1999). The total of nine variable were strengthen by a scree plot test (Pallant, 2013). The results indicated the variables which clearly defined the variation order factors contributing to wastage on construction performance.

Table 6. Variation order contributing to wastage- total variance explained

Total Variance Explained		
Factor	Initial Eigenvalues	Extraction Sums of Squared Loadings

	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	**6.430**	71.448	**71.448**	6.124	68.045	68.045
2	0.978	10.865	82.313			
3	0.710	7.891	90.204			
4	0.333	3.696	93.900			
5	0.221	2.459	96.360			
6	0.123	1.364	97.723			
7	0.094	1.041	98.765			
8	0.059	0.657	99.422			
9	0.052	0.578	100.000			
Extraction Method: Principal Axis Factoring.						

Table 7 indicates the factor loading of the variation order factor contributing to wastage on construction performance. The total of nine variables loaded on one components, since only one factor was extracted the solution cannot be rotated any further. Moreover, the results were strengthened by a scree plot test below figure 1 (Pallant, 2013). The results indicated the variables which clearly defined the impact of variation order on construction performance.

Table 7. Variation order contributing to wastage- factor matrix

Factor Matrix[a]	
	Factor
	1
E18.3	0.915
E18.5	0.880
E19.1	0.857
E19.3	0.840
E18.4	0.834
E18.2	0.820

E18.6	0.786
E19.2	0.783
E18.1	0.688
Extraction Method: Principal Axis Factoring.	
a. 1 factors extracted. 4 iterations required.	
Rotated Factor Matrix[a]	a. Only one factor was extracted.
The solution cannot be rotated.	

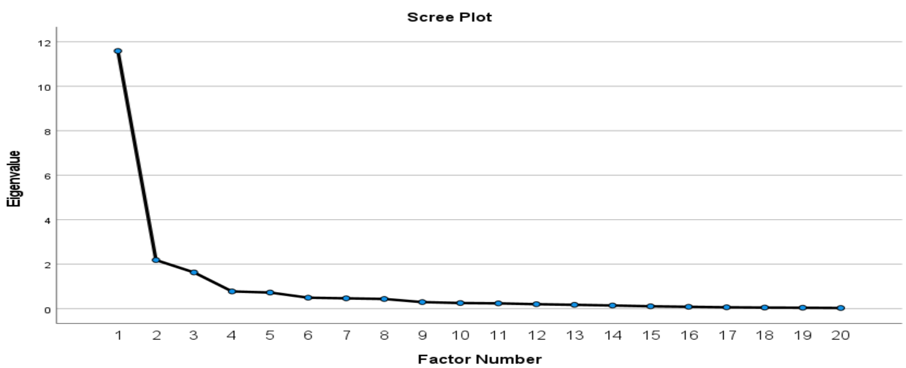

Figure 1. Scree plot for variation order contributing to wastage

4. 3 Validity of variation orders contributing to wastage

Principal component analysis (PCA) criteria were used to test the validity of the factors of variation orders that contribute to wastage. The observed variables were compensating waste of resources of which increased project budget unnecessarily; waste due to uneconomic use of machines (machines lying idle on site); material wastage due to incorrect decisions; waste of material after demolition of a portion of work; waste due to wrong use of material or wrongly specified; waste of time, which results in more labour charges. The factors showed a number of correlation greater than 0.3 which tentatively suggest factor analysis to be appropriate. Empirical reliabilities to determine the validity and reliability of the factors (Hooper, 2012).

5. Conclusion

Variation orders contribute to wastage on construction projects through compensating waste when material ordered for one specific purpose is used for another. For example, facing bricks ordered for external wall erection may be used for internal plastered walls due to change in specification. Furthermore, the waste due to the uneconomic use of plant arising when the plant lies idle on site as a result of a variation order. Moreover, waste of materials due to incorrect decision, inconsistent inspection of works by the project consultant, in addition, waste of materials after the demolition of a portion of work caused by the variation order to change trade. Therefore, good communication and planning must be key to all stakeholders involved in a construction project in reducing variation order. Planning has many phases the first phase is the most important phase, which is called the initial planning phase, which includes preliminary engineering and design. This phase has to take sufficient time to avoid changing inadequate order design. The planning and proper communication channels will reduce the occurrence of variation orders, improve productivity, improve safety, improve professional relations among stakeholders and will encourage the usage of limited resources wisely.

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Drawbacks to the Attainment of Sustainable Road Infrastructure in South Africa

Douglas Aghimien[1], and Ntebo Ngcobo[2]

[1&2] Department of Civil Engineering Technology, Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa
daghimien@uj.ac.za

Abstract
In the quest to attain sustainable cities, sustainable infrastructures such as roads are vital to the everyday activity of dwellers within every community. However, roads within the rural areas are in most cases adjudged to be defective and unsustainable. This unhealthy situation tends to cripple activities within these rural areas in many ways. It is based on this view that this study assessed the causes of defective road infrastructures within rural communities in Limpopo province of South Africa. The study sought answers from rural dwellers and construction workers within the study area through a questionnaire survey. Data gathered were analysed using percentage, mean item score, and factor analysis. The reliability of the questionnaire was also tested using Cronbach alpha. Findings revealed that the principal causes of defective road infrastructure in rural areas are government/municipalities related, construction and maintenance related, and traffic and weather-related. It is believed that the findings of this study will help increase the delivery of sustainable road projects within the rural areas in a bid to provide a better standard of living for rural dwellers.

Keywords Defective roads, Sustainable infrastructure, Rural dwellers, South Africa

1. Introduction

Basic structures and facilities such as roads, buildings, water supply and power supply are necessary infrastructures required for the survival of dwellers of a community. Infrastructure development has overtime become a key issue for most developing countries particularly in Africa where a decay in the infrastructure of most countries is common (Jerome and Ariyo, 2004; El-Rufai, 2012). Although South Africa is not among the least developed countries in Africa (Aghimien *et al*., 2019), the country faces a similar issue of poor infrastructure. In terms of roads, Mamabolo (2016) concluded that South Africa has enough roads, but the major fallout is their unacceptable quality. There are roads in all nine provinces of the country, but their quality has been an issue since maintenance occurs after many years. Many potholes cause damages to vehicles and loss of valuable properties. Northern news (2015) earlier reported the temporary bridge between Vaalwater and Lephalale that was put in place after the road was destroyed during floods and the dangers of it being unable to withhold the load of all vehicles. In rural areas, the case is worse as the movement of products and people are done over long distances. Fungo *et al.* (2017) described road infrastructure as the backbone of many rural and urban transport systems. Rural transport provides assurance for the supply of agricultural inputs and facilitates the delivery of the farm outputs to the markets.

In rural areas, defective road infrastructure causes the farmers to seek better roads that can be used to distribute their goods, and these alternative routes could be longer thus leading to high transport cost. When no alternative routes exist, farmers are forced to travel on defective roads. The resultant effect of this includes damage to vehicles used, high maintenance costs, low profit, low earnings for workers, and a continuous rise of poverty among rural dwellers (Tunde and Adeniyi, 2012). Even though there has been a lot of research on road infrastructure, this matter is still a major concern in most developing countries around the world and South Africa is no exception. The rationale for this study, therefore, lies in the fact that new studies are helpful in discovering the depth of implications and the current issues that the country experiences. Based on this notion, the study assessed the principal causes of defective road infrastructure in rural areas in South Africa with a specific focus on Limpopo province. The subsequent part of this paper includes the review of related literature, the research methodology adopted, the findings and conclusion drawn from the findings. Based on the conclusion, recommendations were made and the areas for further studies were suggested.

2. Review of Literature

"The municipal roads infrastructure grant, public-private partnerships and own municipality revenue streams allocated towards road infrastructure is a comprehensible fiscal strategy for the long-term sustainability for providing road infrastructure services in South Africa" (South African Local Government Association, 2011). Investing in road infrastructure is important for the country in making the roads safe to travel. Van Heerden *et al.* (2015) observed that the Department of Transport has a comprehensive plan for non–motorised transport. The department also strives to implement a rapid public transport network so that regular transport services can be available to the public in rural areas. Investing in roads creates more employment, and avenues to increase the knowledge of road construction, as well as training are being offered. Moeketsi (2017) stated that "road infrastructure in South Africa is a specific area of concern as the development of such infrastructure in the country has been neglected to a large extent in some provinces, thereby imposing significant limitations on growth and development in rural communities".

South Africa has a working road infrastructure network compared to other African countries, which provides a lot in terms of economic and social progress. However, poor quality roads are still evident, particularly within the rural settlements. This poor quality becomes more evident during heavy rainfall where materials used on construction roads gets eroded easily (Mamabolo, 2016). Jerome and Ariyo (2012) indicated that when it comes to quality standards, the roads that are constructed in Africa is far below. Van Heerden *et al*. (2015) note that majority of rural areas have no gravel and tar roads and rural dwellers drive in unsafe conditions.

Okigbo (2012) conducted a study on the causes of highway failures in a similar developing country and observed that inaccurate concrete curing, settlement and restraint at the road joints lead to cracks and subsequent failures on the road. It was observed that majority of roads in the country are planned and designed by personnel who are not familiar with the site and this leads to wrong decisions being made and the roads being designed and constructed poorly. A similar observation was made by Adlinge and Gupta (2012) where it was noted that poor subbase leads to settlement and uneven road surface. Okigbo (2012) noted the issue of heavy traffic affecting road structures in Nigeria. It was noted that as the traffic increases road deformation becomes increasingly evident since it accommodates more cars than it was constructed for. In India, Adlinge and Gupta (2012) also noted that the increase in traffic is bound to affect the road pavement leading to what was described as "alligator cracking". A similar observation was made in Sri Lanka (Harischandra, 2004).

Poor maintenance culture has been a common issue for most developing countries. Evidence abound in the body of literature about the poor maintenance of construction works in these countries (Abdul Lateef, 2010; Abigo *et al*., 2012; Edmond *et al*., 2010). Road projects suffer this same fate as poor maintenance culture adversely affects most roads and subsequently leads to their deterioration. Afolayan and Abidoye (2017) and Oluwatobi (2010) have earlier noted that proper designing and construction of road is necessary as roads contribute immensely to the economy of any nation. Furthermore, after construction, these roads must be maintained to that ensure safety, strength and durability are achieved (2010). There must be appropriate maintenance regardless of the design and construction issue to achieve sustainability. However, in rural areas, maintenance is a major problem in roads and in cases where maintenance is done, it is not planned (Okigbo, 2012). Adlinge and Gupta (2012) and Harischandra (2004) made similar observations in their study. In South Africa, Mamabolo (2016) stated that lack of enough funds from municipalities causes poor maintenance of municipal roads. The Road infrastructure policy for South Africa also stated that the poor standard of many provincial and local roads is further compounded by limited funds as well as a reduced focus on maintenance and limited skills in the public sector. It was further stated that many municipalities and provinces lack the skill, capacity and funding to efficiently manage local road networks.

Poor road facilities, using materials with low quality, poor workmanship, inadequate management, low knowledge base, no local standard of practice, inadequate sanctions for road failures were also noted as key causes of road deterioration in Nigeria (Okigbo, 2012). Similar Harischandra (2004) noted issues such as the age of the road, road geometry, weather condition, road facilities such as drainage, construction quality, and maintenance policy as the key culprit of road failures in Sri Lanka. Adlinge and Gupta (2012) pointed out issues surrounding temperature variation, poor shoulders, poor clayey subgrade, poor drainage conditions, and overheating of bitumen as some key causes of road failure in India. Other studies have noted predominant issues such as inadequate preliminary geological investigation, poor design of roads, bad supervision and workmanship, lack of routine and periodic maintenance, bad drainage, improper use and overloading of roads, inadequate sanction for highway failure (Momoh *et al*., 2008; Oluwatobi, 2010; Osadebe *et al*., 2013; Osuolale *et al*., 2012).

3. Research Method

In assessing the major causes of defective road infrastructure in rural areas, a quantitative survey approach was adopted to gather empirical data (Ikuabe et al., 2022). The study sort answers from rural dwellers and construction workers in the Limpopo province of South Africa using questionnaire. The questionnaire was adopted as the instrument for data collection due to its ease of usage and ability to cover a wide range of respondents (Tan, 2011). A total of 72 questionnaires were conveniently distributed with 65 retrieved and 60 found fit for data analysis. The remaining 5 questionnaires were discarded as a result of inaccurate completion and missing vital information. Some of the questionnaire was self-administered while others were done through the help of field agents who read the questions to some of the rural dwellers who were unable to fully understand the questions asked. The data collection spanned a period of one month. The questionnaire used was designed in sections; the first section gathered information on the respondent's background. The second section sort answers regarding the major causes of defective road infrastructure in rural areas in South Africa. Respondents were provided with a list of causes identified from literature to rate based on their level of significance. A Likert scale of 1 to 5 was employed, with 5 being very high, 4 being high, 3 being average, 2 being low and 1 being very low. Data analyses were done using percentage for data on the background information of the respondents. The reliability of the questions in this second section was tested using Cronbach's alpha test which gave an alpha value of 0.898, thus implying high reliability of the questionnaire used as the alpha value is closer to 1. Exploratory Factor Analysis (EFA) was conducted to reduce the causes of defective road infrastructure assessed into a smaller number of underlying grouped factors (Aghimien *et al*., 2021). EFA was adopted based on the assertion that there is a possibility for some causes to have similar underlying meaning, and as such grouping such causes together will help give better perspective of issues that need to be addressed (Chan and Aghimien, 2022; Ikuabe *et al*., 2022)

4. Findings and Discussion

Background information of respondents

The result on the background information of the respondents revealed that 52% of population was male while the remaining 48% were female. Forty-five per cent (45%) of these respondents are rural dwellers that operate local businesses such as farming and selling of farm products, petty shop owners, motorist and the likes. The remaining 55% are into construction works within these rural areas. For their academic qualification, result revealed that 5% of the respondents had a below matric qualification, 18% had matric, 13% had National Certificate, 37% had a National Diploma, 20% had a bachelor's degree, and 7% had a master's degree. Following these results, it can be said that the respondents for the study have considerable understanding of happenings within the rural environment as they reside in these areas.

4.2 Drawbacks of sustainable road infrastructure

In determining the causes of defective road infrastructure in rural areas in South Africa, 12 major causes were identified from the review of the literature and presented to the respondents to rate according to their level of significance. Since there is the likelihood of some of the identified causes having similar underlying effects, EFA was deemed necessary to reduce these causes into a smaller number of coherent subscales. To conduct EFA, the suitability of the sample size was considered. Although there have been several disparities about the ideal size of a sample for EFA to be conducted, Preacher and MacCallum (2002) suggested that if the communalities are high, and the expected number of factors is small, the sample size is inconsequential. Zhao (2008) went further to suggest a communalities figure above 0.6 as being suitable irrespective of the sample size being adopted. The result from the communalities analysis revealed that 11 out of the 12 assessed variables have communalities figure above 0.6 as seen in Table 1.

Table 37. Communalities of the causes of defective roads

Causes	Initial	Extraction
Lack of funds from municipalities	1.000	0.597
Negligence by municipality	1.000	0.713

Using materials with poor quality for road construction	1.000	0.606
Lack of capacity in public sector	1.000	0.665
Poorly formulated policies by the departments	1.000	0.627
Inadequate sanctions for road failure	1.000	0.668
Poor road management skill	1.000	0.740
Poor maintenance culture	1.000	0.781
Poor drainage construction leading to over-flooding of road	1.000	0.735
Heavy traffic	1.000	0.600
Poor laboratory and in-situ tests on soil	1.000	0.699
Erosion from the adverse weather	1.000	0.640

Extraction Method: Principal Component Analysis

The result in Table 2 shows the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity which were also used to ascertain the suitability of the data for EFA. The result of the KMO test gave a value of 0.778 and a significant level of 0.000 for Bartlett's test. Tabachnick and Fidell (2007) have earlier noted that the KMO index ranges from 0 to 1, with 0.6 being the minimum value for a good EFA. Also, Pallant (2005) submitted that Bartlett's test of sphericity shows whether the correlation matrix is an identity matrix, and this should be significant at p-value < 0.05. The result of the KMO and Bartletts test derived, coupled with the communalities of above 0.6 derived and the 0.898 value obtained from the Cronbach alpha reliability test conducted, proves that the use of EFA for the data gathered is appropriate.

Table 2. KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.778
Bartlett's Test of Sphericity	Approx. Chi-Square	357.204
	df	66
	Sig.	0.000

Having met the necessary requirement for EFA to be conducted, EFA was done using principal component analysis (PCA) with varimax rotation. EFA extracted 3 components with eigenvalues greater than 1 with 0.50 set as the cut-off point for the factor loading. The final statistics of the PCA and the components extracted accounted for approximately 67.3% of the total cumulative variance. This result is above the 50% limit stated by Stern (2010). The 3 extracted components and the variables loading on them are shown in Table 3.

Table 3. Rotated Component Matrix

	Component		
Drawbacks	**1**	**2**	**3**
Lack of capacity in the public sector	0.801		
Lack of funds from municipalities	0.779		
Inadequate sanctions for road failure	0.758		
Poor road management skill	0.736		
Poorly formulated policies by the departments	0.702		
Negligence by municipality	0.636		
Poor maintenance culture		0.844	
Poor drainage construction leading to over-flooding		0.816	
Using materials with poor quality for road construction		0.667	
Poor laboratory and in-situ tests on soil			0.817
Heavy traffic			0.774
Erosion from the adverse weather			0.698

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 5 iterations.

4.3 Extracted Factors

A. Government and Municipalities related causes

The first principal component has the highest factor loading of 6 variables and it accounts for 45.3% of the total variance explained. This percentage is higher than the percentage for the remaining two extracted factors combined. This means that variables loading on this component are a major culprit of defective road infrastructure in rural areas. These causes are; lack of capacity in public sector, lack of funds from municipalities, inadequate sanctions for road failure, poor road management skill, poorly formulated policies by the departments, and negligence by municipality. Based on the latent properties of these variables, this component was named the "Government and Municipalities related causes".

B. Construction and Maintenance related causes

The second principal component has 3 variables loading on it and accounts for 13.3% of the total variance explained. These variables are poor maintenance culture, poor drainage construction leading to over-flooding of road, and using materials with poor quality for road construction. These factors were subsequently named "Construction and Maintenance related causes".

C. Traffic and Weather-related causes

The last principal component has 3 variables loading on it and accounts for 8.7% of the total variance explained. These variables on this component are poor laboratory and in-situ tests on soil, heavy traffic, and erosion from the adverse weather and it is subsequently named "Traffic and Weather-related causes".

5. Discussion

The findings revealed that government and municipalities related issue is one of the major drawbacks to the attainment of sustainable road infrastructures. There is no gainsaying that the government plays a significant role in the delivery of public infrastructure. The activities of the government, therefore, plays a significant role in the development or decay of public infrastructures. Mamabolo (2016) has earlier noted that shortage of funds from municipalities causes poor maintenance of municipal roads which subsequently leads to defective roads within the country. Similarly, defective roads are the resultant effect of municipalities and provinces lack of required skills and capacity to efficiently manage local road networks. Findings of this study further affirm the submission of Okigbo (2012) that inadequate sanctions for road failures is among the principal culprit of defective roads in developing countries. This is because when roads are poorly constructed, the construction participants involved in the delivery are not properly sanctioned, hence no subsequent acts of poor construction are repeated.

Similarly, it was revealed that construction and maintenance issues also contribute immensely the non-attainment of sustainable road infrastructure in rural areas in the country. This finding is in line with the submissions of Adlinge and Gupta (2012), Harischandra (2004), and Okigbo (2012) who discovered that poor maintenance issue affects road infrastructure in India, Sri Lanka and Nigeria respectively. Similarly, the findings also confirm the submissions of Okigbo (2012) and Afolayan and Abidoye (2017) that poor drainage and the use of poor materials for construction can affect the road adversely. Thus, care must be taken during designing and construction and adequate consideration must be given to its maintenance (Afolayan and Abidoye, 2017).

The last principal culprit of defective road infrastructure within the rural community of the country is traffic and weather-related issues. The harmful effect of increased traffic on constructed roads have been reiterated in past studies. The findings of this study are in line with previous submissions which shows that when traffic increases beyond the capacity a road was initially designed for, deformation of such roads occurs and cracks as well as uneven road surface becomes evident on such roads (Adlinge and Gupta, 2012; Okigbo, 2012). This point to the need for experts in the designing and constructing of road networks. Afolayan and Abidoye (2017) have earlier noted that most road projects fail because of lack of adequate planning before construction. If better road projects that can withstand its traffic are to be achieved within the country, adequate pre-planning and planning must be done with the calculation of the current and future traffic to be handled by such road done correctly. Similarly, proper designing of road facilities must be properly done to avoid destruction of road surfaces during adverse weather conditions.

6. Conclusion

This study assessed the major causes of defective road infrastructure in rural areas, with answers sought rural dwellers and construction workers in the Limpopo province of South Africa. Based on the findings, the study concludes that the major causes of defective roads in rural areas are government/municipalities related, construction and maintenance related, and traffic and weather-related. Therefore, if road projects are to improve and serve their intended purposes, the government and municipalities representatives must be willing to champion this course through proper funding of road project, creating capacity in public sector, and ensuring that adequate sanctions for road failure are in place. Similarly, due consideration must be given to road design and construction and their subsequent maintenance.

It is believed that the findings of this study will help increase the delivery of sustainable road projects within the rural areas in a bid to provide a better standard of living for rural dwellers. However, while the findings of this study are essential to the delivery of better road infrastructure within rural settlements, care must be taken in generalizing its findings as the study was limited to a single province in the country. Further studies can, therefore, be conducted in other rural areas in other provinces to compare results and have a wider view of the subject

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Digital Technologies for Effective Value Management in the Construction Industry

Douglas Aghimien[1], Ntebo Ngcobo[2] and Clinton Aigbavboa[3]

[1&2] Department of Civil Engineering Technology, Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa
[3]cidb Centre of Excellence, Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa
daghimien@uj.ac.za

Abstract
This study presents the result of an assessment of the drivers of digital technology diffusion in the value management (VM) process in the construction industry. This was done with a view to improving the use of digital technologies in the quest to create value for construction clients. The study adopted a quantitative research design which informed the use of a structured questionnaire administered to construction professionals that have participated in VM exercises within the South African construction industry. The data gathered were analysed using mean item score, standard deviation, Kruskal-Wallis H-test, and exploratory factor analysis. The study found that the use of digital tools to improve VM process is driven by three major components viz: (1) VM process requirement, (2) digital culture of the construction industry, (3) knowledge and understanding of the need for digital tools. The use of relevant technologies will help improve the speculation and creative phase of a VM workshop, the evaluation phase, the presentation of best value alternatives, the gathering of preliminary information and the overall success of the VM workshop. This study provides a theoretical backdrop for future studies exploring the use of digital technologies for VM practices – an aspect that has not gained significant attention in VM discourse in the construction industry.

Keywords Construction industry, Digital technology, Value for money, Value management

1. Introduction

The pervasive nature of technology advancement, particularly with the fourth industrial revolution, is bringing significant changes to diverse industries, including construction (Aghimien *et al.*, 2021). Studies have shown that the use of diverse digital technologies in the construction industry is rapidly transforming how projects are being delivered as well as the quality and pace of delivering construction services (Adzroe and Ingirige, 2014; Aghimien *et al.*, 2018; Berger, 2016; Rüßmann *et al.*, 2015). As a result of the benefits inherent in digital technologies, several studies have continued to explore their usage in the management of constructions projects (Abedi *et al.*, 2013; Haung *et al.*, 2020; Irizarry and Costa 2016; Zhou *et al.*, 2018). However, there is a paucity of studies exploring digital tools to improve value management (VM) practices within the construction industry. Herein lies the gap in literature that this current study strives to fill.

VM has been described as the process of achieving value for money for construction clients through the delivery of quality products at a reasonable cost (McGeorge and Palmer, 1997). Male and Kellye (1998) described VM as a proactive, creative, problem-solving or problem-seeking service that maximises the functional value by managing its development from concept to use. According to Odeyinka (2006), VM maximises functional value by managing the project's development from planning to the delivery and use of the project through proper audit of all decisions against a value system outlined by the client. Thus, VM has been described as a process that offers construction clients value for money through the analysis functions of projects from inception to completion and use of the project and elimination of non-value-adding elements (Oke and Aghimien, 2018). Unfortunately, the VM process in most developing countries has been challenged by several issues, including the problem of poor communication relevant stakeholders/VM members and technological advancement in employing the electronic VM approach (Chhabra and Tripathi, 2014; Coetzee, 2009; Jaapar *et al.*, 2009).

With the current availability of ubiquitous technologies which are shaping the way projects are being delivered, there is no doubt that the use of some of these technologies can help improve VM practices. For instance, the use of cloud computing and the internet of things on projects have been noted to improve communication and team collaboration among project participants (Oke *et al.*, 2021). More so, through big data analytics, the project team can collect, store, and analyse a large amount of data and make informed decisions necessary to ensure successful project delivery (Bilal *et al.*, 2016; Ganesan *et al.*, 2020). Furthermore, building information modelling (BIM) also creates a platform for project teams to collaborate and share ideas. This creates an opportunity for clashes in designs to be noticed early in the project, and the remedial actions can be taken immediately to correct these issues and avoid unnecessary cost, time and material wastage during construction (Aboushady and Elbarkouky 2015). Based on the foregoing, this research was designed to unearth the significant drivers that influence the use of digital technologies to improve the VM process. Also, the study strives to determine the VM practices that the use of digital tools will impact the most. This was done to improve the use of digital technologies in the quest to create value for construction clients and improve the value delivery performance of the construction industry as a whole.

2. Review of Literature

The concept of VM was first proposed in the United States of America by Miles at the General Electric in the late 1940s. The system, which was initially referred to as value engineering, was developed after the second world war, which brought about the shortage of components needed for essential production. The search for alternative components to meet production demand proved futile due to the adverse effect of the war. Therefore, to ensure continuous production, rather than searching for alternative components, new means of fulfilling the function of those scarce components were sorted. Using alternative approaches was adopted in place of replacing component unavailable components. This method was observed the deliver low-cost products with the same required quality. Owing to the significant benefit of this approach, after the war, the method was retained as a means of removing unwarranted expenses incurred in product delivery and as a way to improve product design through the analysis of functions (Oke and Aghimien, 2018; Palmer *et al.*, 1996).

It has been noted that the VM process can be used to complement the cost planning of construction projects, especially at the inception of the project (Seeley, 1997). As a result, it has been suggested that the implementation of VM must be done early in the projects in order to improve the opportunity to improve on project design before the project commences (Ellis *et al.*, 2003). While the use of the VM process in project delivery can help reduce cost (Kelly *et al.*, 2004), Oke and Aigbavboa (2017) warn that VM is not designed to cut cost but to deliver value through careful assessment of the functions of various elements in a project. The VM process involves conveying a VM workshop at several project stages (Clifford, 2013). The purpose of these workshops is to bring together project stakeholders to brainstorm on the different approaches towards which value can be achieved on the project (Ellis *et al.*, 2003). The workshop follows several phases, which are mostly sequential in nature. First functional analysis is conducted, then comes the creative, evaluation, development and presentation phases (Society of American Value Engineers, 2008). Tanko *et al.* (2017) identified twenty VM activities that were regrouped into the information phase, functional analysis phase and creativity, evaluation development and presentation phase.

To make the VM workshop a success, several factors need to be considered. This is important as several studies have emanated on the hindrances to the success of VM practices in countries around the world. These hindrances include but are not limited to the absence of qualified VM experts, lack of training and management support, difficulties in bringing all relevant stakeholders together, obstruction from the VM team, poor technological advancement and knowledge of the use of electronic VM system as well as poor communication among VM team (Chhabra and Tripathi, 2014; Coetzee, 2009; Hayatu, 2015; Jaapar *et al.*, 2009; Kissi *et al.*, 2016). The use of digital technologies can significantly impact the VM process and help address some of these identified issues. These emerging digital technologies can be in the form of software; methods; hardware network and networking systems for data processing, storage and presentation; repository and databases; and intelligent systems that promote communication, collaboration, and teamwork (Ibem and Laryea, 2014). The use of these technologies can be driven by the need to improve team communication, the gathering of information, and decision making. Digital technology can offer a VM team communication medium that allows for increased flexibility. As such, the long days associated with the VM workshop can be reduced, and contact can be done via online platforms. More so, with the advent of the COVID-19 pandemic and the work-from-home protocol that most organisations have adopted (including construction organisations), using online digital platforms for VM workshops can prove useful and ensure effective communication while maintaining a safe space (Aigbavboa *et al.*, 2022). Coetzee (2009) also noted that the use of video conferencing could help create a new VM delivery process that is more effective than the traditional physical VM workshop practice. Technologies such as BIM, internet of things, cloud computing and big data analytics can all prove effective in ensuring effective communication and understanding of the project requirement, team collaboration as well as faster informed decision making by the VM project team (Aboushady and Elbarkouky 2015; Bilal *et al.*, 2016; Ganesan *et al.*, 2020; Oke *et al.*, 2021). Drawing from general drivers to the use of digital tools and VM, proper understanding of the need for the use of digital technologies, the request from clients, the need for quick VM output and cost-effectiveness of the VM process are some of the drivers assessed in this current study (Aghimien *et al.*, 2021; Eadie *et al.*, 2013). More so, the availability of the required technologies and the availability of training and education can prove useful for the use of digital technologies in the VM process (Becerik, 2004; Kelly *et al.*, 2002; Oke *et al.*, 2018).

3. Research Method

The study is quantitative and the instrument for data collection was a structured questionnaire. The target population for the study were construction professionals that have been involved in VM workshop/practice within the South African construction industry. This set of individuals is few as the VM practice is not common within the industry (Oke and Aghimien, 2018; Oke and Aigbavboa, 2017). As a result, snowball approach was adopted to gather participants that have been involved in VM practices in the country. The snowball approach has become popular among construction researches where the exact number of the target population is unknown from the initial stage of the research (Chan and Aghimien, 2022). Using this approach, the study gathered data from 80 professionals that have been involved in VM practices in the past. The questionnaire used to harness information from these respondents was designed using three sections. The first section sought answers to some background information on the respondents, while the second section assessed the drivers of the use of digital tools for VM practice. The last section unearths the impact of digital tools on VM exercise. These second and third sections were assessed using a five-point agreement scale with five being strongly agreed and one being strongly disagree.

The data gathered on the background information were analysed using frequency and percentage. The data from the second and third sections were first tested for their reliability using the Cronbach alpha test (α). The set cut-off for this test was ≥ 0.7 (Hair *et al.*, 2019). The data from these two sections were analysed using mean item score ($\bar{X}$) to rank the different identified drivers and impacts. The premise for ranking these variables was that variables with the highest mean are ranked first, and others follow in descending order. Where two variables have the same $\bar{X}$ the one with the lowest standard deviation (SD) is ranked first, as suggested by Field (2009). Furthermore, since the respondents were drawn from different organisation types (contracting, consulting and government), Kruskal-Wallis H-Test (*K-W*) was employed to test the disparity in the rating of the variables by the different groups. The *K-W* test gives a chi-square (χ^2) and a *p*-value that shows the significant relationship in the response of respondents from the different groups. Also, exploratory factor analysis (EFA) was conducted to further cluster the different drivers to the use of digital tools in VM practice into a more manageable subscale. While past studies have noted the need for large samples for EFA to be conducted, studies have shown that as long as the communalities derived are adequate (i.e., > 0.5), then less emphasis should be placed on the samples (Preacher and MacCallum, 2002; Zhao, 2008). As a result, construction-related studies with samples of less than 100 have continued to emerge with reasonable outputs (Aghimien *et al.*, 2020). The communalities derived from this study were all higher than 0.5. More so, the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity (BTS) were used to ascertain the suitability of the data for EFA. Both tests gave acceptable values, which merited the use of EFA for further analysis.

4. Findings and Discussion

Background information of respondents

The respondents for this study comprised 62% construction and project managers, 12% architects, 12% engineers, and 14% quantity surveyors. About 49% of these respondents work for contracting organisations, while the remaining 26% and 25% work in government and consulting organisations. The majority (55%) of these respondents have a bachelor's degree, while 27% have national diplomas and 18% have master's degrees. For the years of experience, most of the respondents (65.1%) have been in the South African construction industry for more than five years, with 16.3% having above 20 years of experience in the industry. Only 18.8% have below five years of working experience in the industry. Following these results, it can be said that the respondents for the study have a considerable understanding of happenings within the South African construction industry, and their response is based on their experience in VM shaped by their years of working experience in the industry.

Drivers of the use of digital technologies in Value Management Practices

In assessing the critical drivers that will propel the use of digital tools to improve the VM practice, the respondents were presented with eight drivers to rank based on their level of agreement. These drivers revealed an α-value of 0.810, which is above the set cut-off of 0.7, thus implying that the questions asked were reliable and the variables had significant internal consistency. The *K-W* test revealed that the respondents from the contracting, consulting and government organisations all had a unified view regarding the key drivers, as seen in Table 1. A *p*-value above the conventional threshold of 0.05 was derived for all the assessed drivers. The result derived from the SD also confirmed that there is no disparity in the rating of these drivers by the respondents as SD-values of below 1.0 was derived for all the assessed drivers. As such, the result can be adopted as a true reflection of the drivers needed to promote the use of digital technologies for effective VM practice in the South African construction industry. The respondents agreed that only when there is a proper understanding of the need for digital tools in the VM practice can digital technologies be effectively used to improve VM exercise. This driver was ranked first with a $\bar{X}$ value 4.45. This is followed by the client's request for digital technologies to be used on their project ($\bar{X}$ = 4.41, *p*-value = 0.135), the need for faster VM process ($\bar{X}$ = 4.28, *p*-value = 0.059), and a positive digital culture in the construction industry ($\bar{X}$ = 4.01, *p*-value = 0.171). The least ranked drivers are the need to reduce costs associated with the VM workshop ($\bar{X}$ = 3.76, *p*-value = 0.263) and the need to improve communication in the VM process $\bar{X}$ = 3.28, *p*-value = 0.777). While these drivers might be considered as the least critical, they have $\bar{X}$ values above the average of 3.0. This means when saving cost associated with physical VM meetings is essential and communication is a problem, VM team may result to the use of appropriate digital tools.

Table 1. Drivers of the use of digital technologies for VM practices

Drivers	$\bar{X}$	SD	Rank	*K-W*	
				χ^2	*p*-value
Proper understanding of the needed digital technologies for VM exercise	4.45	0.525	1	4.002	0.135
Client's request	4.41	0.544	2	6.003	0.059
The need for a faster VM process	4.28	0.927	3	3.530	0.171
Positive digital culture in the construction industry	4.01	0.112	4	2.810	0.245
Training and education on VM and digital technologies	3.94	0.401	5	0.709	0.702
Availability of needed digital technologies	3.90	0.704	6	2.698	0.259
The need to reduce cost associated with VM workshop	3.76	0.750	7	2.673	0.263
Need to improve communication	3.28	0.779	8	0.504	0.777

Preliminary analysis of the data gathered on the drivers gave a KMO value of 0.823 which is above the 0.6 thresholds (Pallant, 2011) and a significant BTS output of 0.000. The result in Table 2 gave a communality of between 0.629 to 0.968. These preliminary results show that the use of EFA for the data gathered was adequate. EFA was conducted using principal component analysis (PCA) due to its ability to adequately regroup variables into more manageable clusters (Pallant, 2011). The result in Table 2 shows that at four iterations, three principal components were derived with eigenvalues of above 1.0, and they all account for 84.1% of the total variance extracted. The first principal components account for 44.8% of the variance explained and has four drivers loading on it. These drivers are the need for a faster VM process (97.3%), the need to reduce the cost associated with VM workshops (85%), the availability of needed digital technologies (84.9%), and the need to improve communication (72.8%). This component was renamed as 'VM process requirement'. The second extracted component account for 24.4% of the total variance explained and has two drivers loading on it, viz: client's request (92.9%) and positive digital culture in the construction industry (91.5%). This component was subsequently named 'digital culture of the construction industry due to the latent similarity in the variables. The last component accounts for 14.9% of the total extracted variance and also has two drivers loading on it. These drivers are proper understanding of the needed digital technologies for VM exercise (80.7%) and training and education on VM and digital technologies (78.1%) and was subsequently named 'knowledge and understanding.'

Table 2. EFA of the drivers of the use of digital technologies for VM practices

	Component	Communalities

Drivers	1	2	3	Extractions
Component 1 – VM process requirement (44.8%)				
The need for a faster VM process	0.973			0.968
The need to reduce cost associated with VM workshop	0.850			0.844
Availability of needed digital technologies	0.849			0.857
Need to improve communication	0.738			0.964
Component 2 – Digital culture of the construction industry (24.4%)				
Client's request		0.929		0.866
Positive digital culture in the construction industry		0.915		0.895
Component 3 – Knowledge and understanding (14.9%)				
Proper understanding of the needed digital technologies for VM exercise			0.807	0.703
Training and education on VM and digital technologies			0.781	0.629

Impact of digital technologies on the VM practices

Table 3 present the result of the assessment of the various VM practices that the use of digital tools will impact significantly. The *K-W* test conducted shows that the respondents all have a unified view as a *p*-value of above 0.05 was derived for all the assessed VM practices. More so, the result derived from the SD affirms that there is no disparity in the rating of the impact of digital tools on these practices as SD-values of below 1.0 was derived for all the assessed practices. Therefore, it can be deduced that the result can be adopted as a true reflection of the impact of the use of digital technologies on VM practices within the South African construction industry. From the overall $\bar{X}$ values, it is evident that the use of digital technologies will impact the different VM practices assessed as they all have a $\bar{X}$ of the above-average of 3.0. More specifically, the use of digital tools will impact the speculation and creative phase of a VM workshop ($\bar{X}$ = 3.99, p-value = 0.486) as well as the evaluation or judgment phase ($\bar{X}$ = 3.99, *p*-value = 0.266). Also, digital tools can be used to help improve the overall success of the VM workshop ($\bar{X}$ = 3.98, *p*-value = 0.649), presentation of best value alternatives ($\bar{X}$ = 3.91, *p*-value = 0.452), and in gathering of preliminary information on the project ($\bar{X}$ = 3.78, *p*-value = 0.303).

Table 3. Impact of digital technologies on VM practices

Impact	$\bar{X}$	SD	Rank	*K-W* χ^2	*K-W* *p*-value
Speculation and creative phase of VM workshop	3.99	0.464	1	1.441	0.486
Evaluation or judgment phase	3.99	0.490	2	2.645	0.266
Overall success of VM workshop	3.98	0.503	3	0.866	0.649
Presentation of best value alternatives	3.91	0.455	4	1.588	0.452
Gathering preliminary information on the project	3.78	0.795	5	2.386	0.303
Communication among VM Team	3.55	0.673	6	1.381	0.501
Conducting functional analysis	3.54	0.635	7	1.436	0.488
Management of group by VM facilitator	3.51	0.636	8	1.868	0.393
Development of alternatives	3.35	0.658	9	5.930	0.052

5. Discussion

The findings of this study shows that the use of digital technologies in the VM process can be driven by three main factors (1) VM process requirement, (2) digital culture of the construction industry, (3) knowledge and understanding. In terms of VM process requirements, past studies have shown that the fear of the cost and time associated with the VM process can be a severe problem to the implementation of VM in construction projects (Abidin, 2005; Daddow and Skitmore, 2005; Kissi *et al.*, 2016). As a result, the ability of digital technologies to save cost and improve service delivery to time (Hashim *et al.*, 2013; Berger, 2016) can be a major driver for their implementation in the VM process. More so, when these digital technologies are readily available, adopting them for VM practices becomes easier. Kagermann (2014) have noted that the use of digital technologies will be significantly dependent on the availability of the technologies, among other factors. Furthermore, where communication is an issue, as observed in past studies (Coetzee, 2009; Chhabra and Tripathi, 20014; Jaapar *et al.*, 2009), implementing relevant digital tools becomes necessary.

Regarding the digital culture of the construction industry as a driver for technology adoption in VM, past studies have noted that the construction industry has a poor digital culture (Aghimien *et al.*, 2018; Pärn and Edward, 2019).

However, the improvement in the embrace of technological advancement within the industry will drive the use of digital tools in VM practices. More so, this will lead to clients requesting the use of digital technologies in the delivery of their projects – an act that is currently deterring the use of digital tools within the construction industry (Oke *et al.*, 2018; Yahya *et al.*, 2019). Past studies have affirmed that the demand by clients for the use of digital technologies on their project is a crucial driver to technology adoption (Aghimien *et al.*, 2021; Eadie *et al.*, 2003).

Finally, in terms of knowledge and understanding, evidently, without a proper understanding of the need for digital tools, adopting them to improve the VM process will be difficult. As such, creating medium to enlighten, train and educate participants of VM practice on the need to adopt digital means of attaining the objectives of the VM process is necessary. Becerik (2004) as well as Oke *et al.* (2018) have noted that the availability of proper training can drive the use of digital technologies.

In terms of the diverse VM practices that the use of digital technologies will impact, the findings revealed that the use of digital tools will help improve diverse aspects particularly in the aspects of speculation and creative phase of a VM workshop wherein diverse ideas are postulated for deliberation by the VM team (Oke and Aghimien, 2018). The impact can also be felt in the evaluation or judgment phase where the ideas from the creative phase are adjudged for their merit and applicability (Oke and Aghimien, 2018; Society of American Value Engineers, 2008); the presentation of best-value alternatives to the client; the gathering of preliminary information on the project; as well as the overall success of the VM workshop.

6. Conclusion

The study assessed the drivers of the use of digital technologies to improve VM and the diverse VM practices that will be impacted upon through the use of digital tools. Based on the results, the study found that the requirement of the VM process, such as the need to save cost and time associated with the VM exercise, the digital culture of the construction industry, as well as the knowledge and understanding of VM participants of the need for digital tools are the main drivers of the use of diverse digital tools in VM processes within the construction industry in South Africa. Furthermore, the study found that the use of relevant technologies will improve the speculation and creative phase of a VM workshop, the evaluation phase, the presentation of best value alternatives, gathering of preliminary information as well as the overall success of the VM workshop. Based on the findings of the result, it is therefore concluded that digital technologies can help improve the VM process in the construction industry and, in the process, ensure clients get the required value for money. However, for this to be achieved, there must be a positive digital culture in the construction industry that will promote the use of digital tools by both professionals and clients. More so, there is the need for adequate training, education and enlightening of construction stakeholders on the VM process and how the use of digital tools can be beneficial to the entire VM exercise. The findings of this study provide a good theoretical backdrop for future studies seeking to explore the use of digital technologies for VM practices – an aspect that has not gained significant attention in VM discourse in the construction industry. The study also provides directions for future research based on its inherent limitations. For instance, the study adopted a smaller sample due to the slow adoption of VM practice in the country and the rareness of VM participants. Future works can explore a larger sample and include other project participants to get a wider view of the topic. Also, the current study adopted a quantitative approach. Future works can be conducted using other methods such as qualitative or mixed-method. The findings of the study cannot be generalised for the construction industry in other countries. Thus, other studies can be conducted in the construction industry of countries where such evaluation has not been conducted with a view to compare the findings.

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A Smart Contract Fraemwork as an Alternative Method for Letter of Credit Use in Construction Procurement

Furkan Uysal[1], Salar Ahmadisheykhsarmast[2] and Rifat Sonmez[2]

[1]Ankara Social Sciences University, Ulus, Ankara, Turkey
[2]Middle East Technical University, 06100, Ankara, Turkey
furkanuysal@gmail.com

Abstract
Letter of credit (L/C) use in construction procurement is a common practice particularly for international trades. L/C is a commitment of banks which reduces buyers' and supplies' risks related to transactions. In international trades both buyer and supplier need a third-party involvement in order to ensure smoothness of procurement procedures. However, third party involvement makes trading more cumbersome, add extra fees, credit limit of individual parties may affect the whole process adversely and it is lack of physical control over delivered items such as materials or equipment.

A more reliable, cheaper and faster framework is proposed in this paper as an alternative method to common use of L/C. This framework is based on smart contracts where contractual agreement is made in a decentralized blockchain with smart contracts. Different from routine L/C practice, physical control over delivered item is possible using IOT devices and it makes whole procurement procure more straightforward, cheaper and more reliable.

Keywords
Smart Contracts, Letter of Credit, Construction Procurement

1. Introduction

Procurement is an essential part of construction projects and it is highly labor intensive. From identifying the item to be procured to the final approval, procurement requires several steps. It requires experienced and dedicated expert during estimating quantities, selecting the right equipment, planning delivery times, selecting the right supplier, performing quality assurance and accepting and approval of delivery. Both material and equipment cost could constitute the highest percent of total projects cost. According to Agapiou et al (1998) only material procurement costs can reach approximately %40-45 of total project cost. Most often stakeholders of procurement process do not know each other, maybe separated by distance and may not have a commercial relationship before. Particularly in international trades both seller and buyer have serious concerns regarding transactions and material and equipment acceptance procedures. On one hand, buyer needs to ensure delivery on time, right amount of quantity and with desired quality as described in request for proposal, on the other hand, seller needs to ensure the amount of money is transferred on time and with the negotiated amount. Since it is not easy to create full trust between two parties, both tend to trust a third-party involvement like banks or notaries.

Banks issue special kind of loans to the applicants called Letter of Credit (L/C) to build trust between seller and buyer. It has been an effective way of securing buyers' and sellers' interests in construction business for decades particularly between international stakeholders. It is a commitment by a bank to ensure that a predetermined amount of money will be paid for the account of bank's customer. This payment is made after the documents are obtained and accepted in accordance to L/C requirements. Considered as a bank loan, L/C guarantees the seller's payment and ensures buying action is completed in accordance to L/C requirements. L/C is an effective way of minimizing payment risks in trades, however, it has three major limitations. First, due to the long and cumbersome process and high fees of banks (Li, 2021) it adds extra cost to procurement process. Second, since L/C is considered as a bank loan, buyer's credit limit is used to obtain it (Effiom & Edet, 2018). Third, L/C transaction authorizations is done based on documents only and there is no physical control over material delivery.

Recent advancements in smart contracts can propose number of solutions for aforementioned drawbacks of traditional L/C. Since a third-party involvement is not required in smart contracts, contractual agreement can be automated and costs can be reduced. In addition to automation, adhered characteristics of smart contracts like transparency and immutability could increase its usage in international trading. Moreover, physical control and delivery verification could be possible with smart devices. Therefore, in this paper, a smart contract framework is proposed as an alternative method for L/C use in material and equipment procurement in construction. Framework is configured to make physical control over delivery and the verification of delivery can be done using blockchain network.

This paper is organized as follows: In section two, L/C and its applications in the construction industry are discussed. Smart contracts, their working mechanism and applications are given in section three. Fourth section includes proposed framework and it is explained together with its potential contributions to traditional L/C. Finally, concluding remarks are made for a more effective material procurement in construction with smart contracts.

2. Letter of Credit

In construction procurement, most often seller and buyer are geographically dispersed and have not been involved a commercial relationship before. Therefore, in order to build trust between seller and buyer traditional L/C usage is a very common practice. L/C serves as a document proof of transaction guarantee and minimizes payment risks of both parties. However, material and equipment delivery verification are based on documents only. Traditional L/C process includes several steps. As it can be summarized from Figure 1, this process depends heavily on documents and heavy communication between banks, seller and buyer.

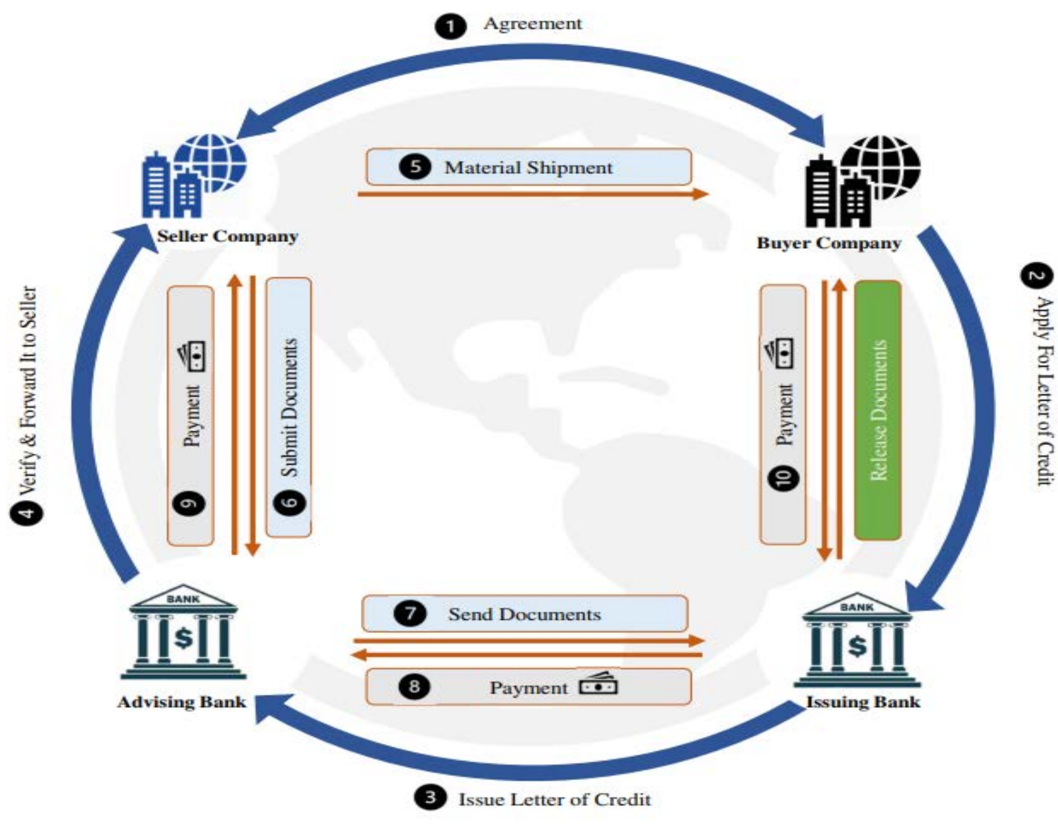

Fig. 1. Letter of Credit Flow in Material Procurement

In order to start material and equipment procurement process, first, buyer and seller makes an agreement. This agreement includes type of procurement item, quality standards, delivery schedule, payment details and any other technical issue related to item itself. Buyer then applies to an issue bank in order to start L/C procedures. Seller also uses his representative bank as an advising bank throughout the whole process. Issuing bank applies to the advising bank together with necessary documents for the delivery process and advising bank verifies the related documents and forwards it to the seller. Seller then applies to the advising bank in order to start payment process at the item delivery. Documents are sent to the Issuing bank and the bank makes the necessary document investigation and verifies the delivery. After the verification which is based on documents only, issuing bank sends payment to the advising bank. Finally, advising bank makes the required amount of payment to the seller.

3. Smart Contracts and Blockchain

The term smart contracts first used by Szabo (1996). Smart contracts are simply agreements made between parties of contract using a code executed in a decentralized blockchain. Blockchain serve as a decentralized community-based data management system where information flow is traceable (Anuradha, 2017). As new data entered to the blockchain, a new block is created to store the information. Each block contains three basic information; data itself, hash and hash of the previous block. Hash of each block uniquely identifies the block among others. After the creation of new blocks, they are chained to the previous blocks and information is stored in a chronological order together with cryptography. Different type of data can be stored in blocks such as transaction data. It is decentralized due the fact that no single person or single group is in charge of the system. One of the strongest features of blockchain is immutability, which defines that data is recorded in an irreversible way.

The transaction process in a blockchain can be summarized with Figure 2. As a first step user requests a transaction and transaction message is sent to the blockchain network. The transaction request is authenticated by the cryptographic keys, Public and private key and it is broadcasted throughout the whole blockchain network. Participants of the blockchain consensus check whether the transaction request is valid and if the user is entitled to spend money. The money is transferred to the wallet address of receiver and the transaction is added as a new block once the transaction is approved by the participants of the blockchain consensus. Newly created block is broadcasted to the other participants of blockchain consensus to validate the transaction. In a decentralized blockchain consensus is achieved by consensus protocols which mainly consist of Proof-of-Work or Proof-of Stake protocols (Nofer, Gomber, Hinz, & Schiereck, 2017). The smart contracts are based on blockchain 2.0 (Aggarwal & Kumar, 2021), can be automatically executed by consensus mechanism in the blockchain which enable to run a coded agreement between parties and can serve as a trusted party without physical involvement of a third party.

4. Literature Review

Applications of smart contract in construction industry is gaining considerable attention in recent years. Since Cardeira (2015) highlighted the potentials of smart contracting in construction, various frameworks and applications proposed from information management in construction (Zhang, 2021) to the quality control (Wu, 2021). However, contractual payment issues found to be the focus of many researches in construction due the the fact that main source of disputes are contracts. An expert panel of construction industry stakeholders listed as smart contracts and novel applications as the highest potential area in order to improve efficiency of payments (Nanayakkara, 2021). Traditional contracting and smart contracting differences are highlighted by Ahmadisheyksarmast and Sonmez (2018) and concluded that smart contracting has high potential to reduce disputes between stakeholders. It is also stated that letter of credit usage in construction is a common problem and smart contracts could be a solution to the problem. Chang et al. (2019) investigated the use of letter of credit in international trades and prospects to facilitate an information flow based on blockchain based smart contracts were discussed together with a conceptual design of an international trade system. Problems related to the proposed system discussed security as the main problem. Kumar and Nerurkar (2020) discussed potentials and problems related to blockchain together with cloud technologies and proposed a secured smart contract framework in a permissioned blockchain. However, to the best of our knowledge this study is the first study which directly focuses on letter of credit use in construction procurement only and proposes an applicable framework with IOT devices which makes it possible to automatically control material and equipment delivery on site.

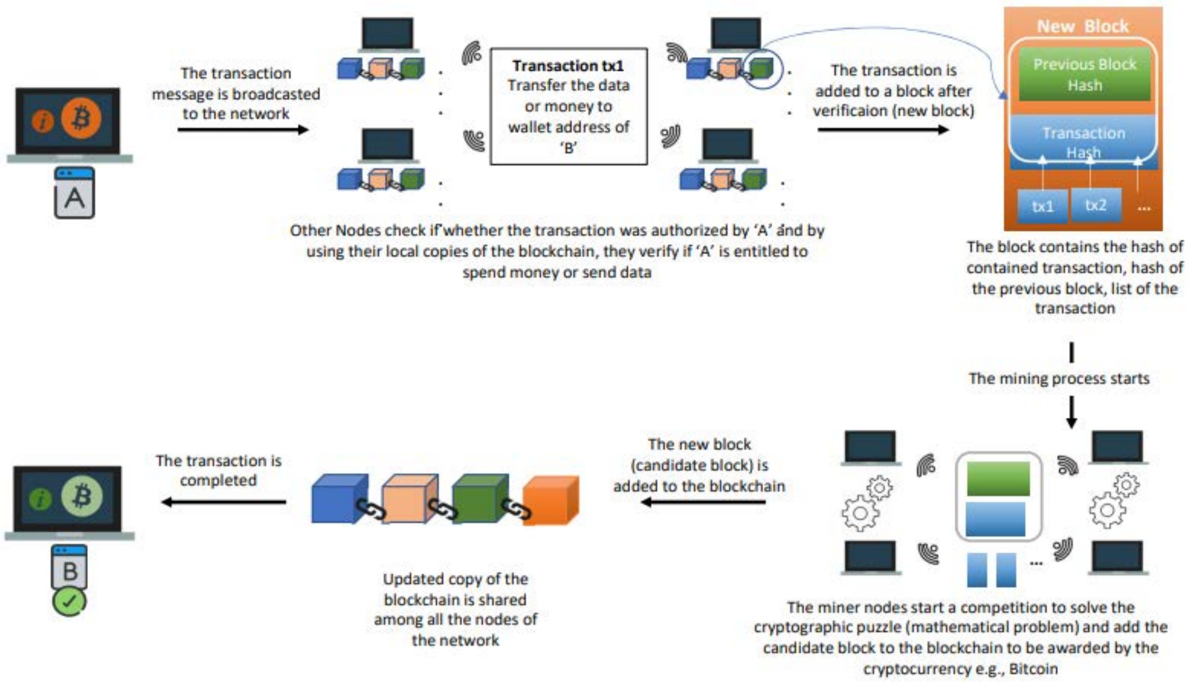

Fig. 2. Transaction in a Blockchain Network

5.Smart Contract Based L/C Framework

The proposed framework is defined to ensure the payments for material and equipment supply of construction procurement domain through smart contracts. As demonstrated in Figure 3, the buyer company and the supplier first make an agreement and then the agreed contractual terms are written as a code through smart contract which is run on the blockchain. As in most construction projects, payments of material are made in two stages, initial payment is made once the material order is submitted and final payment is made once the material is on site and inspected successfully. The suggested framework enables automated payment as well as it records and stores the process information on a secure, transparent, and trustworthy blockchain network.

In proposed framework, the agreement terms of payment are defined as code in the smart contract. The smart contract enables the payment to be blocked in the contract and trigger automatically once the specified conditions met (Ahmadisheykhsarmast & Sonmez, 2020). Hence, payment is embedded in the smart contract. Transparency of smart contract allows participants of contracts to assure that payable amount is blocked in the system in such a way that no parties could access the money till the contract conditions are satisfied. Participants' wallet addresses besides initial and final payment amount are also defined in contract drafting stage. Finally, the smart contract is deployed on a blockchain supporting blockchain Ethereum.

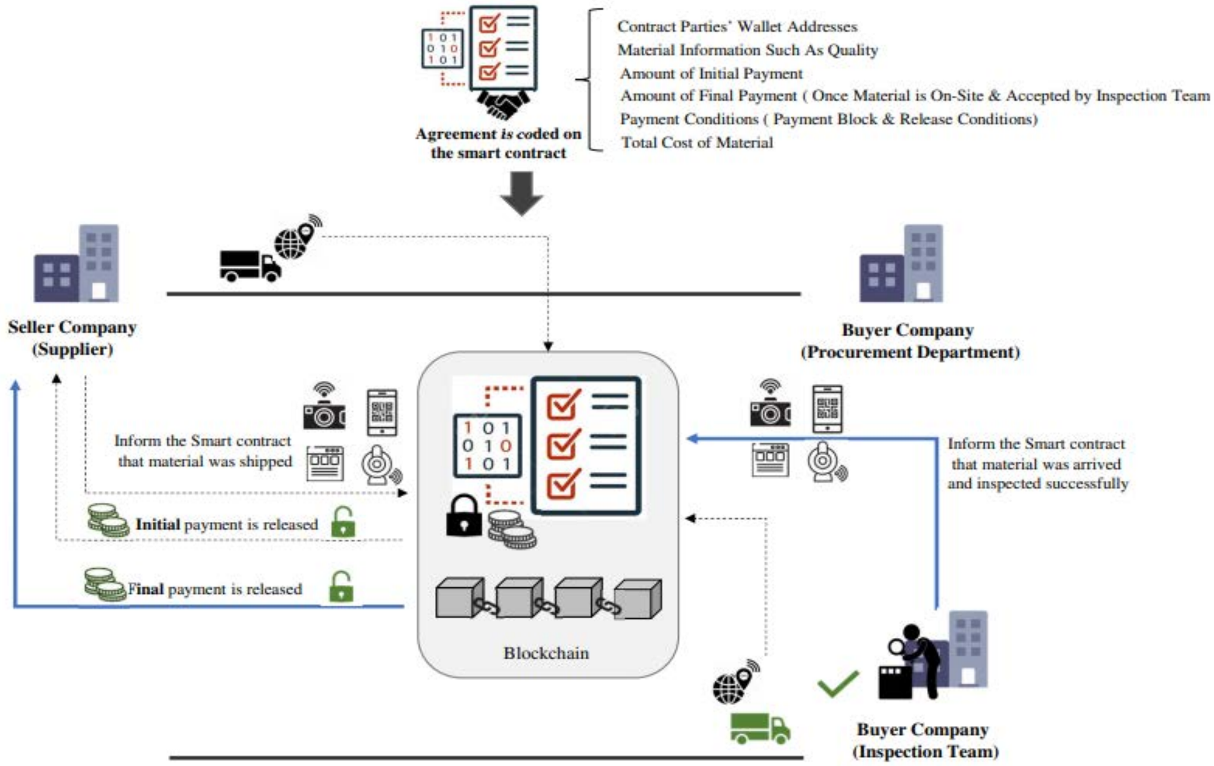

Fig. 3. Proposed Smart Contract Based L/C System Framework

At the first stage of proposed framework, the supplier organization informs the buyer company as the material or equipment is ordered away through the smart contract. The interaction of the parties with the smart contract could be provided by a user interface or IoT devices such as smart sensors or QR codes. Once the smart contract notifies the shipment, the initial payment is deducted from the blocked amount and transferred to supplier's wallet address. The real time shipment status could be provided by the GPS data stored in the blockchain. At the time of delivery of items on construction site, the quality standards, which were drafted in contract in smart contract stage, are verified by the buyer company. To finalize the final payment for the delivered items, The procedure requires buyer's confirmation. So, the smart contract deduces the final amount from the blocked amount and triggers into the suppliers' wallet address once the buyer notifies the smart contract about item verification.

6. Discussion

Applying the smart contract technology in procurement phase promises a significant potential to accelerate the process and reduce the cost substantially. Also, the payments are assured since the smart contract locks up the agreed amount and releases automatically based on the preset conditions. Different from third party involvement and required fees, smart contract framework do not include any extra cost since all the preset clauses are executed by the smart contract automatically. Hence, involvement of the intermediaries to contract execution and payment transaction are minimized. Furthermore, all the information during the process regarding the transactions, operations, real time status of material, and data provided by IoT devices are stored in the blockchain and distributed throughout the contract participants in the secure blockchain network. Due to the fact that blockchain environment is immutable, no data is lost or modified. Hence, the disputes, payment withheld, and ambiguities among the parties could be significantly reduced.

There are various blockchain platforms which support the smart contracts development. Ethereum is one of the common blockchain network with the largest market cap that enables smart contract application. Ethereum is a digital asset and its tradable. One possible critic for the proposed approach may come from the volatility of cryptocurrencies like Ethereum. Due to the increased demand from investors across the world, prices of cryptocurrencies could change from day to day. Ethereum prices for example, grew over %10.000 between the years 2016 to 2021. Considering the fact that construction procurement could take months, both supplier and buyer may hesitate to apply the framework because of the fluctuations. Nevertheless, there are stable cryptocurrencies to hedge the price fluctuations stable coins like Dai or USDC which could be selected as currency of the platform. Both USDC and Dai is aimed to fix 1 unit of cryptocurrency to be equal to 1 U.S. dollar which makes it very suitable to use. Both currencies also work with smart contracts. Therefore, volatility problem could be eliminated in order to create a more efficient framework based on smart contracts for construction procurement. Another possible critic may come from the fact that construction sector cannot adopt new technologies easily. Since smart contracts are very new and not commonly used, both supplier and buyer may hesitate to use this technology. However, there are various applications of smart contracts and use of blockchain network is pervading. If the proposed framework can be proved as an efficient mechanism and advantages can be understood, people would choose to work with this system.

7. Conclusion

Smart contracts promise significant improvement to the traditional L/C applications in construction procurement. Lack of trust between buyers and supplies during international trades can be surpassed using smart contracts, which will ensure a smoother procurement process without any extra fee due to the third-party involvement. Moreover, physical control over delivered items is possible with IOT devices, which significantly reduces the risk of buyer and makes procurement more reliable. In this paper, a framework is discussed in order to show that smart contracts can be used with IOT devices in order to improve the procurement process. At first glance, volatility seems are very important concern for the use of smart contracts. However, as stable blockchain networks arise, this problem automatically diverges. The diffusion of new technology is the biggest challenge against the use of smart contracts in construction. As applications related to smart contracts populate, advantages will appear and construction practitioners would learn from it, which ultimately would make it possible to use this new technology in international trades more often.

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Mechanical Characteristics and Durability of Concrete Made with Treated Domestic Wastewater and Recycled Concrete Aggregates

Abdelrahman Abushanab[1] and Wael Alnahhal[2]

[1] Ph. D. Candidate, Department of Civil and Architectural Engineering, College of Engineering, Qatar University, Doha, Qatar.
[2] Associate Professor, Department of Civil and Architectural Engineering, College of Engineering, Qatar University, Doha, Qatar.
wael.alnahhal@qu.edu.qa

Abstract
Massive amounts of fresh water and natural aggregates are annually used for concrete applications, resulting in a rapid depletion of freshwater and natural aggregate resources. This necessitates the need of replacing fresh water and natural aggregates with recyclable materials such as treated wastewater and recycled concrete aggregates (RCA). This study, therefore, investigates the mechanical characteristics and durability of three concrete mixes with different concrete mixing water types (fresh water and TWW) and coarse aggregate types (natural aggregates and RCA). Tests performed were concrete compressive and flexural tensile strengths and electrical resistivity. Test results showed that concrete with TWW recorded 6%, 7.9%, and 5.4% lower compressive strength, flexural tensile strengths, and electrical resistivity than conventional concrete, respectively. Furthermore, the combination of TWW and RCA resulted in improving the compressive strength and electrical resistivity by about 10%, whereas it increased the flexural strength by 9.2% compared to concrete mixes with TWW and natural aggregates.

Keywords
Treated wastewater, Recycled concrete aggregates, Mechanical characteristics, Durability.

1. Introduction

Significant amounts of concrete have been manufactured worldwide due to the rapid growth in the world population, urbanization, and economic development. The annual worldwide production of concrete is about 9 billion tons and is expected to further increase in the coming years, raising questions about the environmental impact and sustainability of concrete ingredients [1]. On a global scale, concrete manufacturing accounts for 10% of the total CO2 emissions in the environment [1]. Moreover, the annual global consumption of fresh water and aggregates are 2 and 48.3 billion tons, respectively [2,3] Accordingly, there is a pressing need to evaluate the feasibility of replacing fresh water and aggregates with recyclable materials in concrete applications.

Numerous studies have addressed the viability of utilizing non-potable water such as treated domestic wastewater (TWW) for concrete applications [3–9]. Studies performed by Shekarchi et al. [5] and Noruzman et al. [6] revealed that TWW showed no significant difference in the fresh properties of concrete. Asadollahfardi et al. [7] observed that the mechanical properties of TWW concrete were comparable with conventional concrete properties at different ages. Shekarchi et al. [5] pointed out that the compressive strength of TWW concrete was 17% higher than that of conventional concrete. Nonetheless, Shekarchi et al. [5] and Arooj et al. [8] found that the compressive strength and electrical resistivity of TWW concrete were about 15% lower than conventional concrete. More recently, Abushanab and Alnahhal [3] pointed out that TWW showed no significant effect on concrete mechanical properties, whereas it significantly increased the chloride permeability by 40%.

Meanwhile, several alternatives to natural aggregates have been proposed for concrete applications. One is the recycled concrete aggregates (RCA), which are produced from construction waste. The annual global construction waste exceeded 3 billion tons in 2018 [10]. Previous studies demonstrated that the residual mortar on RCA influenced the mechanical and durability properties of concrete [1,11–13]. Wang et al. [11] showed that the slump of 50% and 100% RCA concrete decreased by 15% and 25%, respectively, compared to conventional concrete. Andreu and Miren

[14] and Martı´nez-Abella [15] recorded about 5% lower density when natural aggregates were replaced by RCA. Wagih et al. [16] revealed that 100% RCA concrete achieved 15% to 23% lower compressive strength than conventional concrete. In addition, Wang et al. [11] found that 50% and 100% RCA concrete recorded 37% and 45% lower flexural tensile strength than conventional concrete. However, Alnahhal and Aljidda [12] reported that RCA showed no significant effect on the compressive and flexural strength of concrete. Ali et al [13] showed that RCA concrete had higher pores than normal concrete and thus RCA concrete recorded lower durability properties. In a recent study by Ahmed et al. [17], it was shown that combining TWW and RCA had no significant influence on concrete properties.

According to the previous discussion, investigations on the mechanical and durability properties of concrete with TWW and RCA are very limited. Therefore, further studies on the characteristics of TWW-RCA concrete are required to enrich the literature. To this end, this study investigated the compressive strength, flexural strength, and electrical resistivity of TWW-RCA concrete.

2. Materials and Methods

2. 1 Materials

Wash sand and Normal Portland cement type I was used in all concrete mixes. Two types of mixing water were used: fresh water and TWW. TWW used were received from Doha North Sewage Treatment Plant in Qatar. The chemical characteristics of both types of water are presented in Table 1. Compared to fresh water, TWW used had higher chloride, total dissolved solids, and sulphate concentrations. Two coarse aggregates were used: natural coarse aggregates (NCA) and RCA. The aggregate characteristics and gradation are illustrated in Table 2 and Fig. 1, respectively. It can be seen that all RCAs' properties were within Qatar construction specification limits (QCS-14) [18], except for the water absorption, which significantly surpassed the permissible limit.

2. 2 Concrete mixes

Three concrete mixes were prepared and tested. Concrete mix proportions per 1 m^3 are listed in Table 2. The designation of concrete mixes includes two letters. The first letter represents the mixing water type (F and T indicate fresh water and TWW, respectively). The second letter represents the coarse aggregate type (N and R indicate natural and recycled aggregates, respectively). Mix FN was prepared with fresh water and NCA and considered as the control mix. Mix FN was designed as per ASTM C192/C192M-19 standards [19] with a target cylinder compressive strength of 50 MPa. Mixes TN and TR were made entirely with TWW and/or RCA.

Table 38. Chemical characteristics of fresh water and TWW.

Characteristic	Unit	Fresh water	TWW
pH	-	8.1	7.8
Chloride (Cl^-)	mg/l	14.1	511
Phosphate	mg/l	<0.03	9.19
TDS	mg/l	90	1690
Sulfate ($SO4^{-2}$)	mg/l	6	490

Note: TDS= total dissolved solids.

Table 39. Sand and coarse aggregate properties.

Property	NCA	RCA	(QCS-2014) Limit [18]
Bulk Dry Specific Gravity (%)	2.89	2.47	-
Bulk SSD Specific Gravity (%)	2.91	2.55	-
Bulk Apparent Specific Gravity (%)	2.95	2.70	-
Water Absorption (%)	0.72	3.51	2
Elongation Index (%)	24.0	8.00	35

Los Angeles Abrasion (%)	8.10	27.84	30
Soundness (%)	2.17	12.6	15
Water Absorption (%)	2.89	2.47	-

Note: SSD = saturated surface dry and APP = apparent.

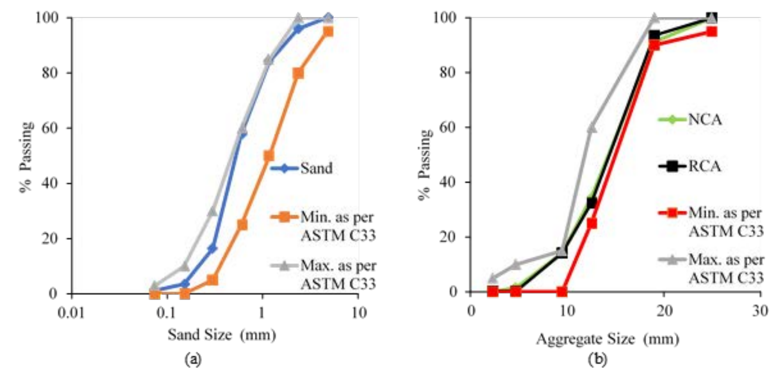

Fig. 46. Gradation of sand and coarse aggregates.

Table 40. Concrete mix proportions (kg/m^3).

Mix	Fresh water	TWW	Cement	NCA	RCA	Sand
FN	156	0	349	1075	0	708
TN	0	156	349	1075	0	708
TR	0	156	349	0	942	708

2. 3 Methods

Concrete compressive strength was evaluated at 28 days using three cylinders of 100 × 200 mm from each batch according to ASTM C39/C39M-20 [20]. In addition, concrete flexural tensile strength was evaluated using three prisms with dimensions of 100×100×500 mm according to ASTM C78/C78M-18 provisions [21]. Moreover, concrete electrical resistivity was tested at 28 days using three cylinders of 100 × 200 mm from each batch according to AASHTO TP 95 standards [22].

3. Results and Discussion

3.1 Effect of TWW

Table 4 presents the compressive strength, flexural tensile strength, and electrical resistivity results for all concrete mixes. It could be seen that the complete replacement of fresh water with TWW in mix TN slightly decreased the compressive strength by 6%. The presented results also indicated that the flexural tensile strength of mix TN decreased by 7.9% at 28 days in comparison with mix FN. That was because TWW contains higher amounts of suspended solids and dissolved oxygen than fresh water, which, in turn, increased concrete pores and decreased the bond between cement and aggregates. The drop in the mechanical properties of TWW concrete could also be related to the high concentration of phosphate in TWW, which alerted the interface layers in concrete and delayed the hydration of cement. The results of Asadollahfardi et al. [7] also confirmed that mixing concrete with TWW slightly decreased the mechanical properties of concrete.

Moreover, it could be seen that TWW slightly decreased the electrical resistivity of mix TN by 5.4% compared to mix FN. This reduction could be attributed to the suspended solid in TWW, which increased concrete internal pores. Furthermore, TWW is composed of higher concentration of iron than fresh water. Thus, the movement of electrons in TWW was promoted in TWW concrete compared to that in freshwater concrete.

3.1 Effect of RCA

It was observed that replacing NCA with RCA in mix TR resulted in a 10% lower compressive strength as compared with that of mix TN. That was due to the residual mortar on RCA, which affected the internal cracks and pores of concrete and decreased concrete bond with aggregates and, in turn, decreased concrete capacity under compression. Nonetheless, it was observed that TWW-RCA prism TR exhibited 9.2% higher flexural strength than prism TN and approximate similar flexural strength to prism FO. This is probably attributed to the chemical reaction between sulfate in TWW and calcium in RCA, which produced calcium monosulphoaluminate hydrate and, in turn, improved the cohesion of the ITZ layers between the old and new mortars. Likewise, the results showed that mix TR achieved about 11% lower electrical resistivity than mix TN, owing to the residual mortar on RCA, which alerted the internal cracks and pores of concrete. The results are in good agreement with Abushanab and Alnahhal [3] and Ahmed et al. [17].

Table 41. Compressive strength, flexural tensile strength, and electrical resistivity results at 28 days.

Mix	Compressive strength (MPa)	Flexural tensile strength (MPa)	Electrical resistivity (kΩ·cm)
FN	50.9	5.32	18.5
TN	47.8	4.90	17.5
TR	42.9	5.35	15.6

4. Conclusions

This study evaluated the compressive and tensile strengths and electrical resistivity of three concrete mixes made with different concrete mixing water types (fresh water and TWW) and different coarse aggregate types (natural aggregates and RCA). The following conclusions could be drawn:

- The use of TWW in concrete slightly decreased the mechanical characteristics and durability of concrete.
- The compressive strength and electrical resistivity of TWW-RCA concrete decreased by 10% and 11%, respectively, whereas the flexural tensile strength increased by 9.2% compared with TWW-NCA concrete.
- Both TWW and RCA affected the internal cracks and pores of concrete.

5. Acknowledgement

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ID 99

Design Error Costs in Commercial Construction Projects: The US Perspective

Khalid Siddiqi[1] and Aslam Hayath[2]

[1&2] Kennesaw State University, USA
ksiddiqi@kennesaw.edu

Abstract

Design errors are a part of almost all construction projects, and they have led to considerable impact in terms of project costs, quality and performance. These errors have contributed to project failures and deliberate efforts are required to analyze and restrain them for successful completion of projects. The objective of this study was to determine the magnitude of design error's costs in mid-sized commercial projects in Atlanta, US with project value up to 20 million, regardless of procurement or contract methods. The research methodology includes collecting data from industry experts who have completed projects in this range through a structured survey questionnaire. In addition, few general contractors were also interviewed in person to seek responses on design-error-based cost increases in their projects. The intended audiences for this study are design professionals and design firms associated with commercial construction projects. This study concluded that design errors, irrespective of contracting methods, contributed to an increase of up to 8 % of project cost in commercial construction projects.

Keywords

Design errors, error costs, project costs, commercial construction, procurement methods.

1. Introduction

The objective of this study was to determine the magnitude of design error's costs in mid-sized commercial projects in Atlanta with project value up to 20 million, regardless of procurement or contracting methods. The study was based on the hypothesis that design errors contribute to an increase of project cost on an average of 5%, in commercial construction buildings in general. Design errors could trigger major project impacts the expectations of owners and contractors in terms of cost, time and quality. To manage and control such risks of design error costs, there is a need to analyze the probabilistic assessment of estimate before construction. The prime purpose of the study was to determine percentage cost increase caused by design errors in scoped range of commercial projects. Extensive literature survey of design errors, causes, classifications, effects, solutions, influences on project type, preventions, identification and quantification methods was carried out, to acquire background information on this subject. Later a structured questionnaire was developed in consultation with contarctors impacted by design errors. A pilot questionnaire preceeded the actual survey. The pilot and its results were discussed, refined, re-framed in collaboration with industry experts before rolling out the survey. The questionnaire survey circulated generated twenty-two respondents, in addition seven industry experts were interviewed in person to seek their feedback to confirm the findings from the study.

In construction industry it has been widely acknowledged that design errors have a greater influence on the project outcomes in terms of quality, time and cost. Design errors dominate the cause of accidents, and it has been revealed that gross errors cause 80 to 90% of failures in buildings, bridges, and other civil engineering structures [9]. Considerable amount of research has been done to learn about error impacts on construction and engineering projects [1]. Even at a project level design error costs are rarely measured, although a proclivity exists for them to manifest as change orders or claims [6]. Much of the past research has examined design error costs is anecdotal or based upon a limited number of cases [1,8].

Design error costs in terms of percentage of project value were determined [11] for construction projects in Australia. This study was based on an approach, similar to the above mentioned research and was intended to determine magnitude of design error costs for mid-sized commercial construction projects in Atlanta US with different parameters. To understand what design errors meant, numerous definitions of error were identified in normative literature [9]. Tucker and Edmonson [13] define error as "the execution of a task that is either unnecessary or in-correctly carried out".

Similarly, another definition of error by Reason and Hibbs was "the failure of planned actions to achieve their desired goal, where this occurs without some unforeseeable or chance intervention" [12]. The term "failure" is often used interchangeably with error; however, a subtle difference between error and failure exists. A failure is "an unacceptable difference between expected and observed performance [2]. A lack of definition has resulted in a great deal of confusion pertaining to the underlying causes and costs of errors in projects [3].

For this study the authors used definition of error as defined by Reason and Hibbs in 2003. According to their definition "An outcome that essentially involves a deviation of some kind whether it is a departure from the intended course of actions, departure from a path of actions planned towards a desired goal or deviation from appropriate behavior at work" [12]. It is important to note that several latent conditions reside within project systems that influence error-provoking activities to take place and, therefore, contribute to design errors occurring downstream during construction [6]. Moreover, when Deisgn Firms are placed under schedule pressure by clients to design and document, a propensity exists for them to omit task or detail to conform to schedule. This often result in errors in contract documentation, which was identified as a major cause of disputes within construction projects [8].
Design errors which were considered in this study are the ones which manifested into

- Rework
- Change orders
- Claims or any design error which trigger cost implications.
- Combination of one or more or all the above parameters.

The cost of design errors was reported to be lower in building projects (Love & Li ,2000) revealing that they accounted for 14% of rework costs. It was revealed that design errors contained within contract documentation alone can contribute to a 5% increase in a project's contract value (Lopez & Love, 2012). Despite the considerable amount of research that has addressed error causation, effects in construction projects the actual costs associated with design errors remain unknown because they are not formally measured by organizations (Lopez & Love ,2012). This paper intends to address this shortfall by deriving design errors costs from experts estimates for the commercial construction projects in Atlanta.

2. Research Methodology

2.1 Data Collection

Atlanta a metropolitan city has always been considered as commercial hub for Real Estate Developers venturing into commercial construction projects. Availability of data and easy accessibility has led to focus this geographical location in the US for the purpose of the study. Projects of contractt value up to 20 M were considered. Instead of developing a survey questionnaire that sought general opinions from respondents about errors in design, respondents were asked to select one of their recently completed projects to answer survey questions. The survey questionnaire focused on the perceived causes, associated costs, organizational and project management practices implemented.

The relevant data for this study was obtained through the following process. Initially a pilot survey questionnaire was devised and discussed with industry expert's to obtain their feedback on its comprehensibility and suitability for identifying Design Error cosrs. Based on the feedback the survey questionnaire was altered and then administered among the General Contractors who were members of Associated General Contractors of Georgia. Survey questionnaire targeted a respondent pool of project professionals mainly from three disciplines designers, general contractors, owners or owner representatives who recently completed commercial construction projects within the range of 20 Million in Atlanta US.

The data was collected by circulating survey questionnaire through email, which had generated forty-two respondents. These include twelve respondents from design professionals, fifteen respondents from contractors and seven from owners. In addition, eight industry professionals, two from owners and three each from contractors and design professionals were also approached individually to cross check the the study findings. Each one of the eight industry professionals interviewed, possessed a minimum of 15 years' experience in industry and had completed entire project involving design errors. Each interview in person lasted from 40 minutes to one hour. Almost all participants spent more than half of the interview time talking about design errors impacts on their project cost and time. Figure1 depicts the mixed pool of respondents based on their profession.

The scope of the study though was restricted to Georgia, but responses were solicited from members of Associated General Contractors (AGC), which is a national organization with chapters in each US State. The members of AGC execute projects all over the US and encounter common problems including design error issues focused in this study.

Preconstruction estimates completed by contractors are based on types of design drawings completed by Designers. These designers include architects, civil, electrical and mechanical engineers, in addition to numerous other designers involved in each construction project. These drawings may have various levels of design errors due to many factors such as unclear overview of the designs, lack of coordination process, and human errors & omissions and mistakes.

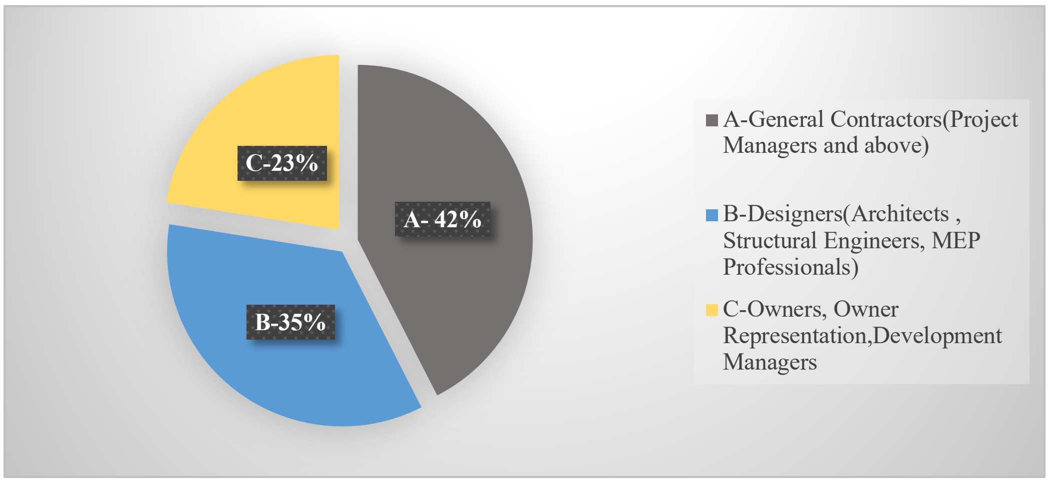

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Fig.1. Survey respondents by professional disciplines

The overall data thus generated from both survey questionnaire by email and in person interviews resulted in a sample size of forty projects to arrive at conclusions. The perceptions of the participants are outlined in results and inferences

The Table 1 below indicates the project typologies and their contract value range which have been accounted in the data collection of forty projects. Certain outliers in the data has been excluded to arrive at design error costs with adequate precision on the basis of available data.

Table 1. Project typology

Project Type	Contract value range in million	No of projects
Hotels	16-18	3
Mixed Use	17-21	4
Commercial- offices	10-15	14
Commercial- retail	8-12	11
Commercial- recreational	8-20	8
Total	-	40

2.2 Data Analysis

The data collected was organized in tables, pie charts or bar graphs based on their suitability for analysis purpose. The dependent variable for the study was Design Error cost and the independent variable (Projects) within a range of $ 20

Million project value. The distilled data was used to process and arrive at the magnitude of design error cost. Ratio scales were used to measure design error costs based on the project value. Mean, mode and average of design costs were extrapolated from the variables and percentage average was derived from the pool of the data collected. Empirical formula was adopted to arrive at the average cost of the grouped data. The data integrity was validated since the experts who both answered the questioners and who were involved in the person interview process had more than a decade of professional experience and expertise in the commercial projects within the prescribed geographical region.

3. Results and Analysis

The data reliability was ensured through the use of experienced professionals having expertise of handling start-to-finish each project surveyed. The Figure 2 below depicts the impact of design errors on time, cost and organization values on a scale of severity from 1(least impact) to 5(severe impact) with respect to three respondents a) Owners b) Design professionals c) General contractors.

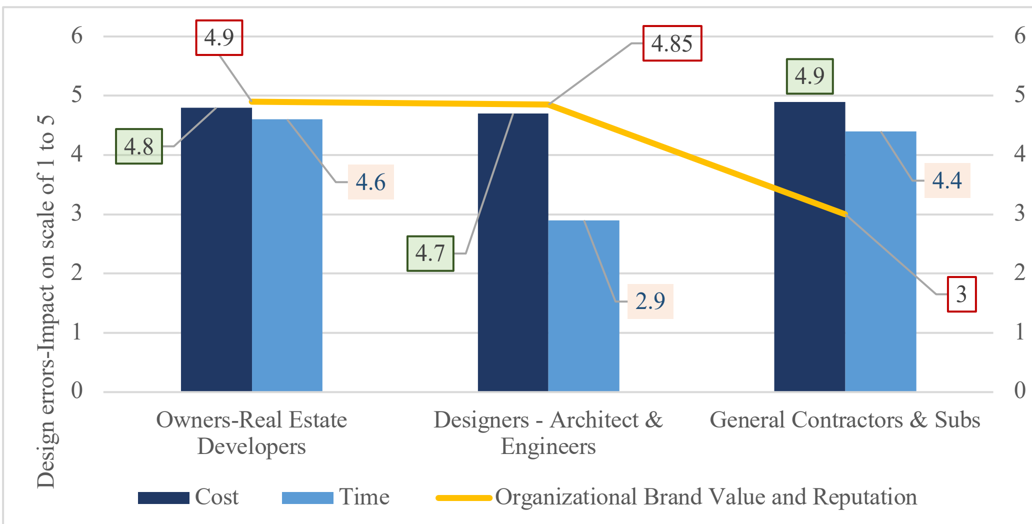

Fig. 2. Design Error impacts on Cost & Schedule and Organizational value based on the survey

All respondents unanimously agreed that design errors had severe impact on Cost with 4.9 value, but there were some variations in opinions with respect to Schedule. General Contractors and Owners both agreed that design errors had severe impact on Schedule with 4.6 value as average, however respondents from designer's pool indicated that impact on Schedule can be compensated by adopting appropriate mitigation measures and the severity was rated as 2.9. They did not consider design errors impact on Schedule as critical as Cost. While designers and owners were on the same page with respect to the impact of design errors on organizational brand value was severe, on the contrary General Contractors had different perspective and their rating was low as 3 out of 5 in terms of severity.

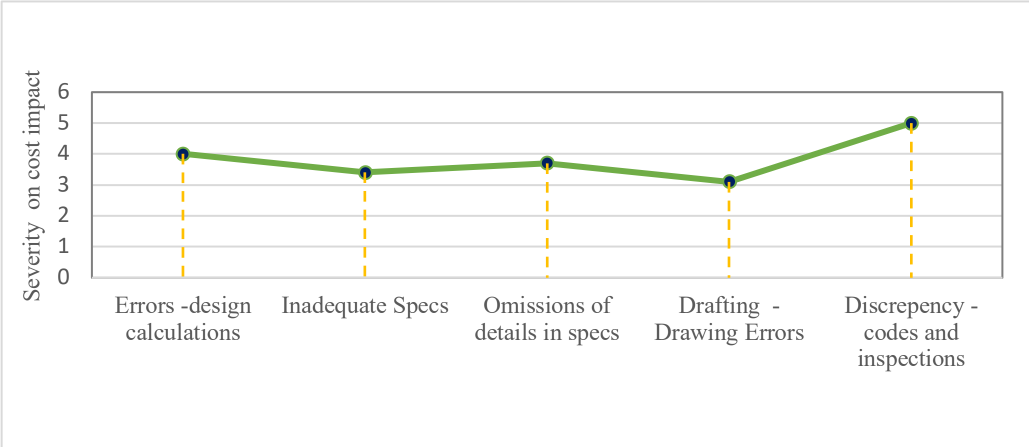

Fig. 3. Impact of Design Error types on Costs

Figure 3 illustrates the cost impact of each design error type on scale of 1 to 5, 1 being least impact to 5 being most severe. As per the data output discrepancies between codes and local inspections had value of 5 (most severe). One major concern of the respondents indicates that there is a gap or technical non-agreement between the Local Regulators. Infact 96% of the respondents indicated that though architects and owners comply with the codes, the local inspectors disagreed, which resulted in escalation of time, cost and additional unanticipated rework. However, 87% of the respondents suggested that Drafting & Drwaing error impact value on project Cost is 3, least but not null. Drafting errors mostly can be mitigated through the RFI process during the construction. It was observed that all respondents didn't rate any of the above factors listed in the graph below 3 in terms of severity.
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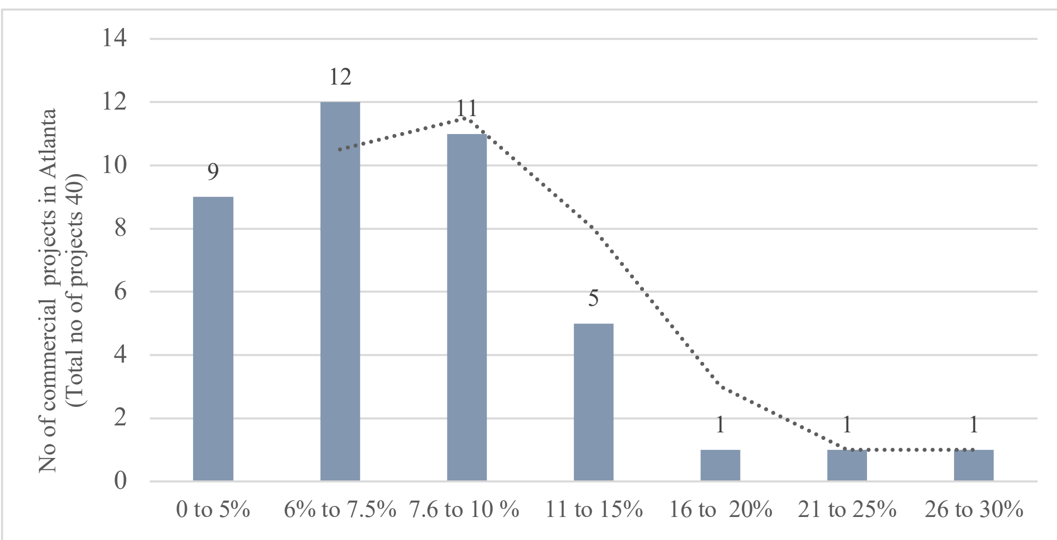

Fig. 4. Design errors costs as percentage of project contract value in commercial projects

In this study average project cost increase due to design errors a sample of 40 projects were analyzed in detail from the collected data. Figure 4 represents the variation of design error costs as a percentage of total project cost arrived at from data (X-Axis). The Y-Axis lists the number of projects included in the analysis. The range of Cost increase varied from 3.5 % to 30% due to Design Errors ,which were manifested as claims, reworks and change orders. It is quite evident from the graph that the mode is 6 to 7.5 % based on the survey. Few projects had the anomaly of 30% increase in terms of project cost. The specific case in which 30% increase in project cost was caused by improper design briefs received by designers. The improper design brief led to inaccurate design calculations, which ultimately resulted in large technical impacts.

It was also quite evident that none of the respondents indicated that design errors costs were nil or zero based on their experience, which again reinforces the fact that design errors are part and parcel of construction industry.

Table 2. Design Error Rankings

Design Error costs range	Frequency	Percentage %	Ranking
0 to 5 %	9	22.5	3
6 to 7.5%	12	30	1
7.6 to 10%	11	25	2
11 to 15%	5	10	4
16 to 20%	1	2.5	6
21 to 25%	1	2.5	7
26 to 30%	1	5	5
Total	40	100	

Table 2 illustrates the frequency of the range of design error costs and their respective percentage and rankings. It is been evident that 77.5% of projects lie in the range of 0 to 10% out of which 30% lie in range of 6 to 7.5%. The mean(average) derived from the data was 8% based on the empirical formula for the grouped data collected from commercial construction projects in the scoped study.

4. Conclusions

This study was intended to determine the design error costs in terms of overall project value for commercial building projects in the range of $ 20 Million in Atlanta, US. The results from the structured survey from the industry experts and subsequent in-person interviews indicated that range of design errors on Costs ranged from 3 % to 30%. In precision design errors increased project cost by 3.5 to 15% for most of the projects. In rare cases design erors had increased project cost by 30%.

The study concluded that the commercial construction project costs had an average increase of 8% of the project value due to design errors for the projects considered in the study scope. It was also revealed that design errors did not vary much based on the procurement or contracting method for commercial construction projects. The study also concluded that these design errors not only had impact on cost but they had also considerable impact on the owner's reputation..The results also indicated that design errors had been prevalent in commercial construction projects even when advanced software's were implemented. The use of software's as per the expert's feedback were able to minimize the design errors to a considerable extent but did not eliminate them. None of the respondents indicated that the design error cost was zero in their projects. Therefore, it is obvious that design errors and their cost implication in projects remains a concern in commercial construction industry.

One outcome of this study was that there is always some level of disagreement between Regulators and Project Team members in terms of code compliance in designs. The discrepancy persists despite code compliance claimed by the Designers. Survey indicated that owners, designers and contractors agree on the same unanimously that there is a technical gap existing between the codes and inspection results that impact Costs and Schedule. Further research is needed to identify specific areas of code compliance disagreements between Designers and Regulators.

This study provides initial platform to examine the design error costs in new commercial projects in scoped in the study. The study focus was for only new projects and did not cover renovation or other types of projects. Further studies are recommended to identify the average design error costs for renovation and refurbishments commercial construction projects.

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Framework for the Classification of COVID-19 Force Majeure Delay Events

Hasan Mahmoud[1], Salwa Beheiry[2]

[1] Ph.D. in Engineering Systems Management, American University of Sharjah
[2]Associate Professor at Civil Engineering Department at the American University of Sharjah, UAE, Corresponding Author
sbeheiry@aus.edu

Abstract
Time is always of the essence in the construction industry, and all projects depend on timely execution for their success. All stakeholders aim to achieve a project's goals within the time constraints set during the planning stage. However, delays do occur, and often some could be due to foreseen or unforeseen risks or an act of God. Moreover, the current outbreak of COVID-19 has meant that the construction industry suffered even more delays. Most of the delays are labelled as force majeure which are events that cannot be foreseen by any party due to the outbreak; however, significant consideration of an event's material circumstances and the forecast-ability of the specific reasons for the delay are required before this labelling is considered in its legal sense. Thus, this study aimed to develop a framework for the identification of delay events during the outbreak of COVID-19 via a logistic regression model, and assessed if such events could be labelled as force majeure. The study examined the literature to identify the factors that lead to the delay event and the force majeure conditions. Moreover, data was collected from industry experts in semi-structured interviews to identify and confirm the factors that are usually considered when a claim of force majeure is evaluated. Finally, the study developed a framework and a Claims Scoring Metric (CSM). The CSM saves contractors the cost of preparing ineligible claims and saves the project owner the cost of reviewing such claims. It assists in the initial identification of delays caused by the COVID-19 pandemic before a thorough evaluation is needed. The framework was validated via a case study with results matching the outcome of the delay analysis.

Keywords
Project Delays, COVID-19, Force Majeure, EOT, Claims Scoring Metric.

1. Introduction

Time is considered the most valuable asset in a construction project, much more important than the actual money value. In his paper Fawzy et al. (2018) stated that any delay in the project's duration has adverse effects on the client as it will delay the start of the earning cycle of the project in terms of project completion and handover to the end-user. Even though the project timeline or program of works is usually insufficient to finish all activities, the delayed parties will still be held responsible for the delays they cause in the project.

There are numerous reasons for project delays or time overrun. They could be ascribed to any of the parties in the project (González,2013). However, as per Birgonul et al. (2015), these variables have started another study field, called delay analysis.

Rules and regulations govern the relationship between the parties in a project, but issues and conflicts are bound to occur. Many issues can arise in a construction project that can cause distress and conflict between the parties, and the predominant ones can delay a project. As such, contractors opt to submit an extension of time claims to reduce or eliminate the liquidated damages that project owners might apply to recover damages that result from the delay of the project being handed over.

While some delays result from a contractor's fault, other delays might be out of the contractor's control, and, in principle, the contractor should not be held responsible for such delays. The latter was manifested during the current outbreak of the COVID-19 pandemic. Although some contractors claimed their projects' delays resulted from the pandemic as a force majeure event, clients were hesitant and without the means of verification to announce the claims as valid.

This paper will build on the previous literature on the application of force majeure and apply the same concept to the recent outbreak of COVID-19 to build a framework for the identification of COVID-19 force majeure events and a logistic regression model to determine the likelihood of an award of such claims using the proposed framework. The developed framework is a result of literature review to develop an understanding of the elements considered while evaluating a claim that has force majeure events, as well the impacts of such delays on the project performance. Afterwards, interviews with industry experts were conducted to highlight the most important aspects of claim evaluation and judgment. Finally, the framework is developed along with a mathematical representation to facilitate the calculation of an index that will assist stakeholders in evaluating the merit of claim on a high level. As a result, the framework will also serve as guidelines of claim preparation to contractors in order for them to fortify the claim and increase the likelihood of award.

2. Literature Review

Construction Projects Delays and Claims

These delays can occur for different reasons and range from an excusable delay to one that could terminate the contract. As Gonzalez et al. (2013) discuss in their paper, there is always a compelling need to study the delays, causes, impacts, causing party, and the fair compensation owed to the affected party.Gonzalez et al. (2013) also classify the types of project delays as excusable and non-excusable, in addition to four further subcategories in the construction industry.

The excusable compensable delays. This type of delay is usually the fault of the owner, owner representatives, or the consultant. This means that the cause of the delay is out of the contractor's hands. Moreover, the owner must compensate the contractor with more time or money or depending on the delay's size and extent. Shahsavand et al. (2018) clarified how configuration changes, end-client adjustment, civil guideline changes, and various requests could be viewed as the most prominent causes of such a delay. For this situation, the owner must then increase the project's duration by granting the contractor an Extension of Time (EOT) as the contractor will require additional time than what was initially planned for the project's execution. Another aftereffect of this deferral could be the proprietor's commitment to making up for the prolongation expense due to time augmentation over the original duration.

The excusable but non-compensable delay. For this type, the project owner must grant the contractor an EOT without granting him any cost associated with the delay, as per Shahsavand et al. (2018). This type of delay is almost always attributed to force majeure, which are out of the contractor's hand, while also not being caused by the owner, such as weather conditions, terrorist attacks, chemical or biological spills, etc., the existence of archaeological remains on site.

The non-excusable and non-compensable delay. The leading cause of this delay is the incompetence of the contractor to execute such a project. This could be due to the contractor's limited financial ability, limited knowledge and expertise, and poor planning and execution. This type of delay entitles the owner to apply the contractor's pre-agreed penalties for delay damages, as Fawzy et al. (2015) explained.

The concurrent delay. As outlined above, delays could be the responsibility of either the contractor or the client in any construction project, but when there is a delay, and the responsible parties of this delay are both the contractor and the client, it is called the concurrent delay. This type of delay could be easily explained when the contractor causes a delay by underperforming in their construction activities, and the client also causes a delay in changing the design or missing payments to the contractor, or even failing to provide information to the contractor. However, this type of delay does not entitle any party to recover damages from the other party. Moreover, both parties must work collectively to put an action plan to mitigate the extent and the impact of the delay (Emam et al., 2014).

There are measures in the construction industry to extend a project's duration, but the contractor's main pretence is that the contractor must not have directly or indirectly caused the delay. When the contractor executes the project on time and an event outside their control occurs, the contractor shall be entitled to submit a claim for the extension of time. The leading causes of such type of delays are strikes, weather conditions, change of specification, change in the design, delay of a nominated subcontractor, delays in receiving information or payments, and Force Majeure (Emam et al. ,2014).

When it becomes known to the contractor that a delay is potentially happening, the contractor shall give written notice to the client describing the delay's nature, the extent of the delay, and the possible measures to mitigate the delay. The owner must then evaluate the contractor's eligibility to get this claim and either grant or reject the claim. Claims assessment is a tedious process, and it usually is referred back to the actual progress on-site and considers the measures that the contractor has implemented to avoid this delay and the period of the notification given to the owner before the actual results of the delay.

COVID-19 as Force Majeure and Construction Delay and Modelling

Force majeure in construction contract terms is defined as an exceptional event that is not in the control of either party, and neither party could foresee before entering into the contractual agreement (Alshammari et al., 2017). Therefore, these events are considered an act of God which neither party controls, and, in good faith, all parties in the contractual agreement have exerted their best efforts to mitigate these events' impact. Therefore, with the recent outbreak of COVID-19 and the several warnings of the pandemic by the World Health Organization (WHO) when the virus outbreak started in Wuhan, China, the world economy has been impacted severely (WHO, 2020).

Many sectors of the economy have taken a significant hit, including the construction industry. Since the construction industry is largely dependent on manpower, the laws of social distancing and reduction of capacities were significantly disruptive. On the other hand, Alenezi (2020) indicated that the most devastating delay factor to construction project was the hyperinflation of materials prices during the pandemic. On the other hand, some of the major reasons for delays in the construction industry have been regarded to the project owners and consultant due to their vast power on the course of the project.

There are several ways the pandemic impacted the performance of construction projects. Gamil, and Alhagar (2020) indicated that other than the shortage of the materials that occurred due to the suspension of world-wide fright during the peaks of the pandemic, there are several impacts that did greater harm to projects. Some of these impacts are the cost overruns due to the limitation of the labour availability, time over runs due to the reduce capacities, suspension of projects due to the uncertainty of survival, and finally the lack of job security which impacted the motivation of the labors severely.

Kabiru and Yahaya (2020) indicated that the very definition of force majeure is related to the ability to foresee the delay event and its impact on the project performance. While in some contract clauses of epidemic are included, other contracts generalize the events that are due to nature as acts of God. Thus, serious consideration by all stakeholders is required to determine the applicability of the force majeure clause in the contract of the project to the COVID-19 pandemic. However, the existence of a force majeure clause in the contract does not relieve the contractor from incurring liquidated damages for the delays caused by the non-performance that are attributed to the impacts of COVID-19 outbreak. Sometimes a careful consideration of the actual language of the clause can contribute largely to its interpretation. Furthermore, the authors believe that there are many conditions and prerequisites for a force majeure claim during the pandemic to be admissible such as the timely submission of the claim and efforts of mitigation that are taken to reduce the impact of the outbreak on the performance of the project.

Additionally, Hansen (2020) illustrated that the pandemic had shown the importance of including a well written force majeure clause in construction contracts to avoid any disputes in case such events reoccur in the future. Moreover, the author indicated that COVID-19 outbreak can be labelled as a trigger for the use of the force majeure clause in construction contract since it is unforeseeable, unavoidable, uncontrollable, impracticable, and beyond the responsibility of either party. Furthermore, Hansen indicated that some standard contract forms such as FIDIC, NEC, and the JCT include provisions of pandemic outbreak, however, they differ in the definition and the application of the clauses.

The global pandemic had taught the construction industry many lessons, none of the least is the use of new innovative materials and building systems that have less dependency on labors on site can be regarded as a significant measure to allow for social distancing which in turn allows for the industry to proceed during such outbreaks. Furthermore, it is important for project owners to support contractors through the pandemic by expediting their payments and instructing consultants to facilitate information transfer (Alenezi, 2020). Furthermore, as the pandemic had an adverse impact on construction projects Iqbal et al (2021) indicate that a crisis management approach is required for the promotion of the productivity during the outbreak while maintain the safety of the labors.

There are many different approaches to determine the contractor's eligibility for an extension of time in the construction industry, as explained by Vasilyeva et al. (2015). Nevertheless, these approaches do not consider the actual functionality of a construction project, i.e., they do not consider the sequence and properties of the construction processes. As a result, Zaho and Ding (2009) suggest more realistic approaches via the field of data analysis. However, the research still shows a gap in data analysis to assess contractor eligibility before submitting an extension of time claims. The data collected from actual projects can build entire databases rather than building assumptions and developing utopian mathematical models.

Nevertheless, in project management and planning and forensic delay analysis, data mining is appropriate as the practices depend on data accumulation. Delay analysis examination can be contemplated and investigated, discovering patterns and connections between factors to distinguish every factor's importance. As shown by Alena et al. (2015), numerous numerical models can be applied to distinguish and gauge the completion date for a specific project holding every other variable constant. Parvaneh et al. (2018) also distinguish those other mathematical models track the project and find the project's likelihood to follow the original plan. However, all these models are based on an ideal situation with no regard to the construction industry's actual complexity and sequence.

The literature has also indicated a need for a framework to classify delay events related to the COVID-19 outbreak and the force majeure clauses' applicability on these events. As such, this study will develop a framework that can assess project owners in classifying delay events during the outbreak of COVID-19 as force majeure results or the shortcomings of contractors.

Therefore, there is a need for exploring the nature of the events that lead to force majeure, as many aspects have to be considered before labelling the COVID-19 outbreak as a force majeure (Glover, 2007). Nevertheless, the actual circumstances of the event have to be analysed before their qualification as a force majeure mainly the existence of a force majeure clause in the contract, the efforts of forecasting the event, and the mitigation efforts of the event (Alshammari et al., 2017).

The study also examined the applicability of force majeure clauses on the COVID-19 outbreak to identify the delay, its reasons, and its implications on construction projects. Furthermore, the literature review aided the study in exploring the use of data analytics in project delay analysis and highlighted the use of binary logistic models in construction contracts.

Therefore, there is a need for thorough consideration of the event claimed to be force majeure caused by the COVID-19 outbreak on a case-by-case basis. There is a need for an identification framework of COVID-19 force majeure events in construction projects. All research and current practices have been based on theoretical approaches, and there are no available tools to aid the contractor in this area. Hence, this research can provide new insights to learn from experience and refine the current practice of project planning. As a result, the authors have identified a gap in the literature regarding practical tools that could be used to assess and classify delay events of projects impacted by the COVID-19 outbreak. Furthermore, the study also aimed to build a logistic model that practitioners can use to validate different claims. Finally, the study will also provide recommendations to the contractors to ensure that their claims meet the clients' stratification and would most likely be granted.

3. Methodology

To meet the objectives, the study collected qualitative and quantitative data. The qualitative data was collected to explore force majeure due to the COVID-19 outbreak and develop the framework. On the other hand, quantitative data was used to build the model, examine the model's variables and eventually test its validity. Moreover, the collected data was used to build the framework, and the CSM was built from the framework to enable a more straightforward application. Finally, a case study application was used to demonstrate the validity of the model and the applicability of the parameters.

Data Nature and Collection

Frameworks Factors Data Collection

The data required for developing the framework of identifying events as COVID-19 force majeure is qualitative data related to the collection of factors that are usually considered when evaluating such claims. All the data was collected via an electronic survey that allowed for the recording of the data. Table 1 below identifies the participants in this study.

Table 1. Study Participants.

Participant	Background
PDCP	Delay Analyst licensed with the local courts and has more than 20 years of experience in the field.
SDCP	Consultant with an engineering background with more than 20 years of experience and an extensive profile in completed projects.
DCP1	Construction director with more than 15 years of experience in the construction industry.
DCP2	Projects manager with more than 12 years of experience in the construction industry.

The choice of the study participants was based on the need to capture a wide range of opinions from different stakeholders as well as the impartial opinion of the delay analyst. The expert panel formed represents participants from the consultant side as well as the contractor side allowing for a larger prospect of expanding the important aspects of both sides of the construction industry.

This data was collected via an open-ended questionnaire sent to PDCP to collect factors that are usually considered when evaluating the extension of time claims relating to events due to force majeure events, after which the resulting factors were sent to SDCP for confirmation. Finally, the factors were also presented to DCP1 and DCP2 to examine the applicability of such factors when submitting a claim for extension of time concerning events that directly resulted from the outbreak of COVID-19.

PDCP has indicated that a routine evaluation of an extension of time claim involves the analysis of the six factors which are adequate notice of claim, the reason for the delay, the contractual basis of the claim, the duration of the delay, the impact of the delay, and the mitigation efforts.

PDCP also indicated that the investigator's judgmental objective mentality also plays a significant role in analysing the claim to assess the degree to which the contractor displayed the "goodwill" or effort to mitigate the delays and impacts. Moreover, PDCP also indicated that knowledge of contracts and proper contract administration usually leads to fewer conflicts between the client's best interest and the contractor.

Moreover, the same factors were sent to SDCP for validation, to which the factors were deemed relevant and essential. However, SDCP also indicated that the client's intention in any project usually sets different contractual events, especially in disputes and claims.

On the other hand, both DCP1 and DCP2 have agreed that these factors and the success to which the contractor can capture the efforts to achieve them in the claim can be a significant reason for approving or rejecting a claim. DCP1 also added that COVID-19 had caused delays in all construction projects worldwide; however, some contractors have used this reason to cover their delays, which is deemed unfair towards clients and their interests.

Taking the above results in mind, the conclusion can be drawn that there is a need for tools that can be used to identify events caused by COVID-19 and events resulting from contractors' faults. Therefore, Figure 1 displays the developed framework which was built from the extracted factors to help clients evaluate claims and the force majeure clause's applicability.

This framework will help the owners classify delay events during the COVID-19 outbreak as force majeure that deserves EOT consideration or as shortcomings from contractors that deserve penalty and liquidated damages for delay. Therefore, such a framework can reduce assessment and consideration times that go into EOT evaluations and guide future force majeure events to be considered.

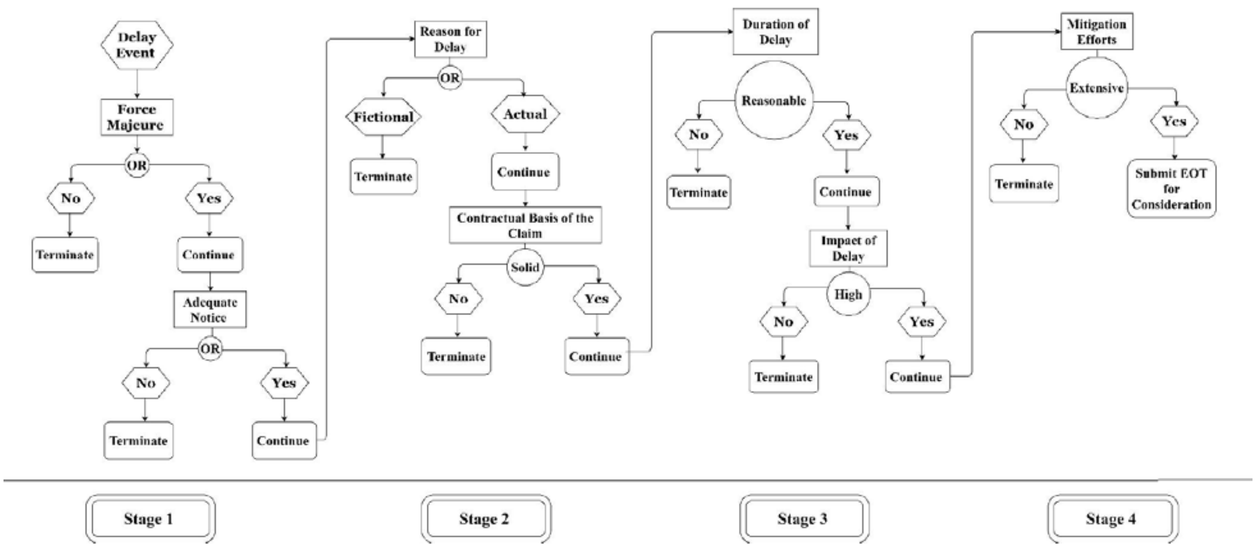

Figure 1: COVID-19 Framework.

Claims Scoring Metric (CSM) Development

After building the framework, the authors decided to build a relative measurement tool that could provide a quantitative representation of the framework to allow for interpretation. Furthermore, as the models and factors presented in the models could entail a subjective opinion in representation, the authors deem applying a linguistic-based numerical model is necessary—table 2 below provides the linguistic scale and the corresponding numerical values. The scale spans from 0 to 6 to represent the linguistic scale ranging from very low to very high.

Table 2. Linguistic Scale.

Linguistic Scale	Numerical Scale
Very low (VL)	0
Low (L)	1
Medium-low (ML)	2
Medium (M)	3
Medium-high (MH)	4
High (H)	5
Very high (VH)	6

The proposed mathematical model entails that the evaluator of the claim or the client shall score the adequacy of achievement of all the six factors based on the event submitted in the extension of time claim and that will provide a reasonable indication about the Force Majeure Occurrence (FMO), based on Scoring Factor (SF) of the six identified factors as presented in Equation one below:

$$FMO=SF1+SF2+SF3+SF4+SF5+SF6 \quad (1)$$

Where:

FMO: Force Majeure Occurrence
SF1: Linguistic Scoring for Factor 1 (Adequate notice of claim)
SF2: Linguistic Scoring for Factor 2 (The reason for the delay)
SF3: Linguistic Scoring for Factor 3 (The contractual basis of the claim)
SF4: Linguistic Scoring for Factor 4 (The duration of the delay)
SF5: Linguistic Scoring for Factor 5 (The impact of the delay)
SF6: Linguistic Scoring for Factor 6 (The mitigation efforts)

The highest score attainable in this model is 36, while the lowest score is 0, thresholds of claim acceptance under this model depending on the attitude and the direction that the client is heading. The threshold of accepting claim or moving forward with claims can be agreed amongst stakeholders on a project-by-project case.

The above model and CSM can significantly benefit the industry as they will streamline the claim assessment's subjective nature, which is the usual practice in the industry. Moreover, the introduced framework and metric will enhance project managers' efficiency, reducing the time required for claim assessment and award. On the other hand, the overall conflicts between contractors and project owners can be reduced if such tools are presented to eliminate bias.

3. Results

To demonstrate the concept application, the authors sought to apply the framework on an actual project in which the contractor submitted a claim for extension of time referring to the force majeure clause in his contract due to COVID-19 impact. The project is an infrastructure project with a value of 37,398,129.00 AED with a total duration of 387 days. The project is located in Dubai, United Arab Emirates, and the scope of the project is to construct a fire fighting and irrigation pumping station that will service two districts. The start date of the project was 17/07/2019, and the planned finish date was 07/08/2020. The equipment required for the construction was to be procured locally. However, the pipes and fittings were to be imported from abroad (China). The pipes for the pumping stations were ductile iron pipes imported from China, and the delivery of materials was planned to be delivered late in the project on (10/05/2020) due to the availability of work fronts and the readiness of the structure to receive the materials. However, the materials arrived on 21/07/2020, and the contractor sought to submit an extension of time claim to recover the delay of the shipping due to the outbreak of the COVID-19 pandemic, and the below chronology was provided:

1. The order for the material of the DI pipes has been placed on 26/02/2020.
2. On 16/03/2020, the supplier sent a notification of delay for the delivery due to the COVID-19 outbreak, which will lead to late delivery of the pipes with a projected delivery date of 09/07/2020.
3. After which, the contractor had gone through extensive deliberation with the supplier and the concerned authorities to mitigate the delay but without benefit.
4. On 21/07/2020, the material was received at the site, and the installation has commenced immediately to mitigate some of the delays.
5. On 22/07/2020, the contractor informed the Engineer of the delay caused by the late delivery via a letter correspondence indicating the contractor's intention to submit a claim.
6. On 18/08/2020, the contractor submitted an extension of time claim to extend the project duration by 72 days due to the late delivery of materials. In his claim, the contractor mentions: "Therefore, the imposed delay was out of the control of the contractor was not possibly foreseen or its effected mitigated. Hence, a total time entitlement as a result of this event was calculated to be 72 days according to the attached extension of time program."
7. On 28/09/2020, the Engineer sent a reply on the contractor's claim, which indicates the rejection of the claim due to the failure of the contractor to submit timely notices in accordance with the contract and the non-availability of factual mitigation measures.
8. The contractor on 11/10/2020 rejected the Engineer's evaluation and requested the determination of a third-party expert on the claim in order to resolve the dispute amicably.

9. Upon approval of the contractor's request, the employer engaged a court expert third party to conclude the determination that confirmed the Engineer's opinion.

The same project will be used as a case study to validate the model throughout the different stages of the framework application. Starting at stage 1 to determine the nature of the event and the at of notice by the contractor, going to stage 2 to identify the reason for the delay and the contractual basis of the claim, moving to stage 3 to assess the duration of the delay and its impact on the critical path of the project, finally concluding with stage 4 to identify the mitigation measures taken by the contractor to mitigate the delay.

Case Study Analysis Stage 1:

The analysis of the delay event in stage 1 as illustrated in Figure 2 below indicates that the delay of shipment and procurement of the ductile iron pipes for the project is due to the pandemic outbreak, which is considered as a force majeure, therefore moving to the next step, one can refer to the contract of the project where the below is specified with regards to notices: "The Contractor shall give notice to the Engineer, with a copy to the Employer, wherever planning or execution of the Works is likely to be delayed or disrupted unless any further drawing, specification, or instruction is issued by the Engineer within 28 days after the event giving rise to the claim has first arisen."

From the above, it is clear that the contractor had surpassed the contractual duration of raising notices of delay for the event, given the fact that the contractor should have raised the notice of delay to the Engineer and the Employer within 28 days from 16/03/2020. However, the contractor raised the notice on 22/07/2020, which is 100 days after the contractual duration. Therefore, the analysis should be terminated with no grounds for extension of time award due to the non-compliance with the contractual notice duration. However, for analysis purposes, the analysis shall continue to identify other grounds of rejection, if any.

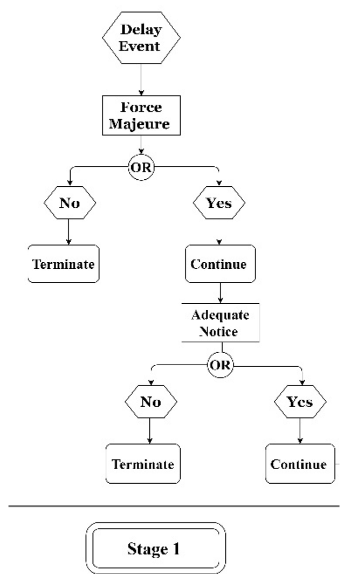

Figure 2: Case Study Stage 1 Analysis.

Case Study Analysis Stage 2:

Analysing the reason for the delay event, which is an actual reason supported by back up document from the manufacturer indicating that the shipment delay from China to Dubai due to the impact of the pandemic on China at the beginning of 2020. Therefore, verifying the actuality of the delay reason and moving on to the contractual basis of the claim, it was evident that the contractor had the right to claim the extension of time based on the impact of the COVID-19 pandemic on the supply chain, considering it as an unforeseen event as per the contract extract below: "Clause 8.4 "Extension of Time for Completion" is of particular relevance and states the following;

In the event of;

i. A Variation,

ii. Any cause of delay referred to in the General Conditions, or

iii. Any delay, impediment, or prevention by the employer, the employer's personal."

Therefore, it is evident that the contractor has grounds for entitlement for an Extension of Time for Completion under the Conditions and the Conditions of Particular Application. As seen in Figure 3 below, the analysis shall continue to stage 3.

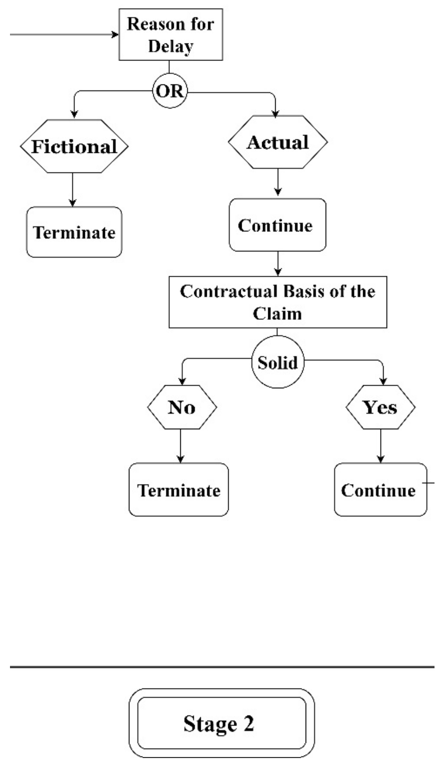

Figure 3: Case Study Stage 2 Analysis.

Case Study Analysis Stage 3:

The delay duration of the ductile iron pipes delivery was found to be 72 days; given the fact that global shipping and especially the shipping from China was impacted severely, the analysis of the duration of delay is found to be reasonable. On the other hand, checking the delay impact on the project's critical path, the mechanical installation of the equipment, including the ductile iron pipes, was found to be on the project's critical path. Therefore, the delay in the delivery impacted the project completion by 72 days. As illustrated in Figure 4 below, this event is considered to be on the critical path and would significantly impact the overall project delivery, which warrants the continuation of the analysis to stage 4.

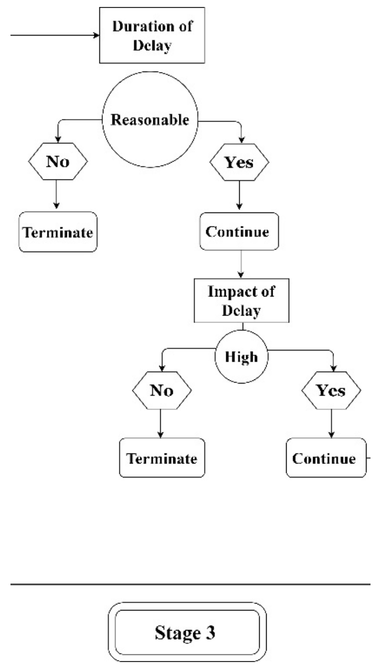

Figure 4: Case Study Stage 3 Analysis.

Case Study Analysis Stage 4:

Stage 4 of the framework investigates the contractor's mitigation efforts to alleviate the damage that would occur to the employer's best interest in case of delays. Although the contractor, in this case, indicated that they were in negotiations with the manufacturer to expedite the delivery of the pipes, not proof or evidence was provided on actual mitigation efforts that were employed. The contractor even failed to provide evidence of pressure applied on the manufacturer to expedite the shipment of the materials. Therefore, the mitigation efforts were deemed not extensive. As indicated in Figure 5 below, the analysis should be terminated to conclude that no extension of time should be awarded.

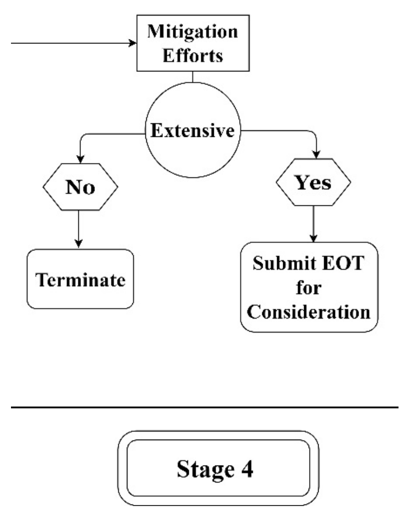

Figure 5: Case Study Stage 4 Analysis.

Applying the CSM equation as per the contractor assessment of the scoring of each of the six factors results in a total score of 21, as indicated in table 3 below:

Table 3. Interviewees Response on Current Practices.

Factor	Adequate notice of claim	The reason for the delay	The contractual basis of the claim	The duration of the delay	The impact of the delay	The mitigation efforts	Total
Factor Score	0	6	3	6	6	0	21

4. Discussion

The study sets out to build a framework that can aid in the evaluation of delay events that could be labelled as force majeure due to the COVID-19 outbreak. Throughout its four stages, the framework evaluates six factors deemed essential to label a delay event as a force majeure. First, noting that time is one of the most critical resources in a construction project, the preservation and conversation of it becomes necessary for the advancement of the construction industry.

For the case study applied, a score of 21 results in the dismissal of the claim as per the developed CSM. The analysis of the delay event via the developed framework and the CSM application and the fact that both confirmed that the contractor has no right to claim for extension of time, which was also the actual outcome of the claim following the rejection from the Engineer and the independent third party, further validated the model applicability in determining the contractor's right in submitting and winning a claim for extension of time amid the COVID-19 outbreak due to force majeure reasons.

Therefore, the applied case study can benchmark the importance of developing such a framework that could reduce the resources required to evaluate an extension of time claims. Furthermore, a further investigation to validate the model with more project data could enhance the model and increase its validity and reliability.

The limitations of the study are the availability of data and the quantity of data availability which limited the ability of the researchers to apply the proposed framework to multiple projects and different scenarios.

5. Conclusions

Time is a fundamental resource in the construction industry. Both the contractor and the development owner are greatly affected by time delays in a construction project. While no party is interested in delaying a project, sometimes events that are out of the control of both parties occur and cause delays in a construction project. For example, during the COVID-19 pandemic, some delays could arise in the construction industry for many reasons, such as the required social distancing or the delay in materials supply. These delays could be attributed to force majeure clauses, but a thorough investigation and analysis must accurately classify those events. This investigation is critical to ensure that the rights of both parties are preserved.

Therefore, this paper aimed to build a framework to assist the project manager and project owners in classifying delay events during the outbreak, if they can be labelled as force majeure or not, and if they deserve EOT consideration or liquidated delay damages. To satisfy this aim, a careful investigation of the literature to identify the factors that constitute force majeure delays in the construction industry followed by a collection of data with the means of semi-structured interviews with industry professionals to identify the factors that are considered when analysing a claim for force majeure was conducted. After which, the authors developed a Claim Scoring Metric that will also enhance and increase the applicability of such a model in the industry to reduce the time required for assessing claims, streamlining claim assessment to eliminate bias, and reducing conflicts in the construction industry overall. Nevertheless, such a model can also enhance contract administration and ease conflicts, and enhance the process of alternative conflict resolution. Moreover, further investigation of the actual project's program and the inclusion of a performance index in the project before the claim can be investigated might impact the project owner's risk attitude.

As such, it can be concluded that COVID-19 induced delay events on the construction industry that impacted the performance of projects, however, not all projects can write off the non-performance during the pandemic as a force majeure event since there are many considerations that need to be taken into account before that is done. One of the most important aspect to consider while labelling a delay event as a force majeure is the existence of a force majeure clause in the contract the prerequisites for its implementation. Therefore, a lesson learnt from the pandemic could be the importance of including well written force majeure clauses in construction contracts to avoid dispute in case such events reoccurred.

Similarly, the findings of this study do not only apply to delays incurred by the COVID-19 pandemic since it tackles any delay event that meets the five requirements of being unforeseeable, unavoidable, uncontrollable, impracticable, and beyond the responsibility of either party. Therefore, future research recommendation could be to tailor the proposed model to other types of delays events to test the applicability of force majeure on them.

One of the study's main limitations was the availability of data and data collection amid the outbreak of the COVID-19 pandemic. However, to overcome this limitation, the authors adopted remote meeting techniques to have access to data and the feedback of the industry professionals.

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ID 103

Utilizing the EC3 Calculator to Compare the Environmental Impacts of Mass Timber and Structural Steel

Khang Nguyen, [1] Steelee Morgan, [2] and Scott Kelting [3]*

[1] California Polytechnic State University, 93402 CA, USA
[2] California Polytechnic State University, 93402 CA, USA
[3] California Polytechnic State University, 93402 CA, USA
khangn8@gmail.com

Abstract
Due to the popularity of lean construction and sustainability, utilizing carbon analysis to form educated, well-informed decisions for a more sustainable built environment can provide a strong case for mass timber construction. This dissertation uses extensive embodied carbon analysis of structural steel and mass timber during the preconstruction phase of a project using data from incomplete construction documents of a confidential project. A critical review of previous literature was conducted and used as precedents for the research. The data from the project estimates were input through the Embedded Carbon in Construction Calculator (EC3 Calculator) to provide extensive total carbon emissions measurements with emphasis on structural steel and mass timber. The data indicated that using structural steel as the primary framing option would decrease the project's overall environmental impact by roughly 84% compared to using mass timber. Additionally, implementing strict sustainability plans on the job site and responsible sourcing of materials can lead to a potential 54% reduction in the project's overall carbon output. From the results, detailed, data-driven decisions can be made regarding the project's more sustainable framing option. The results provide additional evidence supporting mass timber as a sustainable framing substitute for structural steel.

Keywords
Mass Timber, Structural Steel, Preconstruction, EC3 Calculator, Carbon Analysis.

1. Introduction

The construction industry has maintained a so-called "status quo" regarding construction materials. Since the early 20th century, structural steel and concrete's usage has increased on the job site and have created skyscrapers that continuously shape modern skylines. The rapid urban development and growth have had a considerable environmental cost that does not show prominent signs of halting. Different materials used in the construction process have varying amounts of embodied carbon. With the reinvigorating wood construction on the rise, new construction methods involving mass timber have gained traction in Europe and Japan, with North America following suit. Although there has been extensive research regarding the structural aspects of mass timber, there is not much analysis regarding the environmental cost of using mass timber. This paper explores the environmental cost of using mass timber compared to steel on the job site– specifically the embodied carbon from cradle-to-grave and how that carbon analysis can potentially impact the trajectory of a project. These findings may provide a stronger case for using extensive carbon analysis during all stages of the preconstruction phase of a given project to discover the most sustainable material.

2. Background and Methods

Cross-laminated timber (CLT) and other mass timber construction materials are a relatively slower to embrace building material; however, it has gradually picked up momentum in recent years. With sustainability coming to the forefront of discussions in recent decades and the increasing demand for more mid-rise and high-rise wooden buildings, the manufactured material's environmental impacts have come into question.

The purpose of this literature review is to provide further background for the case study. This report follows the relevant previous research of Kavanagh and Nakano (2016, 2020).

Kavanagh (2016) performed a case study that extensively analyzed the life cycle of Stadhaus at Murray Groce in London, United Kingdom– a bamboo veneer building. The case study utilizes eco-cost (€/kg) and global warming potential, measured in $kgCO_2$. The authors presented the immense sustainable prospect for the use of CLT and other mass timber products. The construction speed and the energy costs were of note in the research, both of which were significantly reduced using timber rather than conventional concrete. The paper also noted that a complete life cycle assessment (LCA) had become internationally recognized as a method for assessing certain building materials' potential environmental impacts from cradle-to-grave (Kavanagh, 2016). The researchers developed a standardized panel system to compete with the building's CLT panels and analyzed the complete cradle-to-grave cycle of both design options. The assessment considered the material extraction, transportation, manufacturing maintenance, and end-of-life with notable exclusions such as material and energy requirements. The data used to perform the analysis were the types of construction materials, their quantities, volumes, areas, and weight. Kavanagh and their team concluded that bamboo has a lower environmental impact than CLT. The study found that bamboo grows faster than traditional timber while maintaining the same or better structural elements as timber.

Nakano, Karude, and Hattori (2020) approached the topic differently. The team performed an extensive case study highlighting the environmental impacts of a CLT building in Kumamoto City in the Kyushu Region. Their study investigated the materials and energy used to build the CLT building and relate it to its total environmental impact from the material's manufacturing to the end of construction. Although mass timber is widely viewed as reliable and abundant, its sustainability has varied from regular lumber to engineered wood due to the intricacies of the manufacturing processes. Nakano, Karude, and Hattori surveyed the building and created a hyper-detailed estimate of all materials used. Additionally, the team incorporated an extensive inventory of transportation and installation methods used during the building's construction, close to accurate measurements. Their research concluded that concrete, cement-based stabilizers, and rebar accounted for most greenhouse gas emissions throughout the cradle-to-cradle process. The paper suggests using biomass-based energy and extensive recycling protocols to reduce environmental impacts, especially at the end-of-life stage.

There is a lack of research regarding the ecological impact of mass timber buildings and their life cycle, especially in North America. Both papers' life cycle assessments lead to more significant implications regarding climate change, ozone depletion, and environmental conditions existing in predominantly urban settings, along with detailed breakdowns of the greenhouse gas emissions of certain materials. A bamboo alternative appears to have a lower environmental impact than standard mass timber; however, this paper will strictly analyze the embodied carbon emissions of mass timber due to supply constraints. Although Nakano and their team included the building's foundations in their calculations and assessments, there weren't further comparisons between various framing materials. This paper sets out to add to the body of knowledge by comparing the environmental impacts of mass timber and structural steel of two similar projects using the EC3 tool. One project used mass timber and the other structural steel. The research question for this paper was: Is the EC3 calculator an effective tool to compare structural steel and mass timber in the preconstruction phase?

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3. Results

The EC3 Calculator draws its information from multiple databases to aid manufactures gain a greater transparency on their products. The EPDs utilize a range of total embodied carbon emissions for each construction element; therefore, the results are divided into three primary categories: Baseline, Conservative, and Achievable. The baseline estimates are the standard results the calculator produces based on data from each estimate. Traditionally, the baseline estimates are considered the most conservative or largest emitted carbon of a given product. The conservative results are most realistic estimates given current construction practices and manufacturing standards. The achievable estimates are based on currently available active sustainability practices on the job site and during the manufacturing process. For example, active sourcing and recycling practices are accounted into the achievable results. From the interview with the professional contact, construction documents were provided for a confidential project. The professional contact provided an opportunity to compare the embodied carbon emissions between structural steel framing and mass timber framing with the same building. All columns, beams, and girders were made of steel-wide flanges, particularly W16× 31 and W24× 62 galvanized steel members. The height of each story is assumed to be the standard 10 feet in height. The concrete foundation is thought to be a traditional foundation with a 6-inch footing, and each floor has 3-inch concrete flooring on steel decking per specifications.

Table 1. Embodied carbon emissions calculations of a confidential project with a steel framing option

Element	Baseline (kgCO2e)	Conservative (kgCO2e)	Achievable (kgCO2e)
Concrete Slab	186407.96	208023.44	94256.95
Structural Steel	468882.03	394075.81	195811.62
Concrete Flooring	82133.68	91657.72	41530.79
Decking	995.99	895.28	895.28
Concrete Roofing	771.28	860.72	390.00

The total conservative embodied carbon emissions estimate for the project equated to 6.96×10^5 $kgCO_2$. As previously stated, the concrete foundation's conservative and realistic estimates are the same since they are the most accurate calculations with the provided information. The concrete foundation's entirety accounted for 30% of total emissions, equivalent to roughly 2.08×10^5 $kgCO_2$. The project's structural steel frame accounted for 57% of the total embodied carbon emissions, equating to roughly 3.94×10^5 $kgCO_2$. The rebar used for the foundations and the steel decking present on each floor produced an estimated 1,360 $kgCO_2$, which is a neglectable amount compared to other building elements. However, the 3-inch concrete flooring composed 13% of total carbon emissions, approximately 91,658 $kgCO_2$.

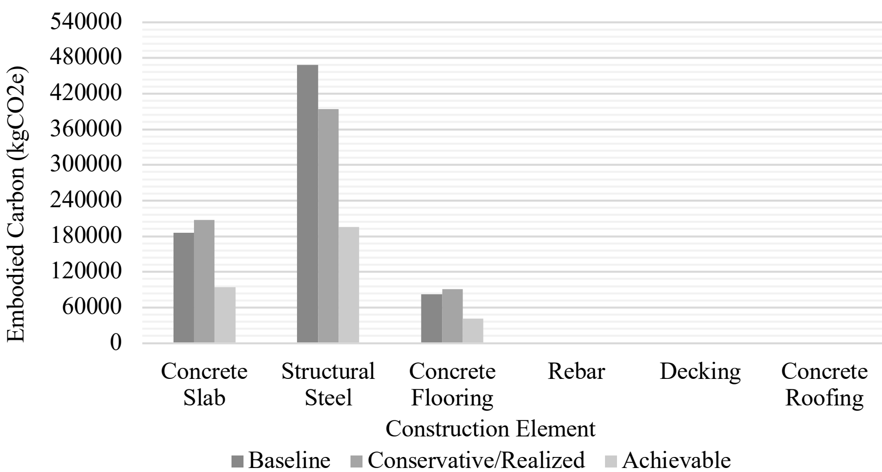

Figure 1. Complete bar graph of embodied carbon calculations of a confidential project with steel framing

The total conservative embodied carbon emissions estimate for the project equated to 6.96×10^5 $kgCO_2$. As previously stated, the concrete foundation's conservative and realistic estimates are the same since they are the most accurate calculations with the provided information. The concrete foundation's entirety accounted for 30% of total emissions, equivalent to roughly 2.08×10^5 $kgCO_2$. The project's structural steel frame accounted for 57% of the total embodied carbon emissions, equating to roughly 3.94×10^5 $kgCO_2$ as shown in Figure 1. The rebar used for the foundations and the steel decking present on each floor produced an estimated 1,360 $kgCO_2$, which is a neglectable amount compared to other building elements. However, the 3-inch concrete flooring composed 13% of total carbon emissions, approximately 91,658 $kgCO_2$.

Implementing proper recycling procedures and proper material sourcing would reduce the total achievable embodied carbon emissions estimate for the project to 3.33×10^5 $kgCO_2$. The prevailing assumption is that the concrete foundation will remain consistent through all estimates for the project. Therefore, the concrete foundation's entirety accounted for 28% of total emissions, equivalent to roughly 94,256 $kgCO_2$ as shown in Figure 1. Additionally, the project's structural steel frame accounted for 59% of the total embodied carbon emissions, equating to roughly

1.96×10^5 $kgCO_2$ as shown in Figure 1. The rebar used for the foundations and the steel decking present on each floor produced an estimated 1,156 $kgCO_2$, which is a neglectable amount compared to other building elements. The 3-inch concrete flooring composed 13% of total carbon emissions, which is approximately 41,531 $kgCO_2$ as shown in Figure 1. Although the embodied carbon percentage of structural steel for the achievable estimates is greater than the conservative estimates, there is a drastic difference of 1.98×10^5 $kgCO_2$ between the conservative and achievable estimates. In addition to the difference between the structural steel, the concrete slab's embodied carbon emissions can be significantly reduced by 1.14×10^5 $kgCO_2$ if there are extensive sustainability measures taken before, during, and after the project's construction.

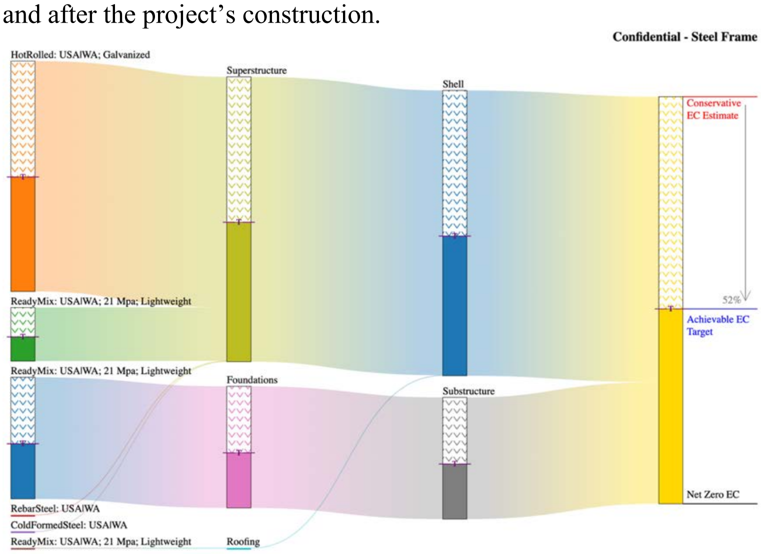

Figure 2. Mass diagram of confidential project using structural steel framing option produced from the EC3 Calculator

The mass diagram was produced from EC3 Tool using data from the estimates. The diagram breaks down each construction material related to the project and showcases its carbon output in relation to the material's total mass. The entirety of the material is displayed a single bar with a hatched pattern and a solid pattern. The material's total estimated carbon emissions are the sum of the hatched and solid pattern while the material's estimated achievable carbon output is solely the solid pattern at the bottom of each bar.

From that, the building's EPD indicated that the structural steel members produced the greatest amount of carbon emissions; however, the building's mass is primarily comprised of the concrete foundation and flooring system. As previously stated, the structural plans indicated that each floor of the building would include 3-inch concrete flooring, which contributed the third highest total embodied carbon emissions while having the second highest contribution to the building's overall mass as shown in Figure 2. Although the project's structural steel frame produced the greatest amount of carbon emissions, it had the third highest contribution to the structure's mass. The three construction elements whose mass contribution and carbon emissions draw a direct correlation are the rebar, stee decking, and concrete roofing and shown in Figures 1 and 2. All three materials had almost negligible contributions to the overall structure's total carbon emissions and mass.

Using the same construction documents, the mass timber option was thoroughly analyzed. All estimates were as accurate as possible per the original plans and specifications. All columns, beams, and girders were glulam laminated timber ranging in size from dimensions as small as $6\frac{3}{4} \times 12$ to as large as $10\frac{3}{4} \times 22\frac{1}{2}$. As previously stated, each story's height is assumed to be the standard 10 feet in height. The concrete foundation is believed to be a traditional foundation with a 6-inch footing. Additionally, the first floor will use 5-ply CLT panels, while the second floor will use 3-ply CLT panels.

Table 2. Embodied carbon emissions calculations of a confidential project with a mass timber framing option

Element	Baseline (kgCO2e)	Conservative (kgCO2e)	Achievable (kgCO2e)
Concrete Slab	186407.96	208023.44	94256.95
Timber Frame	126793.78	61652.78	30634.58
Structural Steel	1691.76	1421.85	706.50
CLT Panels	6642.45	2475.69	1486.65

The total conservative embodied carbon emissions estimate for the project with the mass timber framing option equated to 2.74×10^5 $kgCO_2$. As previously stated, the concrete foundation's conservative and realistic estimates are the same since they are the most accurate calculations with the provided information. The prevailing assumption will be that the concrete foundation will remain the same throughout the project's analysis. The concrete foundation's entirety accounted for 76% of total emissions, equivalent to roughly 2.08×10^5 $kgCO_2$ as shown in Table 2. The project's mas timber frame accounted for 23% of the total embodied carbon emissions, equating to roughly 61,653 $kgCO_2$. The building's structural steel component produced an estimated 1,422 $kgCO_2$, which is a neglectable amount compared to other building elements. However, the CLT panels composed 1% of total carbon emissions, approximately 2,476 $kgCO_2$ as shown in Figure 3. The rebar estimates for the structural steel option were used as precedence for the rebar estimates for the mass timber option. As a result, the rebar for the concrete slab was a negligible amount that accounted for approximately 0% of the project's total embodied carbon emissions as shown in Figure 3.

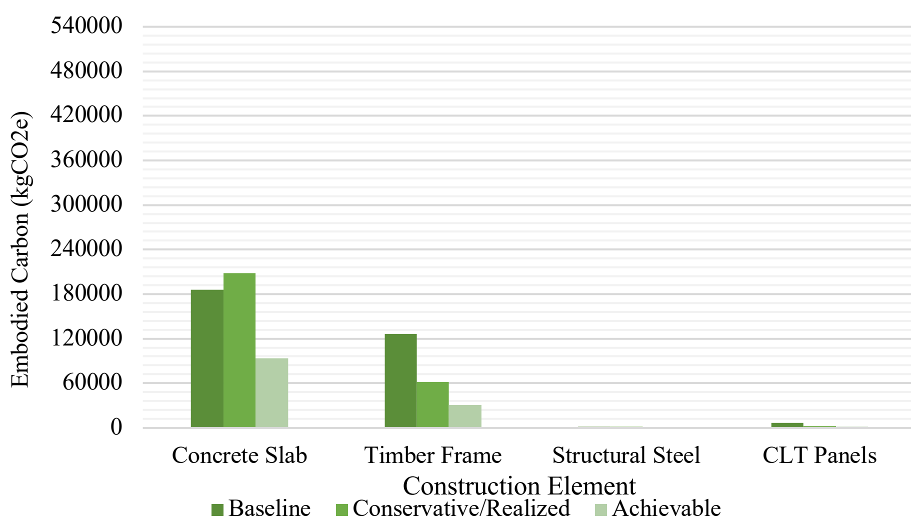

Figure 3. Complete bar graph of embodied carbon calculations of a confidential project with mass timber framing

The total achievable embodied carbon emissions target for the project equated to 1.27×10^5 $kgCO_2$. The concrete foundation's total contribution remained the same at roughly 94,257 $kgCO_2$ or 74% of the project's total emissions. The project's mas timber frame accounted for 24% of the total embodied carbon emissions, equating to approximately 30,636 $kgCO_2$. The building's structural steel component produced an estimated 707 $kgCO_2$, equating to roughly 1% of the building's total embodied carbon. Additionally, the CLT panels composed 1% of total carbon emissions, approximately 2,476 $kgCO_2$ as shown in Figure 3. As previously stated, the rebar estimates for the structural steel option were used as precedence for the rebar estimates for the mass timber option. As a result, the rebar for the concrete slab was a negligible amount that accounted for approximately 0% of the project's total embodied carbon emissions as shown in Figure 3. The carbon emissions for the concrete foundation saw a reduction of roughly 1.14×10^5 $kgCO_2$. The most substantial reduction would be the mass timber framing and CLT panel building components, seeing an almost 50% or 31,018 $kgCO_2$ and 989 $kgCO_2$, respectively. Another building element that saw a dramatic decrease was the structural steel component with a reduction of more than 50% or 715 $kgCO_2$.

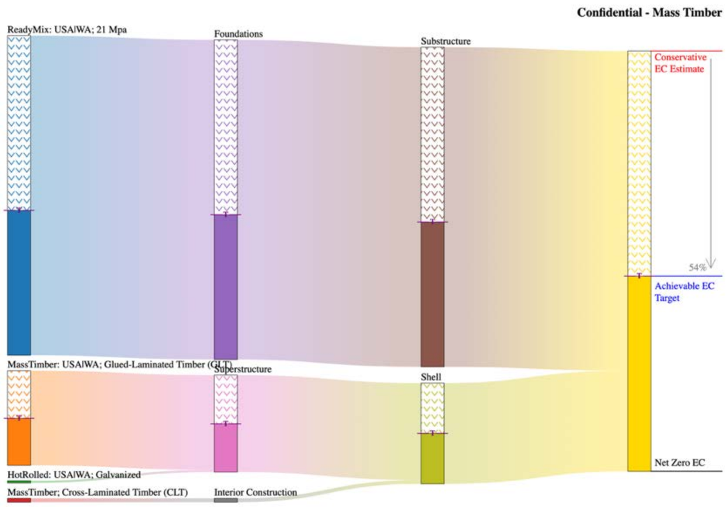

Figure 4. Mass diagram of confidential project using the mass timber framing option produced from the EC3 Calculator

The mass diagram for the mass timber framing option follows the typical patterns regarding mass and total embodied carbon emissions. The concrete foundation had the highest contribution in terms of mass and the carbon emissions of the building while the mass timber frame accounted for the second highest embodied carbon emissions and the building's overall mass as shown in Figures 2 and 4. Even though the project utilizes the same floor plan with different framing options, the concrete foundation has prominent contribution to the project's overall carbon footprint is as noticeable as its reduction in emission. The construction elements that had almost negligible impact to the building were the CLT panels and structural steel.

4.2.3. Comparing Structural Steel and Mass Timber Framing Options

The confidential project offered a variety of statistics regarding the building's total embodied carbon. The only constant building element throughout the analysis is the concrete foundation. The realistic and achievable estimates of both framing options were 2.08×10^5 $kgCO_2$ and 94,257 $kgCO_2$ respectively. The only difference between the foundation's framing options was its embodied carbon emission percentage compared to the project's total emissions. For the steel framing option, structural steel comprises most of the building's total emissions with the conservative and achievable containing 3.94× 10^5 $kgCO_2$ and 1.96×10^5 $kgCO_2$ respectively as shown in Figure 5. However, the difference between using structural steel and mass timber is more drastic, with a conservative decrease of 3.32×10^5 $kgCO_2$ and an achievable decrease of 1.65×10^5 $kgCO_2$ when using mass timber framing rather than structural steel framing as shown in Figure 5. This translates to an 84% reduction of conservative and achievable carbon emissions estimates. Aside from the rough framing differences, the flooring systems also indicate a drastic difference in total carbon emissions. The steel decking and the concrete flooring will be considered one flooring system, equating to 92,553 $kgCO_2$ and 42,426 $kgCO_2$ for the conservative and achievable estimates, respectively. Using CLT panels instead of the steel flooring system, there is a conservative decrease of 90,077 $kgCO_2$ and an achievable decrease of 40,939 $kgCO_2$. Additionally, there would be a total decrease of 39% and 38% for the realistic and achievable embodied carbon emissions.

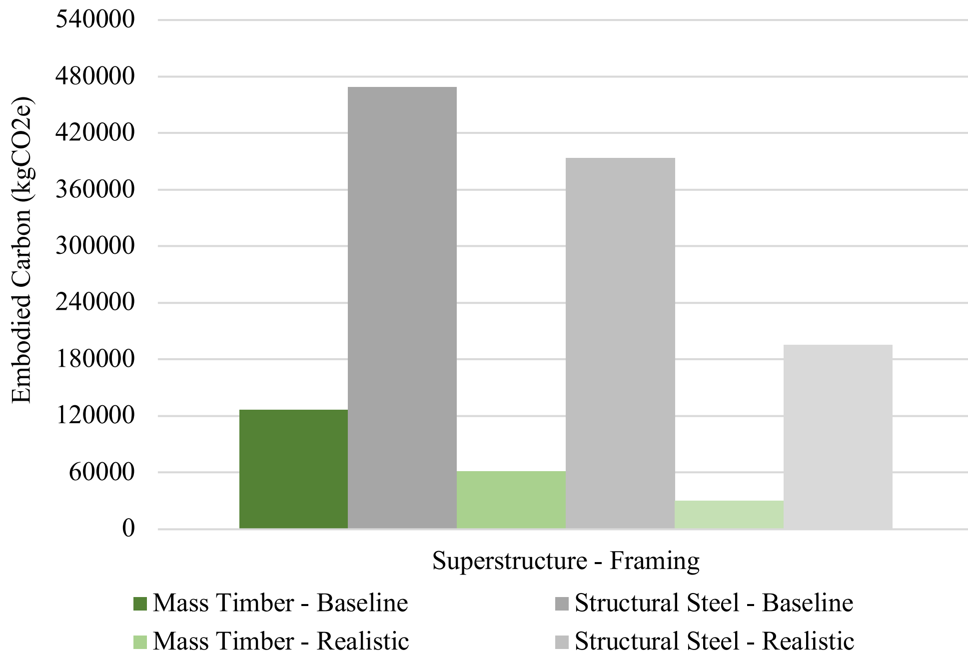

Figure 5. Complete bar graph of embodied carbon comparisons of a confidential project with structural steel and mass timber framing

From the mass diagrams of both framing options and the data presented, there is a greater reduction in carbon emissions from the mass timber framing option than the steel framing option. The overall project's achievable carbon footprint can be 54% lower than the conservative estimates, which is 2% lower than the steel option, but significant nonetheless as shown in Figure 4. A probable explanation would be the amount of construction elements involved in the building's framing. The steel option has roughly 67% more building components than the mass timber option thus making the mass timber framing option less involved than its steel counterpart as shown in Figures 1 and 3. As a result, its carbon emission contribution is less significant than the steel framing option.

4. Discussion

The designs of the confidential project were in their preliminary stages when it was analyzed for the paper. The industry professional discussed that the project is still in its preconstruction phase and had a vague idea of which framing material was more suited for their client's goal for a sustainable building. The data produced from the EC3 Tool visibly provided evidence that supported mass timber as a more sustainable alternative for structural steel; however, a notable point of contention from the research was the limited access to manufacturers, as previously stated. Nevertheless, the data and the direct comparisons provided a clear contrast between the two materials' carbon output. It was fortunate that the confidential project was in the early stages of development because questions concerning its sustainable output could be answered upfront before it breaks ground. Thus, the EC3 Tool and the data it produced could be used to make well-informed decisions driven by empirical data. The decisions made from the data could potentially range from selectively sourcing the materials, significant alterations to the design of the building, and the development of more stringent stormwater pollution prevention plans. The data could impact every aspect of the project to reduce its environmental impact.

A notable flaw in the tool was most likely due to it still being in its beta phase, and limited access is granted to the public and students. As a result, it was challenging to produce more precise data. Additionally, the project was in its infancy; therefore, the provided plans were incomplete, and the vendors were not providing more accurate data collection. Although the tool–at the time it was used for this paper–was still in its beta phase and there were limited resources regarding the project, it produced incredible data that proved invaluable to the report. Additionally, with the EC3 Calculator slated to be integrated into Revit and Tally, carbon analysis of a given project is gradually incorporated into the preconstruction phase (EC3 Tool, 2021). California recently adopted the series of building codes from the International Code Council (ICC) to accelerate the transition, joining four other states as early adopters of the 2021 codes (Softwood Lumber Board, 2020) The regulations provided specifications for constructing mass timber buildings ranging from 9 stories tall to 18 stories tall. Codifying building codes for mass timber has indicated California's and the country's transition to a more environmentally conscious built environment. The move towards sustainability will force every industry to adapt, especially the construction industry. With the tool's future integration into design software, designers, contractors, and owners can perform in-depth analysis on their project regarding all aspects of its construction, including the most sustainable building materials.

5. Conclusions

The construction industry is continuously changing, and it must continue to trend towards sustainable construction practices such as mass timber framing. Mass timber is growing in popularity within the construction industry and marks the future of the green and sustainable building. CLT and other mass timber products transform the built environment among European countries and Canada as we speak. The United States is beginning to rediscover the uses of mass timber and is now reaping its benefits. However, due to its overly prescriptive building codes and limited manufacturers, more extensive research continues to be hampered in the states. As discussed above, carbon emissions are just one of the benefits of mass timber. More to be explored on how mass timber could impact the construction industry and the built environment.

The study's environmental analysis of structural steel and mass timber provided evidence that the EC3 Tool can prove to be a crucial tool in the move towards a more sustainable built environment. Investing time upfront to solve potential issues is the cornerstone of preconstruction, and with the rapid demand for more sustainable projects, carbon analysis of the building will be part of that equation. The research performed for this project was done to support the integration of carbon analysis into the preconstruction phase by comparing two different framing options of a project that's still in its preliminary design stage. Although the EC3 Calculator was developed a few years ago, it is still in its beta stages of development, which indicates greater opportunities for the tool to produce more accurate data and other useful information. While there is room for improvement, the authors' found the EC3 Calculator to be and effective tool. The authors plan to conduct similar studies as the EC3 Calculator continues to improve.

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Drivers of Industry 4.0 Implementation in the Construction Industry

Almat Abilez, Abid Nadeem, Gulzhanat Akhanova

[1] Nazarbayev University, Nur-Sultan, 010000, Kazakhstan
abid.nadeem@nu.edu.kz

Abstract

The construction industry significantly influences the economy and development of a country. However, the construction industry is conservative and cannot make quick changes. The main reasons are the uncertainty and complexity of the construction projects. Compared to the speed of development of the manufacturing industry, the construction industry is relatively slow to change the usual practice and develop technologically. Therefore, the construction industry must review and implement modern technologies that make the construction processes faster and cheaper. The fourth Industrial Revolution may become a decisive factor and a driver for its development. This work analyzed the importance of Industry 4.0 for the construction industry and the main driving factors for its implementation. Its driving factors are technological, economic, social, and environmental. The state of the construction industry in Kazakhstan was studied using the example of a leading construction company. The results yield that private construction companies should investigate and implement more digital technologies. The limitation of the part about Kazakhstan is the lack of available information due to low transparency. Thus, more companies with various statuses and from different locations should be evaluated for a more rigorous analysis.

Keywords

BIM, Construction Industry, Cyber-physical systems, Industry Revolution 4.0, IoT

1. Introduction

The construction industry significantly influences the economy and a country's development. The World Bank (2020) reports that the construction industry had approximately 6% and 7% of the world and Kazakhstan's GDP in 2019. The construction sector involves many other subsectors, such as producing and manufacturing construction equipment and creating many workplaces for unskilled workers (Berk & Biçen, 2017). It consumes approximately half of steel manufacturing and creates 18 million workplaces in Europe (Craveiro et al., 2019). According to Maskuriy et al. (2019), the world's urban population increases by 200,000 people every day. The demand for the construction industry is increasing with the rise of the urban population and the need for affordable housing, roads, and infrastructure. For a long time, construction processes have used inadequate and unsafe technologies. The industry implements new technologies and slowly transforms (Wesam et al., 2020). However, the construction industry must review and implement modern technologies making the process faster and cheaper.

After the first three industrial revolutions, which accelerated manufacturing industries with steam engines, mechanical automatization, electronics, and the Internet, the fourth revolution brought the digital transformation. It includes modern technologies such as Building Information Modelling (BIM), Internet of Things (IoT), additive manufacturing, 3D printing, drones, sensors, scanners, collecting of all data and their analysis, etc. (Woodhead et al., 2018). Industry Revolution 4.0 (Industry 4.0) or Construction 4.0 offers a sustainable complex manufacturing system of high-level technologies integrated into design, manufacturing, and construction processes (Wesam et al., 2018). With Industry 4.0, construction companies could effectively plan and schedule their work processes, tackling project overruns and delays (Horváth & Szabó, 2019). As a result, both the industry and the clients can benefit from it.

However, the construction industry is conservative and slow to change due to the complexity and uncertainty of the projects. Most construction projects include many stakeholders with their interests, and it is not very easy to transform all of them. Fragmentation of processes, employee turnover, and uniqueness of all projects are the challenges (Oesterreich & Teuteberg, 2016). All these factors decelerate the transformation process.

The driver factors of Construction 4.0 could urge the industry to implement digital technologies faster despite obstacles. These factors could include technological directions and economic, social, and environmental factors. Studying these factors is essential, as it could investigate the construction industry and its transformation process. Found data may help predict the future of the industry. This paper aims to find and clarify the main driving factors of the Industry 4.0 implementation in the construction industry. The objectives of the study are:

1. To describe the importance of Industry 4.0 in the perspective of the Construction Industry,
2. To identify the main economic, technological, social, and environmental factors which promote the development of Industry 4.0,
3. To study Kazakhstan's progress in the construction industry in Industry 4.0.

Many research papers and reviews limit their area to technological and economic factors. However, the implementation process is more complicated, so social and environmental factors could also be necessary. This paper investigates the social and environmental possible factors and determines the links between them. It also includes a study of the development of the construction industry in Kazakhstan. The study of the state of the construction industry in Kazakhstan was reviewed for the first time in this paper.

2. Methods

The methodology includes the collection and analysis of research papers. Keywords for the search were industry revolution 4.0, construction 4.0, digital construction, and modern construction. Sources that include these phrases were selected from the Scopus and Elsevier databases. After a quick scan of numerous papers, the most relevant papers were selected and analyzed. In this paper, the state and importance of Industry 4.0 are defined in terms of the construction industry. Its main driving factors were technological, economic, social, and environmental categories. The construction industry's status quo was analyzed, and the implementation status of modern technologies was evaluated.

In the literature, there is a lack of information about the construction industry in Kazakhstan. For identifying the status of Industry 4.0 and the overall construction industry in the country, mainly information from the media was used. One of the biggest construction companies was interviewed to examine the quality of the country's construction sector. The data analysis and the interview results were included in the article.

3. Results

3. 1 Drivers of Industry 4.0

Recent research on the development of Industry 4.0 in the construction industry found that the most critical development drivers are economic, technological, and social factors (Wesam et al., 2020). The study authors examined the reviewed literature and conducted a survey. The data obtained were analyzed using the Six Sigma Quality Initiative and DMAIC methods. The three factors mentioned above were the most relevant among the seven factors, including political, environmental, legal, and security (Fig.1). For this research, economic, technological, and social factors were chosen as the most critical factors. Environmental factors were also analyzed due to their increasing importance to global warming. The driving factors by categories have been outlined in Table 1 and explained.

Economic Factors

Savings by optimization. According to the World Economic Forum (2018), only 1% of construction optimization can save $100 billion worldwide. With the development of the industrial revolution, technology could save time and materials and minimize industrial risks.

Reduce construction time. The presence of a unified system, computing power, and the ability to quickly share information could make it possible to work efficiently and without significant losses. New supply chains for materials and equipment could reduce time, and work could be finished on schedule (Craveiro et al., 2019). Sensors, cameras, and drones could follow the workflow, and necessary changes or errors could be found and fixed in a short time (Stergiou et al., 2018). Reduced construction time could decrease the cost of delays and wages.

Increasing construction speed. The development of prefabrication and/or additive manufacturing technologies could make massive production of the main parts. It could increase the speed of construction compared to conventional methods (Craveiro, 2019). Moreover, mass production decreases the cost of construction.

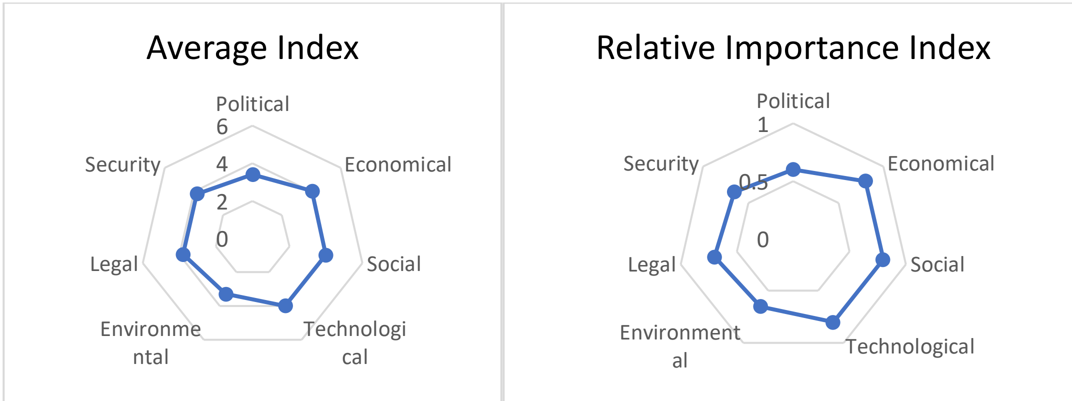

Fig. 1. Average and relative importance indexes of the studied factors (Wesam et al. 2020)

Table 1. Driving Factors by categories

1. Economic	2. Technological	3. Social	4. Environmental
5. Savings by optimization	6. Improved quality	7. Communication between stakeholders	8. Reduction of carbon dioxide emission
9. Reduce construction time	10. Monitoring	11. Digitalization	12. Reduction of waste generation
13. Increasing the construction speed	14. Quality	15. Virtual opportunities	16.
17. Automatization	18.	19. Improve the industry image	20.

Automation. In the future, autonomous machines and robots could be used by necessity. Their advantage over people is that they can work effectively for a long time, are connected to a single base, and have a machine learning system (Ben-Ari & Mondada, 2017). In the long term, they could save money on people's salaries, increase the efficiency and speed of work, and minimize the human error factor. On a global scale, implementing demonstrated automation technologies in industries could affect half of the world's economy, or 1.2 billion employees and USD 14.6 trillion in wages. The Industrial Revolution 4.0 could affect the world more than any other revolution.

Technological factors

Improved quality. The development of modern technology could improve the quality of construction and minimize possible defects. A single self-training system on a database could determine the most effective construction methods for each case (Wei & Li, 2011). It could be possible to monitor the quality of work during and after construction. The development and implementation of additive manufacturing and 3D printing could increase the construction works. The buildings (or their parts) made by machines could make mistakes with a lower probability than humans.

Monitoring. The use of sensors that determine the work's condition could reduce the risk of shoddy quality work. Sensors for concrete could determine the hardening and curing processes. After a long time, it could be possible to monitor the concrete state and, if necessary, carry out repair work on time (Song, Gu & Mo, 2008). The same sensors can be designed for each particular type of job. Drones with laser scanners could determine welding or masonry quality (Goessens, Mueller & Latteur, 2018). With these technologies, the quality of the work performed could be increased.

Safety. The construction industry is one of the most dangerous workplaces. Because of short-time activities and the work industry, tracking the workers' safety is challenging. The sensors and cameras connected to the intelligent database could alarm the possible hazard, and the risks could be minimized efficiently (Howard et al., 2018).

Social factors

Communication between stakeholders. For completing one project, the construction industry attracts many stakeholders, such as owners, architects, contractors for various works, suppliers of materials and equipment, etc. Communication and interaction between all actors considerably influence the time and quality of work (McCaffer, 2014).

Digitalization. Innovative technologies could create new types of interaction among all actors. Outdated models of contracts and businesses have some difficulties with bureaucratic processes (Wesam et al., 2020). The digitalization of the industry could offer new ways to interact with partners and customers.

Virtual opportunities. By applying simulation technologies like augmented reality, virtual reality, and mixed reality combined with mobile devices or wearable computing, construction companies can provide project owners with more significant insight into the building's details and design before being built (Dallasega, 2018). Therefore, customers can be involved in the planning process to customize the building better.

Improved image of the industry. The construction sector is notorious for its difficult working conditions and lack of digitization. As a result, it has a negative employer reputation and often fails to hire qualified employees (Oesterreich, 2016). The tech transformation could improve the image of the whole sector.

Environmental Factors

The building and construction sector is responsible for 38% of all energy-related carbon dioxide emissions caused by energy consumption and high waste levels during its construction processes (UN, 2019). Several approaches have been proposed for construction waste minimization to handle these environmental problems, reduce project emissions through strategic project management, or use BIM to create design alternatives.

Reduction of carbon dioxide emission. According to UN statistics, 11% of global CO_2 emissions come from the construction industry. The central part of which is the production of construction materials such as cement, glass, and steel (UN, 2019). In Industry 4.0, research and experiments with new materials will produce fewer emissions. It is critical to aggressively explore ways to reduce CO_2 emissions and promote energy conservation. To reduce the weight of concrete buildings, McCaffer (2014) devised a method for printing concrete with differing densities by combining concrete with aluminum powder and lime, which react to create hydrogen gas bubbles and form a foaming structure.

On the other hand, Oh et al. (2015) used a robot and a programmed syringe dispenser to inject the aluminum solution into the precise position of a white cement panel, resulting in customized patterns of holes. Herrmann and Sobek (2017) have used graded spraying techniques to create structural components that were mass optimized. These innovations can decrease the use of cement and, as a result, CO_2 emissions.

Reduction of waste generation. A resource-efficient construction sector with lightweight structural components will reduce waste generation, emissions, and global resource consumption. Furthermore, thin/light walls avoid overloading the building structure, reducing cement consumption, which is responsible for approximately 5 to 8% of CO_2 worldwide (Craveiro, 2019). The development and usage of more eco-friendly materials minimize waste production.

In Table 2, the influence of Industry 4.0 technologies has been conceptually mapped to the driving factor categories.

Table 2. Conceptual matrix of how driving factor categories affect Industry 4.0 technologies (H – high, M – medium, L – low)

21. Industry 4.0 Technologies	22. Economic	23. Technological	24. Social	25. Environmental
26. Additive Manufacturing/ 3D Printing	27. H	28. M	29. L	30. M
31. Artificial intelligence	32. M	33. H	34. L	35. L
36. Augmented reality / Virtual reality	37. M	38. H	39. H	40. L
41. Big Data Analytics	42. M	43. M	44. L	45. L
46. Building Information Modelling	47. H	48. H	49. H	50. H
51. Cloud computing technology	52. L	53. H	54. L	55. M
56. Cyber-physical systems	57. M	58. H	59. L	60. L
61. Drones / Unmanned Aerial Vehicles	62. M	63. M	64. M	65. M
66. GIS mapping	67. M	68. M	69. M	70. L
71. Internet of things (IoT)	72. H	73. H	74. M	75. M
76. Laboratory research	77. L	78. H	79. L	80. H
81. Laser scanning	82. M	83. H	84. L	85. M
86. Robotics and automation	87. H	88. H	89. M	90. M
91. Sensors / Semantic product memory	92. H	93. H	94. M	95. L

3.2. The status of Industry 4.0 technology in the Construction Industry in Kazakhstan

The construction sector in Kazakhstan remains one of the most critical sectors of the economy and one of the most attractive investment areas. This sector accounts for up to 7% of Kazakhstan's GDP; the construction sector provides about 700,000 jobs. The stabilizing macroeconomic situation with moderate growth in real GDP will affect the construction sector in Kazakhstan. According to the World Bank (2020), the share of operating legal entities in the construction industry is slightly more than 13% of the total number of organizations conducted in the republic. The increase in operating legal entities from 2012 to 2016 amounted to approximately 34%. The volume of completed construction work in nominal terms demonstrates positive dynamics.

Construction in Kazakhstan is subdivided into constructing buildings and structures, civil engineering, and specialized construction work. They are carried out as part of the general construction process, with further division by area. The specific share of completed construction work falls to the private sector in ownership forms. 66.2% of all construction works were done by private companies, 33.2% by foreign companies, and only 0.5% by national companies in 2016. The high share of foreign companies could be explained by EXPO 2017 when they were involved as contractors. Usually, the percentage of foreign companies fluctuates at 20-25%.

The most prominent specific shares are concentrated in the construction of non-residential buildings (up to 23%), the construction of roads and highways (up to 19%), and the construction of residential buildings (up to 10%) (World Bank, 2020).

3.3. The Industry 4.0 in Kazakhstan

Since 2017, Kazakhstan's Government has begun preparing and developing a plan to introduce state-owned enterprises' latest technology. According to the Kazakhstan Institute for Industrialization Development, Industry 4.0 can solve the country's following problems: 1. Systematic staff shortage 2. Labor in hazardous areas 3. The insufficient domestic market for mass production, and 4. High transport costs and being landlocked (Informburo, 2017). Turkyilmaz (2020) found that for SMEs in Kazakhstan, Industry 4.0 could improve companies' economic performance by reducing costs and increasing labor productivity. Moreover, implementing new technologies could help companies react quickly to market changes.

However, at the beginning of 2018, according to the Ministry of Investment and Development, most Kazakhstani companies were not ready for a full-fledged transition to Industry 4.0. According to the data presented at the next meeting of the Government, 84% of enterprises in the processing industry and more than 56% in the mining industry correspond only to Industry 2.0 - this is a semi-automated production or a stage of transition to automated production (Informburo, 2017). Based on their analysis, the main constraints for the implementation of Industry 4.0 are:

- Insufficient business understanding of the economic benefits of digitalization
- Poor development of domestic development and competencies in automation and digitalization
- Lack of qualified personnel
- Limited Financial Resources
- Infrastructural Constraints

Except for the given reasons, Turkyilmaz (2020) added the absence of a proper strategy and the shortage of financial resources as the SMEs' additional weaknesses in Kazakhstan.

Under government programs, pilot innovation projects occur mainly in mining and oil and gas enterprises. These companies export to the international market and need to be competitive. For example, ERG's Sokolovsko-Sarbaisky Mining and Concentrating Production Association has launched the Smart Quarry and Smart Factory projects (Informburo, 2017). In 2016, Kazatomprom-SaUran launched the Digital Mine pilot project. Another mining company, Kazzinc, implements seven digitalization projects at once (Informburo, 2017). In addition, by 2019, 14 projects were implemented for 7.5 billion tenges and planned to introduce digital solutions for another 90 enterprises by 2022.

Construction companies are not yet on the list of innovative ones. The reason may be the problems mentioned above in the construction industry and that most of the state's construction sector is private. For this reason, construction companies have to take matters into their own hands. However, advanced digital enterprises in the country and the state's support can attract more investment, helping develop the construction sector.

4. Discussions

The construction industry's future is highly dependent on the direction and speed of the development of new technologies. Industry 4.0 technology will cover all construction stages, including planning, design, construction, and management (Wesam et al., 2020). Due to automation, each separate phase of the construction process could be cheaper and more qualified.

BIM technology allows planning construction in several directions in one system, including design, scheduling, progress, and the project's economic components. With augmented reality technology, BIM could see how construction could solve possible problems and inconsistencies even in the planning stage (Hu & Zhang, 2011). BIM could analyze the previous data with machine learning and neural networks and offer optimal solutions and construction plans (Davtalab, Kazemian & Khoshnevis 2018).

Cloud computing technologies could quickly analyze data from BIM and various sensors and share the information with everyone in real-time (Birje et al., 2017). The data can be accessed on the construction company servers and the tablets and phones of workers and engineers (Xu et al., 2015). This technology could improve information delivery and communication speed among different stakeholders.

Every digital equipment on the construction site could access the Internet and send/update new information to the server. This technology is known as the Internet of Things (IoT) (Woodhead, 2018). The data obtained from BIM, cloud computing, and IoT could be extensive, and advanced big data technology could be needed for their analysis. The developed cybersecurity technology could also be necessary for this data's security (Alavi & Gandomi, 2017). The blockchain and/or other advanced technologies for data encryption could be used.

With the development of the technologies mentioned above, the management of necessary materials and logistics could become more efficient. Logistics managers could see the number of materials in the warehouse; when they run out, they could order the amount required in advance without mistakes and monitor the delivery process (Craveiro et al., 2019). This mode could save time and reduce the risk of delays.

Unmanned aerial vehicles (UAVs), or drones, can survey the construction site and track the construction process. With the help of cameras or laser sensors, drones can obtain data about an area's landscape or the 3D dimensions of particular objects (Caterpillar, 2017). This data could be processed and be available to be used for design. Drones can also track progress and safety at a construction site (Howard et al., 2018).

Developed laboratories and the study of various building materials could discover or create new durable and inexpensive building materials that could also change the vision of the construction industry. With the development of new materials, the problems with concrete (low tensile strength) or steel (corrosion) could finally be solved (Das & Mitra, 2014). 3D printing technologies, autonomous machines, and robots could be massively used in construction in the distant future. These vehicles could transmit all data in real-time, analyze it continuously, learn, and develop themselves (Oh et al., 2015).

The development of all possible technologies could improve the speed and quality of construction processes. These technologies could be connected to one system, and all data could be analyzed and show progress in real-time. They could improve the construction management supply chain and make construction cheaper; new technologies could minimize the number of mistakes and make the construction more qualified and environmentally sustainable.

To study the development of new technologies in the construction industry in Kazakhstan, as part of the research, an interview was conducted with representatives of the country's largest construction company. The company works on the development and implementation of new technologies in construction. During the consultation, the application of modern technology in Kazakhstan was discussed.

Modern technologies are used in the planning and construction stages of the company. Standard software for BIM is used in the early planning stages, like *Autodesk Revit*. Furthermore, Russian developers' software parametric is also used to compile an automatic sketch model. The *BIM Check* software checks the plan for possible errors, such as inaccuracies in measurements or impossible pipe crossings.

Drones equipped with modern cameras and laser scanners survey the territory and construction sites. Drones explore the region, and particular software can automatically draw a 3D landscape of the place. Later, drones are also used to check the facade and compare it with the design. Drones can additionally calculate massive volumes of materials such as sand or cement. They are fast and efficient and help to get the job done in a short time.

Sensors are also used during construction. Leakage sensors are installed at the lower levels, and if water starts to leak, inform workers about it. The leak can be repaired very quickly and without damage to the project. Concrete sensors help monitor the quality of pouring, hardening, and curing. If necessary, concrete is repoured, and the risk of poor-quality pouring is minimal.

The cameras are placed along the perimeter of the construction site and connected to the main servers. Here, the recordings from the cameras are analyzed, and if unusual actions are detected, it informs the security about what is happening. These recordings help to monitor site safety more efficiently.

The company is authorized to develop solutions to systematic problems. In Kazakhstan, construction regulations prohibit work at high wind speeds. Wind speed data are received from the *Kazhydromet*, which has meteorological stations outside the city. However, most construction work is done in the city, where the wind speed is less than outside. Few portable meteorological stations have been developed to determine the construction site's wind speed to solve this problem. Now, using these stations allows builders to not delay work due to inaccurate data.

The company is now developing software to optimize project planning and new neuro links to draw the most efficient parking spaces within a specified zone. They have also been practicing trained neural networks to evaluate their property cost for a long time. The algorithm can determine the price change in the market in real-time and, depending on the given factors, the optimal price for the estate. 3D printing and autonomous work are still being tested in the company, but they will not be used in large quantities as in the whole world soon.

Technology development is generally comparable in Kazakhstan relative to the world's construction industry. However, the limitation of this research is that the leading companies' practice was studied. Many small construction companies still use outdated technologies. Broader research is needed to get a complete picture of the country's technology development status.

5. Conclusions

The construction industry needs the development and efficient implementation of new technologies. The current challenges facing the industry cannot be overcome without effective optimization. The development of Industry 4.0 could be a possible solution. With the evolution of numerous technologies, the construction process is already changing. BIM and gadgets such as drones and sensors are already widely used; other technologies like IoT or cloud computing are in the implementation stage. Future technologies, such as advanced materials or autonomous vehicles, are not considered due to the industry's possible high cost and conservatism. As part of the study, the importance of the industrial revolution for the future of the construction industry was studied, and the main driving factors of development were found. The economic, technological, social, and environmental driving factors were investigated and explained. The potential monetary benefits, high-tech quality of construction work, well-established communication, and environmental sustainability will promote Industry 4.0 in the construction industry.

The state of the construction industry in Kazakhstan was studied and analyzed. The data shows that private construction companies should investigate and implement more digital technologies. The limitation of the part about Kazakhstan is the lack of available information due to low transparency. All the information from the media could be biased. For the primary search, only one construction company employee was interviewed. More companies with various statuses and from different locations should be evaluated for a more precise analysis.

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A New Metric for Labor Productivity: Case Study of a Multi-Family Residential Project

Neziha Yılmaz[1], Farrukh Arif[2], Mehmet Emre Bayraktar[3] and Bartu Koloğlu[4]

[1,3,4] Istanbul Technical University, Istanbul, Turkey
[2] NED University of Engineering and Technology, Karachi, Pakistan
yilmaznez@itu.edu.tr

Abstract

The aim of this study is to present a labor productivity metric analysis with a case study. The objectives of this analysis include (1) to help project managers compare the project progress with labor productivity and take managerial actions quickly regarding the project performance; and (2) to fill the gap in the literature on case study-based labor productivity examinations of repeated construction units. In the first step of this research, a literature review was conducted on the productivity measurement of labor in the construction sector. After the literature review, the labor productivity metric was developed as a gap analysis that uses labor productivity to revise the schedule in project management and make quick decisions. A case study of a multi-family residential project involving multiple repetitive processes was performed to identify challenges and lessons learned. According to the results of the case study, a delayed project was rescheduled using efficiency data. During the case study, interviews with experts involved in the project were conducted, and relevant site reports were examined for data collection. The consensus of the experts is that the metric is useful and applicable. However, in order to increase the practicality of the metric, it is necessary to try it in more numbers, on a larger scale and in some specific projects, and to create a broad knowledge base.

Keywords

Worker Productivity, Case Study, Schedule Delay, Project Controls

1. Introduction

The construction sector contributes directly to the national economy. The sector fosters economic growth by increasing demand for the inputs that the industry needs to produce goods and services. The construction industry is a significant source of employment and a key driver of overall economic growth (Berk et al., 2017). Existing studies of the construction sector in developed countries have emphasized the industry's contribution to economic growth (Hillebrandt, 2000; Lean, 2001; Erol and Unal, 2015). Because of the construction industry's attractiveness to investors, competition is increasing, and as a result of being able to differentiate and stand out from competitors, today's projects can be carried out in larger scopes, with more complex structures, and using unconventional technologies. As a consequence, despite the construction industry's significant contributions to the economy, several studies show that the industry is frequently criticized for poor performance (Kagioglu et al., 2001; Bassioni et al., 2005; Durdyev et al., 2012; Barg et al., 2014; Hasan et al., 2018; Momade et al., 2021). Construction projects are labor-intensive (Shan et al., 2021). Internal and external variables such as socioeconomic culture, legal and environmental restrictions, improper management measures, extreme weather, excessive work hours, and transportation conditions all have a significant impact on the construction industry (Ghodrati et al., 2018; Durdyev et al., 2018; Tan et al., 2019). Worker performance and productivity are more difficult to measure than other sectors because they are dependent on so many factors.

2. Study Objectives

When the models for measuring construction project performance are examined, determining the factors and determining the impact of such factors requires intensive and long-term studies. In these intensive and time-consuming studies, while some factors can be expressed with measurable metrics, the values of some factors are collected subjectively through expert opinion. Considering that most of today's construction projects cannot be completed within the specified time, it is very important to quickly calculate the factors affecting the project performance and their impacts so that some remedial measures can be taken quickly while the projects continue. In those projects where use of a performance measurement model is not possible, a simple-to-use yet effective labor productivity metric will enable decision makers to take quick action in cases of lagging project performance.

Construction projects have many iterative processes, and all of these processes can be expressed as construction units. In other words, instead of separating a construction project into business activities or cost items, it is possible to divide it into repetitive processes, namely construction units. Studies on productivity calculations in the construction industry generally focus more on the use of materials and equipment to determine how efficiently a project uses its resources. And there are examples where work activities are handled individually and efficiency is determined. However, in these studies, the use of manpower for the periodic completion amounts of the construction units and the determination of labor productivity are not studied in detail.

The aim of this study is to present a labor productivity metric analysis with a case study. The objectives of this analysis include (1) to help project managers compare the project progress with labor productivity and take managerial actions quickly regarding the project performance; and (2) to fill the gap in the literature on case study-based labor productivity examinations of repeated construction units. In the first step of this research, a literature review was conducted on the productivity measurement of labor in the construction sector. After the literature review, the labor productivity metric was developed to make quick decisions. A case study of a multi-family residential project involving multiple repetitive processes was performed to identify challenges and lessons learned. During the case study, interviews with experts involved in the project were conducted, and relevant site reports were examined for data collection. The focus group method was used to validate the case study results. The results of the interviews and document investigation were discussed with four experts. In focus group interviews, expert interviews were held and questions were asked about the applicability, usefulness, and practicality of the developed metric.

3. Literature Review on Labor Productivity

Low productivity in construction is most frequently accused of causing late delivery of the project and cost overruns (Lessing et al. 2017). As a result, productivity remains one of the most critical indicators for measuring and assessing the performance of a construction project (Shoar and Banaitis, 2019; Momade et al., 2021). Many studies have used different definitions of productivity. In general, productivity is the proportion of work completed by workers in a construction project (Griego and Leite, 2017) or the number of worker hours produced per unit of the finished product (Ibbs, 2012; Kazaz and Acıkara, 2015). There are many studies focusing on productivity in the construction industry (Park, 2006; Dolage and Chan, 2013; Fulford and Standing, 2014; Hasan et al., 2018; Kumar and Rana, 2021). When the available literature is examined, the topics of interest generally revolve around two concepts. The first one is the factors that affect productivity (Hasan et al., 2018), and the second one is measuring productivity or performance (Crawford and Vogl, 2006; Tekçe, 2010; Ilıcalı and Giritli, 2020). In addition to these, the available studies evaluated productivity at the industry level (Vogl and Abdel-Wahab, 2015https://ascelibrary.org/doi/full/10.1061/%28ASCE%29ME.1943-5479.0000194?casa_token=h0Rw4ZeJph0AAAAA%3ARmGncD4LM4OHcZlFuprPaKd7PZgi9_3bqNRiMXW4vbcC8C6xATv5G-XbemJLcZUS_NRLicyjW5MypA), at the project level (Ayele and Fayek, 2019; Ilıcalı and Giritli, 2020; Park et al. 2005; Ellis and Lee 2006), at the firm level (Tekçe, 2010; Park et al. 2005; Ellis and Lee 2006), and at the activity level (Sonmez and Rowings, 1998; Tischer and Kuprenas, 2003; Zayed and Halpin, 2005; Ayele and Fayek, 2019).

The majority of studies focusing on productivity in construction focused on factors affecting labor productivity (Jarkas and Bitar, 2012; El-Gohary and Aziz, 2014; Ghoddousi and Hosseini, 2012). The most popular method for measuring labor productivity is by measuring hourly outputs (Yi and Chan, 2014). Most researchers use labor hours to determine the completed work quantities (Thomas and Yiakoumis, 1987; Sonmez and Rowings, 1998; Hanna et al., 2008). This represents the actual work hours required to conduct the acceptable units of work. A lower productivity value represents greater productivity. Hourly output is broadly acknowledged as a reliable measure of productivity for construction operational activities.

The completed work quantities completed in the studies are generally evaluated in terms of concrete production (Yi and Chan, 2014), rebar production (Li et al., 2016), and similar specific work items. Dividing a project as a whole into meaningful segments and using the segments for efficiency measures is an often-undescribed process. However, measuring the labor productivity of a project is challenging. The performance of all work activities with a holistic approach is important for decision makers to make quick decisions. Labor productivity in construction is evaluated for comprehensive prediction and project scheduling by using labor hours as input and the produced quantities as output (Dozzi and AbouRizk, 1993). The S curves, which are often used in the construction industry to interpret financial values, can show the variable slope of the cost curve and the varying progress of work per unit of time (Chao and Chen, 2015). They can be used to interpret the results of labor performance metrics.

As a result, all construction projects, regardless of project type (e.g., residential, commercial, highway, etc.), necessitate an empirical method for tracking progress and effectiveness. The projects' success is determined by a number of factors, including cost, time, quality, health and safety, innovation, shareholder satisfaction, and environmental issues (Ilıcalı, 2020). The performance of field and management personnel, on the other hand, is regarded as one of the most important factors in the success of a project and/or an organization (Sherafat et al., 2013). Current performance measurement metrics can be used to measure employee productivity. However, these metrics should be applied to the calculated parts of the project as a whole, not to the specific work activities of the projects. In addition, the labor hours used in the metrics should be considered with modifications that will eliminate the time spent on construction sites other than performing work activities. Calculated labor productivity data can be interpreted quickly with the help of the S curve and can manage the actions of decision makers.

3. Application of Labor Productivity Metric

3. 1 Proposed Labor Productivity Metric

The type of construction is very important for determining the use of project performance metrics in construction projects. Vertical construction (architectural and other building-type projects) and horizontal construction (highways, railroads, bridges, etc.) are the two broad categories of construction projects (Runde and Sunayama, 1999). These two categories differ from each other in work schedule, payment procedures, and contract type. However, they can use similar performance measurement methods as they can be projects that include repeatable procedures. For example, work activities in a road project can be continued by repeating them for a certain distance (km). Either, in an apartment project with the same floor plan, the work activities determined for one floor might be repeated on the other floors. These iterative processes can be used to divide projects into logical units. This study focuses on construction projects that include large-scale repeatable processes. The case study in the study focuses on apartment complexes that have the same basic floor layout for large portions of the project.

To set a labor productivity measurement metric, the goal is to find out how many people are required in a progress payment period to generate one unit of progress value. In a payment period, it should be calculated how effectively manpower is used to achieve progress in the targeted unit. Therefore, two types of information need to be collected from the construction site. The first of these is how many units of work are produced in a specified payment period, and the other is how many people work for the completed work unit.

The first piece of information collected for efficiency analysis in construction projects is how many units of work are done on the site. For this purpose, the division of construction projects into logical units is very important in determining project efficiency. In order to determine the effect of worker productivity on the percentage of completion of the project in an apartment complex project, information on the completed project units is needed in each payment period (in general, the monthly progress payment is applied in construction projects). While determining the completion percentage, the ratio of the completed project units (for example, the structural work of the ground floor) to the total project units should be used. In this study, the term "unit metric" refers to the measurable units of the project that are included in the site reports or progress payment documents that are used to look at how efficient the project is.

Another piece of information collected for efficiency analysis in construction projects is how many resources are used for a unit of work. These resources are manpower, materials, equipment, and the resources for supporting processes such as testing and inspection. Since this study focuses on labor productivity, the concept of "manpower" is used to represent how many people work in the field for a unit of work. This information can be obtained from daily, weekly or monthly reports on the site. Using the direct average of on-site labor force data in productivity analysis can be misleading. It may be necessary to add an external factor in the calculations for the representation of non-working days at the construction sites in the productivity analysis. In order to use the exact time spent at the construction site in productivity analysis, "modifying the manpower" data in the field reports by considering the days without work will make the analysis error-free.

The metric proposed in this study is expressed by Formula (1): "LP" in the formula refers to labor intensity, "MP" refers to modified average manpower, "UN" refers to unit numbers, and "PC" refers to the percentage of complete. Having LP results close to 3 is considered a positive value for worker productivity. For this reason, the construction site's days off are taken into account when figuring out the average manpower. Modified manpower is used to avoid this problem.

$$LP = MP / (UN \times PC) \qquad (3)$$

Measuring labor productivity at the end of each payment period refers to periodic labor productivity. However, periodically, worker productivity depends on many factors such as project characteristics, firm financing, weather conditions, market conditions, etc., and productivity results can vary dramatically from period to period. For this reason, periodic productivity measurements can be misleading when evaluated for the total worker productivity of the project from a broader perspective. In addition, the decision makers need the average worker productivity information up to that period in order to delegate the resources for the next stages of the project and take the necessary actions. So, the results of the study are shown in terms of periodic labor productivity and average labor productivity.

A Case Study of and Multi-Family Residential Project

A multi-family residential project was chosen to use the proposed labor productivity metric and evaluate its results. The project consists of 216 repeating units. In general, the project consists of a 7-story residence and a 2-story precast concrete garage in South Florida, delivered in a lump-sum contract. The total cost of the project is $4.8 million. The number of the repeating units was determined according to the bedroom layout that spans one, two, and three-bedroom configurations. The first planned completion date for the project has been set for May 27 by the planning office.

Within the scope of the project, information about the work done and how many units were made was obtained from the subcontractors in the field, and this information was compiled with the productivity metric and conveyed to the field and management personnel. In the monthly coordination meetings, information about the progress of the project was shared with all stakeholders (main contractor, subcontractors, and consultant) along with the efficiency analysis (Table 1). In these meetings, labor productivity information at the time of realization of the activities on the critical path according to the work schedule was especially examined. These reviews use an S-curve to talk about monthly and average worker productivity and expectations for each month (Fig. 1).

The data from site reports is processed using the following parameters: The targeted unit number (TUN) is calculated by multiplying the targeted completion (TC) ratio by the project's unit. Similarly, the actual unit number (AUN) is calculated by the multiplication of the actual completion (AC) ratio and the unit of the project. Labor productivity is the result of dividing the modified manpower (MP) value by the actual unit number (AUN). Average labor productivity represents the mean productivity to date.

Table 42. Site reports data and calculated labor productivity

Months	TUN	TC	AUN	AC	MP	LP	ALP
September	0	0,00%	0,00	0,00%	2,43	NA	NA
October	0	0,00%	0,00	0,00%	2,13	NA	NA
November	1,08	0,50%	2,16	1,00%	1,47	0,6806	0,6806
December	2,16	1,00%	2,16	1,00%	1,55	0,7176	0,6991
January	2,16	1,00%	2,16	1,00%	5,42	2,5093	1,3025
February	6,48	3,00%	1,08	0,50%	10,1	9,3519	3,3148
March	12,96	6,00%	2,16	1,00%	15,82	7,3241	4,1167
April	17,28	8,00%	8,64	4,00%	26,32	3,0463	3,9383
May	19,44	9,00%	8,64	4,00%	38,89	4,5012	4,0187
June	21,6	10,00%	9,72	4,50%	43,65	4,4907	4,0777
July	21,6	10,00%	6,85	3,17%	48,93	7,1460	4,4186

August	20,52	9,50%	8,92	4,13%	52,24	5,8560	4,5623
September	17,28	8,00%	15,77	7,30%	55,42	3,5147	4,4671
October	15,12	7,00%	10,80	5,00%	64,55	5,9769	4,5929
November	12,96	6,00%	10,13	4,69%	51,94	5,1271	4,6340
December	12,96	6,00%	8,34	3,86%	45,86	5,5004	4,6959
January	10,8	5,00%	8,25	3,82%	48,29	5,8525	4,7730
February	8,64	4,00%	13,61	6,30%	65,08	4,7825	4,7736
March	6,48	3,00%					
April	4,32	2,00%					
May	2,16	1,00%					
Total	216	100,00%	119,38	55,27%			

TUN: Targeted Unit Number; TC: Targeted Completion According to Schedule; AUN: Actual Unit Number; AC: Actual Completion According to Site Reports; MP: Modified Manpower (Monthly); LP: Labor Productivity (Monthly); ALP: Average Labor Productivity.

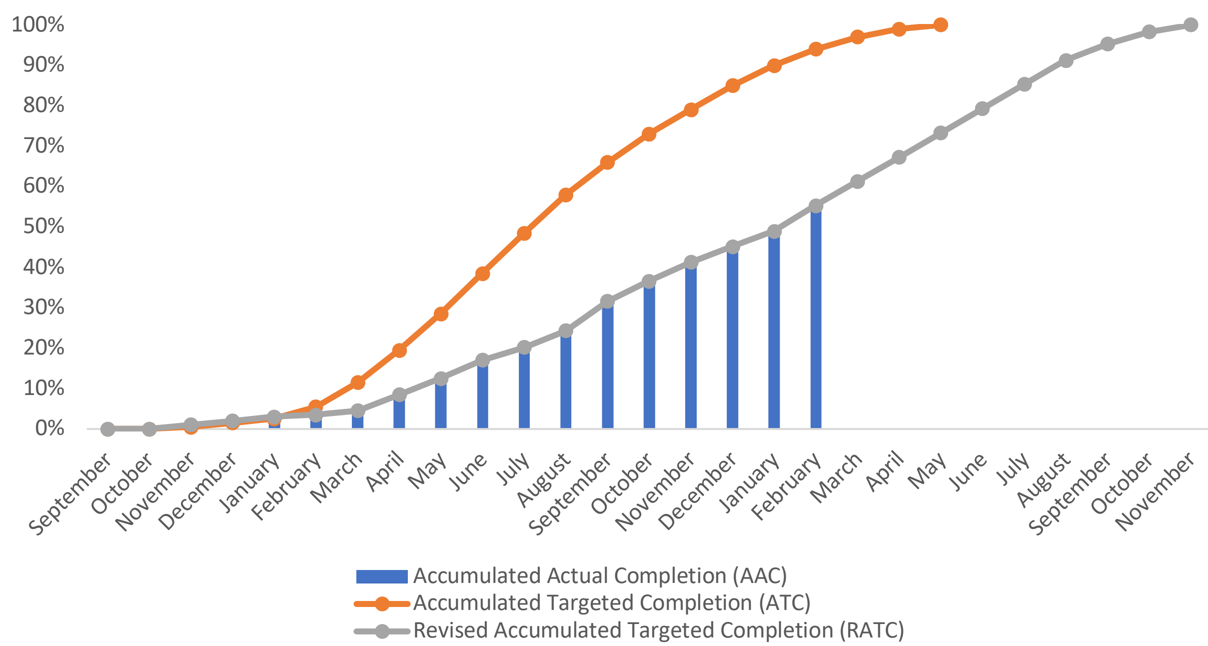

Fig. 1. S Curve for revised project schedule using the labor productivity

In the case study, field data from subcontractors was collected until March, and a worker productivity metric was calculated. The fact that the worker productivity metric values are quite high means that the actual productivity is low. As of February, the percentage of completed work is dramatically below the percentage of planned work. This is because, although construction has begun, the design is still ongoing and potential problems that arise are hampering field progress. The changes in the design and the inability to solve the incomprehensible issues on time prevented the project from reaching the targeted monthly amount of work. Although this provides a prediction that the project cannot be completed on time, it does not provide a clear idea of when the work can be finished. In addition to this, to avoid production delays, the manpower at the construction site has been gradually increased every month to keep up with the planned production and the project schedule. Thus, it aims to prevent delays by increasing production per unit time. However, since the contradictions related to the design and the design are still not completed and no problem can be solved with the increasing workforce, the worker productivity values could not be reduced and worker productivity could not be increased to the desired level. This has been interpreted as a wasteful use of resources and working hours by both the general contractor and subcontractors. It results in decreased worker productivity and profits for all parties. By using the worker productivity values, the amount of work remaining in the project was re-planned and the planned completion percentages were modified. According to the modified work schedule, the project is expected to be completed in November. The use of the worker productivity metric helped predict a delayed, albeit delayed, completion date for the project (Table 2).

Table 2. Revised project schedule using labor productivity metrics

Months	TC	ATC	RTC	RATC	AC	AAC
September	0,00%	0,00%			0,00%	0,00%
October	0,00%	0,00%			0,00%	0,00%
November	0,50%	0,50%			1,00%	1,00%
December	1,00%	1,50%			1,00%	2,00%
January	1,00%	2,50%			1,00%	3,00%
February	3,00%	5,50%			0,50%	3,50%
March	6,00%	11,50%			1,00%	4,50%
April	8,00%	19,50%			4,00%	8,50%
May	9,00%	28,50%			4,00%	12,50%
June	10,00%	38,50%			4,50%	17,00%
July	10,00%	48,50%			3,17%	20,17%
August	9,50%	58,00%			4,13%	24,30%
September	8,00%	66,00%			7,30%	31,60%
October	7,00%	73,00%			5,00%	36,60%
November	6,00%	79,00%			4,69%	41,29%
December	6,00%	85,00%			3,86%	45,15%
January	5,00%	90,00%			3,82%	48,97%
February	4,00%	94,00%			6,30%	55,27%
March	3,00%	97,00%	6,00%	61,27%		
April	2,00%	99,00%	6,00%	67,27%		
May	1,00%	100,00%	6,00%	73,27%		
June			6,00%	79,27%		
July			6,00%	85,27%		
August			4,00%	91,27%		

September	3,00%	95,27%
October	1,73%	98,27%
November		100,00%

TC: Targeted Completion According to Schedule; ATC: Accumulated Targeted Completion According to Schedule; RTC: Revised Targeted Completion According to Schedule; RATC: Revised Accumulated Targeted Completion According to Schedule; AC: Actual Completion According to Site Reports; ATC: Accumulated Actual Completion According to Site Reports.

Expert Opinion

The worker productivity metric and case study application were conveyed in focus group meetings held with the participation of four experts. The focus group meeting method evolved as a purposeful sampling startegy and a bridge strategy between scientific research and local knowledge (Cornwall & Jewkes, 1995). In participatory research, meetings are regarded as a "cost-effective" and "promising replacement" (Morgan, 1996), giving a basis for opposing concepts or ways of thinking (O. Nyumba et al., 2018). In these meetings, a questionnaire containing short, open-ended questions was given to the experts in order to understand the effectiveness, benefits, and limitations of the proposed labor productivity metric. Since some studies recommend more than or equal to four and less than or equal to fifteen participants (Fern, 1982; Mendes de Almeida, 1980), the minimum number of four participants was used in this study.

The first of the experts was a CEO with 30 years of experience in residential and commercial construction projects. This person is also an expert in using worker performance methods. Another expert interviewed was a construction director with 30 years of construction experience, mostly on large-scale residential and commercial projects, but with few actual uses of productivity tools. The given case study is selected from a complex project that includes more than one sub-construction project. For this reason, the first of the other two experts interviewed was the general superintendent of a complex project and had 35 years of professional experience. The other person was the senior superintendent of the construction project in the case study, who has worked in the field for 25 years. Expert evaluations were examined under the titles of usability, applicability and practicality.The effectiveness of the use of the metric in a case study according to current practices was evaluated.

Expert # 1 stated that the metric used and the case study were effective in understanding the progress of the projects and how the resources of this project would be used. It was stated that the experience gained from the case study could be used in the project development phase in the planning of future projects. While the usability and applicability of the relevant metric were found to be quite high, its practicality was evaluated at a relatively low level. The case study is thought to be incapable of providing specific data for specific project types. It was stated that the practicality of the worker productivity metric in the projects could be increased by conducting more case studies and including specific project types in these studies.

Expert # 2 stated that the metric and the case study allowed for a comprehensive review of construction management at a high level and that the usability was high. He noted that the metric used provides vital information to management personnel who are unable to visit the construction site on-site and personally analyze and judge it. The biggest obstacle to the effective implementation of the metric was interpreted as the fact that the company personnel using the metric did not understand how positive and beneficial it could be for the project.

Expert # 3 stated that the usefulness of the metric used in the case study was at a high level. He mentioned the potential of the labor productivity metric to become the main guideline for all workers in the field when delegating resources. Another positive use of the metric is that it will provide leverage to ensure that project subcontractors work diligently and effectively to help the project produce as much output as possible. He agreed with other experts that more data is needed to help figure out which subcontractors aren't producing well and quickly.

Expert #4 stated that the current situation, from the top management to the field personnel, is not well communicated according to which analysis and production are measured, and that the gap on this issue can be filled with the metric used. By giving workers information about how well or poorly they are doing on the project each month, it helps them keep morale high on the job site because they know that their work will still be done on time.

4. Conclusions and Recommendation

This paper provided a quantifiable labor productivity metric and a case study of a multi-house residential project. According to the results of the case study, a delayed project was rescheduled using efficiency data. In addition, the competencies of the workers in performing the project were provided to the project decision makers and enabled them to make inferences that could be used in future projects. The discussion of the metric and the case study was carried out with the experts working in the sector and on the project specified in the case study. The consensus of the experts is that the metric is useful and applicable. However, in order to increase the practicality of the metric, it is necessary to try it in more numbers, on a larger scale and in some specific projects, and to create a broad knowledge base. The obstacle to the applicability of the metric is the resistance of the field personnel to using the metric and their inability to transfer field data in a healthy way. The limitation of this study is that for the performance of the metric to be effective, the records from the field must be complete and accurate. For this reason, the operability of the metric should be effectively explained to field workers. In future studies, it is recommended to conduct more case studies on different types of projects and to manage these studies with defined processes by experienced construction professionals who use and learn the metric. In addition, the workload pressure factor can also be calculated if the activity standard for each construction unit is to be determined. This will assist with planning and scheduling.

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The Identification of Underpinning Criteria of Employee Mental Health and Wellbeing in the Construction Industry

Sara Saboor[1], Vian Ahmed[2]

[1,2] Department of Industrial Engineering, American University of Sharjah, United Arab Emirates.
g00080300@aus.edu

Abstract
Over time, the concept of mental health has been viewed as a critical issue for a community's well-being and a nation's success. Where one out of every four people on the planet suffers from some type of mental health problem, resulting in a global economic cost of one trillion dollars per year in lost productivity. As a result, it is critical that the concept be adopted as part of the policymaking process and political agenda. Several research on the idea of individual mental health have been documented in the literature. However, one component of personal life, the work-life, was not addressed in depth. Though the literature has proposed criteria and scales for mental health. However, these studies and scales, are narrowly focused on a certain component and set of criteria that affect employee mental health and wellness. Furthermore, there has been little or no report of mental health studies in terms of conceptual framework in the construction industry. As a result, the aim of this research is to identify the set of underpinning criteria that describe employee mental health and wellbeing in the construction industry to propose a conceptual framework.

Keywords
Mental Health, Construction sector, Social Sustainability, Employee Wellbeing

1. Introduction

Over time the concept of mental health has evolved into numerous theories. Despite the concept's dynamic nature, one of the assumptions that scientists and researchers continued to hold was the distinction between mental health and mental illness (Westerhof & Keyes, 2010). Mental health and mental illness are orthogonal to each other, as shown in Figure 2, because they belong to two distinct but connected continuums.

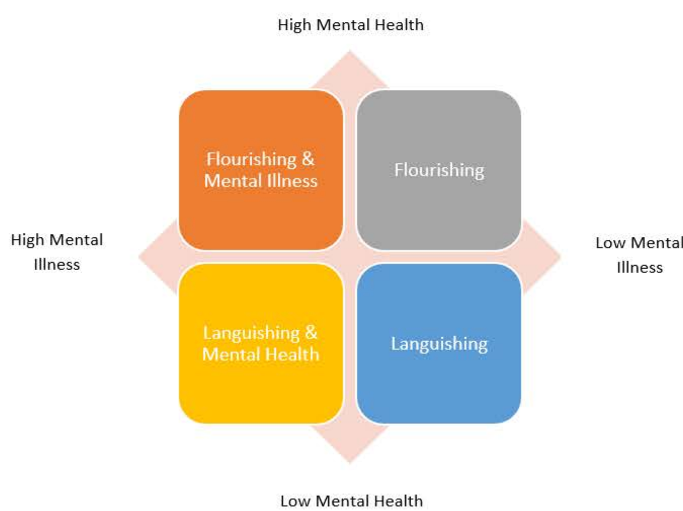

Fig.1. The Dual Continua Model of Mental health and mental illness, Source: (Westerhof & Keyes, 2010)

The picture illustrates the hypothesis of two continua, one of which represents mental health and the other, but orthogonal, continuum representing mental illness. An individual with high mental health and lower mental illness is said to be flourishing, as shown in the first quarter (clockwise). However, a person with high mental health and high mental illness can still be described as flourishing, even if they have challenges or periods of mental illness, as shown in the fourth quadrant. This means that mental health and mental illness are distinct ideas, and that the absence of mental illness does not necessarily imply the presence of mental health.

Mental Health and wellbeing have been recognized as a significant concept for the communities' wellbeing and to a nation's success. With the inclusion of this concept in the Sustainable Development Goals as an integral part of the came as an encouraging effort to promote the construct on a united global agenda. The universal nature of SDGs commits the world to prioritize and promote mental health and wellbeing (World Health Organization, 2016).

Therefore, this study focuses on the concept of Mental health and intents to identify the underpinning criteria that define mental health especially employees' mental health and wellbeing in an organizational setup.

2. Mental Health and Wellbeing

Throughout the history, the concept of mental health has been developed into three theories since 1958 till date namely, the pathogenic approach, salutogenic approach, and the complete state approach (Keyes, 2007).

Amongst which the first approach introduced was the pathogenic approach, informed by the Greek word pathos, which implies suffering or emotion of empathy. This approach describes health as the absence of illness. Later in history around 1979, the salutogenic approach was introduced that perceived health as the existence of positive feelings, capabilities, behaviour, and thinking. Finally, the last approach informed from the word hale implies being whole was called the complete state model (Iasiello et al., n.d.). Since then, the theory of mental health as a complete state of an individual's wellbeing has been adopted and accepted by the researchers that can be evident by the definition proposed by the World Health Organization (Allen et al., 2014),(World Health Organization, 2002) in their historic report in 2002 that defines mental health as:

"a state of well-being in which every individual realizes his or her potential, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to her or his community"

Thus, based on the explanation the complete nature of the construct as described by the World Health Organization can be described in terms of subjective wellbeing (emotional, psychological, and social wellbeing) where the person can perform positively and productively; is adopted for this study.

In addition, to the development of the concept itself, the measurement scales have also evolved in parallel. Which will aid the study understand and identify the criteria focused on by these scales and their limitation to define mental health and wellbeing.

2.1 Measurement Scales

The literature presents a range of theories and definitions related to mental health that have evolved over time and remained associated with various scales developed over time by various scholars and researchers to measure the concept. As a result, the purpose of this subsection is to highlight the most widely accepted and reliable scales by analysing when they were proposed, their purpose, and reliability measurement (Cronbach alpha) for internal consistency. As a result, the study will be able to identify present practices and scale limitations to address the issues. The literature has identified several scales; nevertheless, the section presents the most frequently acknowledged and dependable scales, such as:

A. The Mental Health Continuum—Short Form

The 14-item scale was developed from the long scales calculating the three forms of well-being including psychological, emotional and social wellbeing (Westerhof & Keyes, 2010). The scale has been used over the years in studies, with the internal consistency (Cronbach alpha) found to be 0.83 for psychological and emotional wellbeing and 0.74 for social wellbeing. The scale rate 0.89 on the reliability of the total measurement scale.

The most significant questions in the scale mentioned are: *"In the past month, how often did you feel: …happy? …that your life has a sense of direction or meaning to it? …that people are good?".*

B. The Brief Symptom Inventory (BSI)

Derogatis 1975 proposed the scale with the aim to determine the effect of the last seven days in an individual life. The scale has been widely adopted in the American mental health care. However, the scale is used to measure Obsessive-compulsive Complaints, social phobia, Depression, Anxiety, Hostility, Phobic Anxiety, Paranoia, and Psychoticism (Westerhof & Keyes, 2010). The item in the scale includes: *"During the past 7 days, how much were you distressed by nervousness or shakiness inside?" and "During the past 7 days, how much were you distressed by feeling afraid to travel on buses, subways, or trains?"*. The BSI has been validated and considered reliable with an internal consistency of 0.95.

C. LSI-Z Life Satisfaction.

The scale developed in 1969 aids in the multidimensional measures by comparing the past and present life with a focus on own self and the mood tone of others around the individual (Himmelfarb & Murrell, 1983). The scale consist of 13 items on a five Likert scale was proposed especially for the elderly. The scale was intended to determine mental health generally but morale especially. The reliability of the total scale (Cronbach alpha) was found to be 0.743 for community patients and 0.837 in a clinical setting.

D. Trait-Anxiety Inventory.

The scale was developed by Spielberger et al. (1971) to measure the trait-anxiety. The 20-item scale with the four-point Likert scale includes measures for an individual overall feeling to determine the stable aspect of anxiety (Himmelfarb & Murrell, 1983). Where the internal consistency of the scale was found to be 0.87 for community patients and 0.929 in a clinical setting.

E. The Center for Epidemiological Studies Depression Scale (CES-D)

The scale was created by the National Institute of Mental Health Center for the general population. The 20-item scale on a four-point Likert response intended to measure the symptoms of depression with the emphasis on mood. The scale was designed to access the rate of occurrence of the symptoms over the former one week (Himmelfarb & Murrell, 1983). The reliability of the was found to be 0.851.

F. General Well-Being Scale:

The scale was developed in 1970 as a 14-item scale with a aim to act as a global index to subjective wellbeing and distress. The scale was intended to measure the feeling of an individual for the past month, (Himmelfarb & Murrell, 1983). The reliability of the total scale (Cronbach alpha) was found to be 0.881 for community patients and 0.915 in a clinical setting.

G. Affect Balance Scale:

The scale was developed in 1965 by Bradburn for the general population to measure life satisfaction in terms of positive and negative affect. The 10-item scale access the life satisfaction of the individual for the past few weeks with a yes or no questions (Himmelfarb & Murrell, 1983; Keyes, 2002). The reliability of the total scale (Cronbach alpha) was found to be 0.64 for community patients and 0.695 in a clinical setting.

It can therefore be argued that despite the fact that literature reports on various reliable scales to assess mental health, as shown in Table 3, these instruments tend to work in isolation or lack comprehensiveness, and do not reflect the World Health Organization's definition (WHO). This indicates a research gap; as a result, it is critical to create a comprehensive set of mental health underpinning criteria that can be used to improve employee mental health and wellbeing.

Table 1. Measurement Scale of Mental Health. Source: Author

Name	Year	Scale
Mental Health Continuum—Short Form	2006	14 items which correspond to our theoretical formulation of emotional, psychological, and social well-being.
The Brief Symptom Inventory (BSI)	1975	Somatization, Obsessive-compulsive Complaints, Interpersonal Sensitivity (social phobia), Depression,

		Anxiety, Hostility, Phobic Anxiety, Paranoid Ideation, and Psychoticism
LSI-Z Life Satisfaction.	1969	Morale (Mental Health) - 13 items on a five Likert scale
The Center for Epidemiological Studies Depression Scale (CES-D	National Institute of Mental Health Center	The 20-item scale on a four-point Likert response aimed to determine the symptoms of depression with the focus on mood
Trait-Anxiety Inventory	Spielberger in 1970	The 20-item scale with the four-point Likert scale comprises of measure for an individual general feeling to determine the stable aspect of anxiety
General Well-Being Scale	1970 by Dupuy	The 14-item scale was aimed to act as a global index to subjective well-being and distress
Affect Balance Scale	1965 by Bradburn	The 10-item scale was aimed to access the life satisfaction of the individual over the period of past few weeks with yes or no questions.

However, despite all these efforts by international organization such as World Health Organization (WHO) and proposed measurement scales over the period of time. The literature reports on several failures in the industry that leads to low productivity and performance, costs of illness, absenteeism, staff turnover, and onsite accidents as obvious from the case of the UK where about 80 million days are lost every year due to mental health illnesses that cost up to 1-2 billion pound each year (World Health Organization, 2016).

Therefore, it is essential to identify the underpinning criteria that affect employee mental health in the industry with a focus on the construction sector that is believed to be the backbone of the economy.

The construction sector is thought to be a substantial contributor to the global economy because of being a government and international investor-driven business. The construction business as a whole aids in the development of other industries; the construction industry's activities are scattered throughout several sectors such as transportation, real estate, manufacturing, commerce, warehousing, wholesale, and leasing services. It is regarded as the world's single largest industry as the construction sector alone employs 25% of the world's workforce, with the United Kingdom's construction sector alone generating 2.4 billion employments in 2019 (Smith et al., n.d.; UK Parliament, 2020).

In addition, reports have shown that Australia and the United Kingdom constructions sector has a 2 to 3.5 times greater rate of suicides than the other sectors of the industry nationwide (Kotera et al., 2020)(Sang et al., n.d.). In addition, the literature mentions several alarming reports that have been undertaken in the field. Work stress is also identified as a major issue affecting employee productivity, efficiency, and well-being in the Malaysian construction sector by (Joshi et al., 2020).

Thus, given the significance of this industry and the number of employment opportunity build by the sector, it is critical to address it while building a conceptual framework for employee mental health and well-being. Therefore, this study aims to identify the comprehensive set of underpinning criteria that define Employee mental health and wellbeing to develop a conceptual framework mental health and wellbeing in the construction sector.

3. Employee Mental Health and Wellbeing

This section aims to define employee mental health and its underpinning criteria that affect the wellbeing of an employee in an organizational setup.

Based on the definition by World Health Organization (WHO); employee mental health and wellbeing can also be defined as the state of an individual to realize his potential, to cope with natural life anxieties and strains, to be able to be productive and to make a contribution towards the community (World Health Organization, 2022).

Additionally, the research conducted by (Page & Vella-Brodrick, 2009) defines the concept of employee mental health and wellbeing by focusing on what, why, and how of employee wellbeing and mental health. The research proposed three essential items of employee well-being as (1) subjective well-being; (2) workplace well-being and (3) psychological well-being

However, from the literature, (National Program for Happiness & Wellbeing, 2018) it was found that the concept of employee mental health and wellbeing has been related globally with different outcomes only such as: ***United States of America*** focus on health care cost to evaluate the outcome of employee mental health, ***Asia*** assess the result of employee mental health and wellbeing in terms of Absenteeism, ***Singapore*** adopts social capital as a measure of employee mental health and wellbeing, ***Europe*** assess the outcome of employee mental health and wellbeing in terms of High Morale and ***UK*** determines the outcome of employee mental health and wellbeing in terms of Productivity

Therefore, it can be argued that these results only provide a general picture of an employee's mental health and do not describe the comprehensiveness and in-depth understanding of employee mental health and wellbeing as proposed by the World Health Organization (WHO). As a result, the next section aims to uncover the underpinning criteria of employee mental health and wellbeing that can be used to provide a conceptual framework.

3.1 Underpinning Criteria of Employee Mental Health

The literature reports on several studies that looked into the impact of various criteria or elements on employee mental health and wellbeing. However, these studies were limited in that they concentrated on only one or a few factors, failing to give a comprehensive evaluation and definition of employee mental health and wellbeing in the workplace. This study conducted an extensive literature review that identifies the underpinning criteria of Employee mental health & wellbeing and categorizes them into four categories: organizational factors, personal factors, social factors, and environmental factors.

1. Organizational Factors

The workplace or an organization is a predominant part of an individual life. The size, business activities, and sectors of an organization vary; nonetheless, despite these variances, organizational factors have an important impact in an employee's life and mental health. Organizational factors, as defined by (Valaitis et al., 2018), are the pillars that support the whole structure of the company and help with operational and functional management. The organizational structure (hierarchy), operational policies of the organization (Work Design, Management involvement, and awareness, Welfare schemes, Appraisal scheme, Supervisory Competencies, Growth Opportunity, and Training), and functional policies of the organization (Shift System, Work Timings) are all examples of such factors as summarised in Table 2.

Table 2. Organizational Factors. Source: Author

Factors	Criteria	References
Organizational Factors	Organization Structure (Hierarchy), Shift System, Management involvement and awareness, Work Timings (No. of hours), Flexible work systems or Fixed, Work Design (Job control, job fit, autonomy, challenge, and job meaningfulness), Growth opportunity (Promotion) Timely Payment of Salaries (Satisfaction Pay/inflation) Welfare schemes, Appraisal scheme, Role conflict/ambiguity/ role clarity, Competencies of supervisors, Training	(Spell & Arnold, 2007), (Ailabouni et al., n.d.; Lambert et al., 2006; Lim et al., 2020; Rahman et al., 2017; Valaitis et al., 2018)

2. Personal Factors

Though external factors have a substantial impact on employee mental health and wellbeing, but personal determinants are individual features and characteristics that influence how people make decisions, behave, and form relationships. As a result, personal issues have a substantial impact on an individual's and an employee's overall wellbeing at work [63]. Some of the personal factors identified by literature are Demographics (Age, Education, Past Experience, Level of Academic Achievements, Individual Culture), Personality (Work motivation/ Intrinsic motivation, Optimism, Trait Anxiety, Hostility), and Situational factors are (Sleep Quality, Emotional Exhaustion, Contract Type, Work-Life balance, Spousal support, Job demand, and Job satisfaction) as summarised in Table 3.

Table 3. Personal Factors. Source: Author

Factors	Criteria	References
Personal Factors	Work motivation/ Intrinsic motivation, Sleep Quality, Emotional Exhaustion, Spousal support, Optimism, Level of academic achievements, Education, Past experience, Age, Individual Culture, Trait Anxiety, Hostility, Job demand, Job satisfaction, Contract Type, work-life balance	(Ailabouni et al., n.d.; Allen et al., 2014; V. A. Lambert et al., 2007)(Ibrahim & al Marri, 2015; Sageer, 2012)(Ibrahim & al Marri, 2015)

3. Social Factors

Since an individual's life is made up of two domains: the organizational domain and the personal domain. Therefore, social aspects and support in both are deemed necessary for a calm and productive life [82]. Many research [50, 54] have indicated that interpersonal relationships/workplace conflict, group dynamics, peer support, leadership style, supervisor support and acknowledgement, and organizational commitment are all important drivers of employee mental health and wellbeing. As investigated from the literature, the relationship between employee wellbeing and social support (the frequency with which employees receive support or assistance from co-workers, supervisors, friends, and families) and discovered that social support is negatively related to depression and has a significant impact on employee health and wellbeing. Some of the social factors are summarised in Table 4.

Table 4. Social Factors. Source: Author

Factors	Criteria	References
Social Factors	Social support, Association with supervision, Employee perception of supervisor's, Interpersonal conflict with co-workers/ bullying, harassment and violence, Social Relationships, Group/Team structure/ Workgroup attachment, Leadership Style, Organizational commitment, and Demographic nature of Team	(Allen et al., 2014; Chatziioannidis et al., 2018; Ibrahim & al Marri, 2015; Rahman et al., 2017; Repetti, n.d.)

Environmental Factors

Several studies in the literature suggest that the environment has a positive impact on employee mental health and wellbeing. Where [88] argued in that work environment factors such as lighting, noise, color, and air quality affect employee productivity, health and wellbeing, job satisfaction, and morale. The research took a descriptive technique, obtaining data from secondary sources such as websites, journals, and books. The study concluded that the workplace environment does have an impact on an employee's overall well-being, and that the company should bear this in mind. Following environmental factors that impact Employee mental health and wellbeing are summarised in Table 5.

Table 5. Environmental Factors. Source: Author

Factors	Criteria	References
Environmental Factors	Organization Arrangement, Culture, Working environment and condition (Lighting, Noise, Colour, and Air quality), Work stress/ Workload and Job Security/Safety	(Han & Hyun, 2019; Patterson et al., 2004; Sarode & Shirsath, n.d.)

As a result, this study conducted a thorough literature analysis in order to identify a set of underpinning criteria for employee mental health and wellbeing. The study divides the underpinning criteria for employee mental health and wellbeing into four categories: organizational factors, personal factors, social factors, and environmental factors and proposes a conceptual framework a shown in Figure 2.

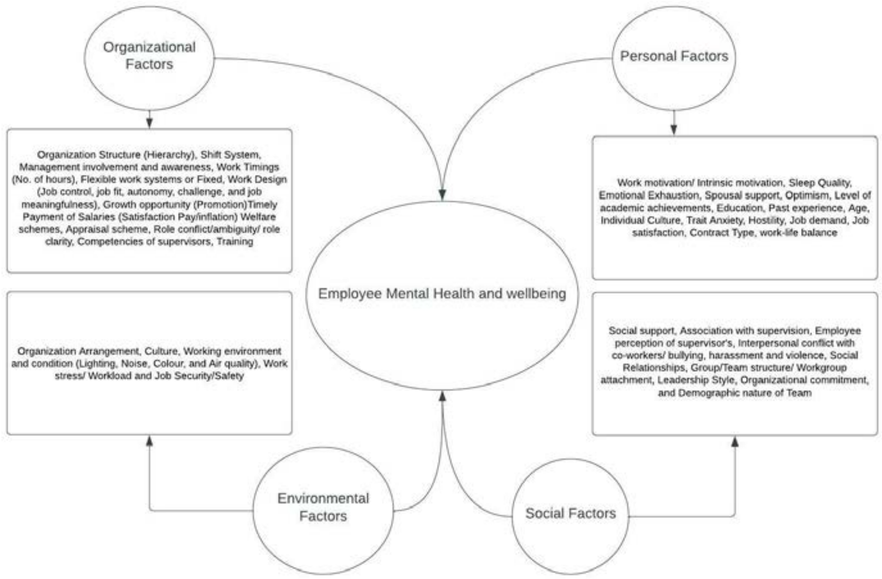

Fig 2. Employee Mental Health & Wellbeing Conceptual Framework. Source: Author

It can therefore be concluded from these findings that organizational, personal, social, and environmental factors have an impact on Employee Mental Health and wellbeing as presented in the conceptual framework. Thus, the framework can be adopted for decision making process that can aid organization take strategic decision to enhance Employee Mental health and wellbeing of their employees.

4. Conclusion

Mental health and wellbeing especially employee mental health has been identified as a significant factor of success and competitive advantage for an organization over its competitors. Where construction sector has believed to be the most sensitive sector that reports alarming statistics of mental health issues. Thus, to address the research gap of literature which reports that the existing studies tend to focus on a specific or narrow range of criteria which fails to explain the comprehensive nature of the concept.

This research aids in identifying the extensive set of 37 underpinning criteria that define employee mental health and wellbeing in construction sector. The proposed conceptual framework can be validated by adopting Structural equation modelling to provide empirical evidence regarding the relationship and impact of identified criteria on EMW. Furthermore, the criteria can be adopted for the development of decision support tool that allows the organizations or decision-makers to enhance Employee mental health and wellbeing in their organization.

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An Analysis of Contract Modifications: USACE Jacksonville District, Jacksonville, Florida

Scott Kramer[1] and James McRae[2]

[1] Auburn University, Auburn, AL 36849
[2] USACE – Jacksonville District, Jacksonville, FL, 32207
kramesw@auburn.edu

Abstract

Construction projects generally solve someone's problem or situation whether it be new construction, renovation or operations and maintenance projects. During the process of solving these problems, various issues arise along the way and must be addressed. These issues lead to changes and result in modifications to the contract called change orders. From 2003 to 2019, U. S. Army Corps of Engineers, Jacksonville District awarded four hundred fifty-seven (457) construction contracts and executed a total of four thousand six hundred seventy-seven (4677) contract modifications on these contracts. This research seeks to identify the causes of these change orders and determine if actions could be taken on future contracts to reduce the number of change orders. The results of this study indicate that additional design phase and pre-award activities such as additional scrutiny, review and vetting have a definite possibility to reduce the number of these types of change orders. This study is relevant to USACE project managers, construction contract administrators, and other Construction Management Professionals.

Keywords

Change Orders, Government Contracts, U. S. Army Corps of Engineers, Jacksonville District, Contract Administration

1. Introduction

Construction is a problem driven industry. Construction projects generally solve someone's problem or situation whether it be new construction, renovation or operations and maintenance projects. During the process of solving these problems, other problems arise along the way and must be addressed. These new and potentially different problems may result in changes to the way the contract is executed. Potentially, these changes result in an increase or a decrease in the cost to execute the contract and potentially affect the time it takes to complete the work. These potential changes result in modifications to the contract called change orders.

The American Bar Association defines a "change order" as an industry term for an amendment to a construction contract that changes the contractor's scope of work. Most change orders modify the work required by contract documents (which, in turn, usually increases the contract price) or adjust the amount of time the contractor has to complete the work, or both. For there to be a valid change order, the owner and contractor must both agree on all terms. (*Construction 101: The Basics of Change Orders*, n.d., p. 101). Change orders affect the construction process in many ways depending on the contract type. Projects that are hit by change orders are usually prone to delays, cost increases, and reduced labor productivity (Günhan et al., 2007). A contractor does not perform work in a vacuum; rather he must properly allocate his limited resources within projects and between actual and potential projects. Consequently, whenever a change, suspension or delay occurs, a contractor must make adjustments to work under the contract and reallocate time, material and labor resources. (Dunn III, 1999).

While change orders are sometimes unavoidable, it's difficult for teams to accurately estimate their impact. On average, change orders result in a 30% loss of productivity. Understanding the true cost –direct, indirect and consequential – can help construction teams to minimize the effects.(*What Does A Change Order Actually Cost You?*, 2019) Minimizing the number of contract change orders on a project is in the best interest of all parties involved in the contract the owner, the Government and the contractor to avoid additional time, costs and potentially litigation.

2. Background

It seems that disputes over change orders are inevitable for all construction projects (Cox, 1997). These disputes range from the scope of the change, cost associated the with work required under the change, any changes to contract time associated with the change to the contract, who caused the change and ultimately who bears legal and financial responsibility for the impacts of the change. It is important for each party to understand their role in the project and the change management process. The owner should strive to structure the acquisition strategy and contract structure that manages and allocate risk as well as provide a means to prevent and resolve disputes in a timely manner. The contractor's role is to recognize the risk assumed by entering onto the contract, be cognizant of any changes clause in the contract, and be prepared to provide cost for all added and changed work. Cox indicated that successful management of change orders and claims beginning construction and continue through the close out of the contract.

In GAO's, Report to Congressional Requesters GAO-19-500, FEDERAL CONSTRUCTION, Army Corps of Engineers and GSA Need to Improve Data on Contract Changes, in fiscal year 2018, federal agencies spent more than $36 billion on construction contracts. 45 percent of these contract went to small business. Typically, construction projects involve some degree of change as the project progresses. Some federal construction contractors have raised concerns that delays in processing contract changes and making payments creates challenges, particularly for small businesses (Office U.S. Government Accountability, 2019). For this report GAO was tasked to review federal construction contract change processes and timeframes for two agencies with large amounts of obligations on construction, GSA's Public Buildings Service and USACE. Completing the study, GAO reviewed relevant regulations, agency policies, analyzed available data, and interviewed officials from the two agencies. The review identified factors that affect the time it takes to finalize contract changes, and it assessed the extent to which selected agencies monitor time frames for finalizing contract changes. The report found that GSA nor USACE routinely monitors the length time it requires to finalize construction contract changes, which limits their respective management's ability to identify and respond to problems. GAO stated that a variety of factors affect how long it takes to process a contract change. The factors include the time needed for making a change determination, creating a cost estimate, identifying funds, negotiating with the contractor, completing reviews, and processing the change. (Office U.S. Government Accountability, 2019). According to agency officials, some of these steps play a role in protecting the government's best interests. For example, creating robust cost estimates helps provide the government with information to inform negotiations with the contractor.

The Associated General Contractor of America (AGC) echoed the GAO's finding "As AGC has known, GAO confirmed that one of the main issues that delayed change orders causes an interruption in cash flow to a contractor(*Change Orders | Associated General Contractors of America*, n.d.). They articulated, that the longer it takes an agency to identify and process a change order, the longer it will take for contractors to get paid for the additional work and it impacts. These impacts include project schedule disruption that can limit the ability of contractors to successfully execute the contract. AGC also articulated that any delay in processing change orders not only costs contractors valuable time and money, it cost the Government as well.

The Jacksonville District of the United States Army Corps of Engineers administers approximately $500 million placement on construction contracts each year. The Construction Division is tasked with administration/execution of these construction contracts. The Construction Division is divided up into regional Areas of Responsibilities (AOR), called Areas. The Areas are further subdivided into office call Resident Offices. A summary outline of the Jacksonville District's current construction contract administration structure is provided in Table 1.

Table 1. Jacksonville District Construction Contract Administration Structure

AOR	Area Office	Resident Office	Work Type
	Antilles	North Puerto Rico	Major and Minor Civil Works Construction

Puerto Rico, Cuba and Lesser Antilles		Rio Puerto Nuevo	Contracts with Minor Military Construction Contracts
South Florida	South Florida	West Palm Beach Resident Office Miami Resident Office Hebert Hoover Dike	Major and Minor Civil Works Construction Contracts with Minor Military Construction Contracts
North Florida	North Florida	Jacksonville Melbourne/IIS Tampa/Sebring	Major and Minor Civil Works Construction Contracts with Minor Military Construction Contracts

The USACE process for processes change orders is out lined in the SADDM 1110-1-1 Contract Administration manual. The process is summarized below

1. Identify and scope the work required under the change
2. Prepare and send a properly executed Request for Proposal to the contractor requesting proposal in within a set amount of time
3. Once proposal is received analyze the proposal against the Independent Government Estimate (IGE) prepared while the contractor is preparing his proposal
4. Prepare a Pre-negotiation Objective Memo (POM) documenting the Government pre-negotiation position for approval by the Contracting Officer prior to entering negotiations
5. Conduct negotiations with the contractor
6. Prepare a Price Negotiation Memorandum (PNM) documenting the negotiation with the contractor that emphasizes the reason why a contractor's price was accepted and clearly articulating deviations from the original Government position documented in the POM for legal review and Contracting Officers approval.
7. Prepare Special Form (SF) 30 (contract modification document) and send to the contractor for execution
8. Receive contractor executed SF 30 and obtain Contracting Officers signature to finalize modification.

The process outline above can have a lengthy time frame to complete depending on the complexity of the modification.

USACE utilizes the Resident Management System (RMS) to administer all aspect of a construction contract. It is a USCAE developed system that is congressionally mandated to be used on all USACE construction contracts over one million dollars. The contract administration functions in RMS utilized by USACE include but are not limited to contract correspondence, submittal and shop drawing submission and approval tracking, quality control and assurance reporting, and contract financials such as progress payment and change order.

Once a modification is identified and entered into RMS, the database tracks each contract modification with an assigned code. Each code is classified as either controllable or uncontrollable. In layman's terms a controllable change is a change that could have reasonable foreseen or prevented with proper due diligence and an uncontrollable change is due to conditions or circumstances that could not have been reasonably foreseen or prevent proper due diligence. To better track the changes and their causes USACE further classifies controllable/uncontrollable changes into causal description codes. Modification Code Description as outline in USACE Engineering and Construction Bulletin 2002-27 and defined in RMS are as shown in Table 2.

Table 2. RMS Modification Reason Codes

RMS Code	Modification Reason	Description
1	Engineering Changes	Changes, accountable to the U.S. Army Corps of Engineers, which are necessary to remedy deficiencies in the contract plans and specifications. This could be an AE Responsibility issue. (Controllable)

4	User Changes	Changes resulting from conditions differing from the original design, e.g. new federal regulation, code, criteria, mission changes, or enhancement. These changes must be directed or requested by a government agency, using/programming command/service or customer and generally relate to ease of maintainability, operability, or an enhancement of quality of life for the user (soldier). (Uncontrollable)
5	Contract Option Exercised	Exercised with construction funds after award of the basic contract. The option must be specifically identified in the original Bid Documents. (Uncontrollable and Controllable)
6	Miscellaneous Changes	Changes resulting from various reasons such as changes in tax as a result of tax law changes, decrease in inspections, decreases because of inaccurate price or description furnished by the contractor etc. (Uncontrollable)
7	Differing Site Conditions	Subsurface or latent physical conditions at the site which differ materially from those identified in the contract or unknown physical conditions at the site, of an unusual nature, which differ materially from those ordinarily encountered and generally recognized as inherent in work of the character provided for in the contract and not identified through a normal engineering site investigation. (Uncontrollable)
8	Value Engineering Change	Change those results in reducing the contract price or estimated cost without impairing essential functions or characteristics. (Controllable)
9	Administrative	Change that does not affect the substantive rights of the parties (e.g., a change in the paying office, appropriation data, contractor address change, funding change such as continuing authority civil contracts, etc.). The change MUST be for no cost to the contract price and no time extension. (Not recorded as Controllable or Uncontrollable)
E	Excusable Delay for No Fault	Change in contract period for weather (including floods), strikes, fires, epidemics, freight embargoes, material or supply shortages, delays of subcontractors or suppliers, and other events which are determined to be beyond the control and without fault or negligence of both the contractor and the subcontractors or suppliers. Change involves time only, no contract cost. (Uncontrollable)
G	Government-Furnished Property (GFP)	Corrections in deficiencies in equipment or property supplied by the Government including delays by the Government in providing the GFP. (Controllable)
Q	Variations in Estimated Quantities	Overruns and underruns of quantities included in the contract. The quantities MUST be listed as Contract Line Items and entered as such in RMS.(Uncontrollable)
S	Suspensions or Termination of Work	Temporary work stoppage on all or part of a contract with the intent of restarting work at a later date (Suspensions). (Controllable)
T	Termination of Work	Permanent work stoppage on all or part of a contract by deleting a portion of the scope from the contract requirements. (Controllable)
V	Construction Change	Changes not falling into one of the other reason codes. The reason for selecting this code MUST be provided in the Necessity for Change block of the BCD. (Controllable)
A	Adverse Security Conditions	Modification required for construction destroyed, damaged or delayed by hostile/friendly actions. (Uncontrollable) (Is in RMS but not ECB)
R	Revaluation	Foreign Currency

3. Results

To identify primary causes for of construction contract change orders, the following 2 research methods were utilized: (1) A survey of the District's ten construction contract administration personnel to identify their perceptions about change orders in the AOR and (2) an extensive review and analysis of charge order data from the District construction contract administration database, RMS.

The USACE business model put the responsibility for identification, quantification negotiations, and administration of change orders on personnel with delegated contract authority called an Administrative Contracting Officer (ACO). How those engaged in the solution of a problem perceive the problem is often paramount in solving the problem. To gauge personnel perception of change orders a survey was provided to the District's 10 Administrative Contracting Officers with the following Questions:

1. Are most of the contract changes in your AOR Controllable or Uncontrollable?
2. What is the most common form of Controllable Change your office experiences?
3. What is the most common form of Uncontrollable Change your office experiences?
4. Are there any measures pre-award that could reduce the number and magnitude of Controllable Changes?
5. Are there any measures pre-award that could reduce the number and magnitude of Uncontrollable Changes?

Nine (9) of the ten (10) responded. There responses are summarized in Table 3 below.

Table 3. Contract Administration Personnel Perception

Question	Questionnaire Response	Positive Response	Negative Response	ACO Perception
Are most of the contract changes in your AOR Controllable or Uncontrollable?	Controllable	4	5	
	Uncontrollable	5	4	Uncontrollable
What is the most common form of Controllable Change your office experiences?	Engineering Changes	8	1	Engineering Changes
	Contract Options	1	8	
	Value Engineering Change	0	0	
	Government Furnished Property	0	0	
	Suspensions or Termination of Work	0	0	
	Termination of Work	0	0	
	Construction Change	0	0	
What is the most common form of Uncontrollable Change your office experiences?	User Changes	0	0	Variation in Estimated Quantities & Differing Site Conditions
	Miscellaneous Changes	1	8	
	Variation in Estimated Quantities	3	6	
	Differing Site Conditions	3	6	
	Excusable Delay for No Fault	1	8	
	Adverse Security Conditions	0	0	
Are there any measures pre-award that could reduce the number and magnitude of Controllable Changes?	More thorough/better Plan Reviews	1	8	Early Construction Staff Involvement
	Different Contract Acquisition Strategy (RFP vs IFB)	0	0	
	Increased/Better site investigation/surveys	1	8	
	More experienced Design team	1	8	
	Increased/better Design Team Coordination	2	7	
	Early Construction Staff Involvement	4	5	
	Other (Please Describe Below)	0	0	

Are there any measures pre-award that could reduce the number and magnitude of Uncontrollable Changes?	More thorough/better Plan Reviews	1	8	
	Greater upfront coordination with end user	0	0	
	Different Contract Acquisition Strategy (RFP vs IFB)	0	0	
	Increased/Better site investigation/surveys	4	5	Increased/Better site investigation/surveys
	More experienced Design team	0	0	
	Increased/better Design Team Coordination	1	8	
	Early Construction Staff Involvement	1	8	
	Other (Please Describe Below)	2	7	

Data Summary: Due to the differences in work load and primary work type conducted by each office some variation in response was anticipated. Based on analysis of the responses to the questionnaires, most ACOs viewed perceived that the majority of changes in their AORs were uncontrollable. The data indicates that additional design phase and pre-award activities such as early involvement of construction management personnel, additional security, review and vetting have a definite possibility to reduce the number of these types of change orders.

3.1 RMS Database Information Analysis

Jacksonville District maintains data on change orders in the District's RMS database. The data base contains information from contracts dating back to 2003. While the database may not contain all construction contracts executed by the District because the district executes contracts within its boundaries for construction programs owned and executed by some of its sister Districts, it is reasonable representation of scope and magnitude of contracts the District executes as regular basis. A review of the District's RMS database yielded four hundred fifty-seven (457) contracts of vary size, scope and complexity with a total value of approximately $4,1 billion dollars. On these four hundred fifty-seven (457) contracts at total of four thousand six hundred seventy-seven (4677) contract modifications were issued for various reasons adding approximately $736 million dollars and a cumulative total of 69,603 days to contract durations. Or a cost growth of 17.8% and a time growth factor of 49%. As detailed below, of the four thousand six hundred seventy-seven (4677) contract modifications, one thousand six hundred ninety-five (1695) or 36.3% of those modification were controllable change orders (Table 4) and two thousand nine hundred eight-two (2982) or 63.7% were attributable to uncontrollable change orders (Table 5). The analysis validated the ACO perception of controllable versus uncontrollable changes.

Table 4. Controllable Modifications

RMS Code	Modification Type	Number of Modifications	Percent of Controllable	Percent of Total Modifications
1	Engineering Changes	953	56.19%	20.38%
5	Contract Options	132	7.78%	2.82%
8	Value Engineering Change	33	1.95%	0.71%
G	Government Furnished Property	12	0.71%	0.26%
S	Suspension of Work	57	3.36%	1.22%
T	Termination of Work	14	0.83%	0.30%
V	Construction Changes	494	29.14%	10.56%
Total Number Controllable Modifications		1695	100%	36.2%

Data Summary: Based on analysis of the data the three most prevalent controllable changes are Engineering Changes, Construction Changes and Contract Options. Again the analysis validated the ACO perception of the controllable changes. Contract Options are not a relevant comparison as they are priced at the time of bid and do not factor into time and cost growth statistic for USACE. Engineering Changes are changes due to remedy deficiencies in the contract plans and specifications. Construction changes do not fall into one of the other reason codes and are a bit ambiguous. However, there are code controllable and in terms of this study should be treated like Engineering changes. The data indicates that the ACOs perceive that additional design phase and pre-award activities such as additional security, review and vetting have a definite possibility to reduce the number of these types of change orders.

Table 5. Uncontrollable Modifications

RMS Code	Modification Type	Number of Modifications	Percent of Uncontrollable	Percent of Total Modifications
4	User Changes, Discretionary	555	18.61%	11.87%
6	Miscellaneous Changes	614	20.59%	13.13%
7	Differing Site Conditions	409	13.72%	8.74%
9	Administrative Change	458	15.36%	9.79%
A	Adverse Security Conditions	4	0.13%	0.09%
E	Excusable Delay for No Fault	228	7.65%	4.87%
I	Incremental Definitization of Work	2	0.07%	0.04%
Q	Variations in Estimated Quantities	711	23.84%	15.20%
R	Revaluation - Foreign Currency	0	0.00%	0.00%
Z	COVID-19	1	0.03%	0.02%
Total Number Uncontrollable Modifications		2982	100%	63.8%

Based on analysis of the data the three most prevalent controllable changes are Variation in Estimated Quantity, Miscellaneous Changes, and User Changes. The analysis validated the ACO perception of the controllable changes. Variations in Estimated Quantities changes stem from overruns and underruns of quantities of unit price items included in the contract. Miscellaneous Changes result from various reasons such as changes in tax as a result of tax law changes, decrease in inspections, decreases because of inaccurate price or description furnished by the contractor etc. User Changes result from conditions differing from the original design, such as new federal regulation, code, criteria, mission changes, or enhancement. It is important to note that these changes must be directed or requested by a government agency, using/programming command/service or customer and generally relate to ease of maintainability, operability, or an enhancement of quality of life for the user. The data indicates that additional design phase and pre-award activities such as additional scrutiny, review and vetting have a definite possibility to reduce the number of these types of change orders.

4. Conclusions

“Management of change orders is management of risk” (Cox, 1997 p.24). Review of the data indicates that there is opportunity to reduce the number of change orders on construction contracts within the Jacksonville District. While there are some contract changes that cannot be reasonably anticipated, such as adverse weather, acts of God, etc., many other causes for contract changes can be potentially identified prior to formulation of the contract and incorporated prior to contract award. The data supports this position for different classifications of both controllable and uncontrollable change orders. Additional design phase and pre-award activities have the potential to reduce change orders. These activities add to project costs and schedule in different ways as well. The question must be asked, “Is the risk worth the reward?’ Is the additional time and monies required up front less than what might be required later? Additional study is required to answer these questions. Future research is recommended to build upon this dataset to seek to determine the magnitude of saving that may be possible if additional design phase and pre-award activities are considered and implemented.

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Artificial Neural Networks for Predicting Conventional Cost of Industrial Construction Projects

Konstantinos Efthymiou[1], George Aretoulis[2]

[1] Hellenic Open University, Parodos Aristotelous 18, Patra, 26335, Greece
[2] Aristotle University of Thessaloniki, University Campus, 54124 Thessaloniki, Greece
garet@civil.auth.gr

Abstract

Artificial neural networks (ANN's) are an important tool for solving complex problems leading to an extensive application in project management. For that purpose, the aim is to develop a model to predict the actual cost of construction projects related to industry infrastructure. A literature review is carried out on the latest research regarding the application of ANN's in the construction industry followed by the relevant findings. Then the research methodology for the implementation of artificial neural networks is presented, and finally construction of ANN based models took place, based on a sample of 20 industrial construction projects.

The most successful models for forecasting actual cost of industrial construction projects are presented and the results are considered satisfying despite the limited amount of case studies. The considered independent variables included: Type of premises, contact with neighboring construction, distance from headquarters (km), project budget (€), initial project duration (days), area of premises (m^2), earthworks (m^3), reinforced concrete (m^3), metal bearing construction weight (tn) and finally average daily number of workers. Finally, ANNs' predicting capabilities is discussed, showing great accuracy, and a number of suggestions are presented for further improvement and future research.

Keywords

Project Management, Project Organization and Planning, Artificial Neural Networks, Industrial Projects, Cost Forecasting.

1. Introduction

Artificial neural networks are mathematical models that belong to the category of empirical capacity models. Their architecture consists of hidden layers with various artificial neural cells that contain activation functions. Several studies focus on project cost, estimates, compensation methods, contract types and artificial neural networks (Anagnostopoulos et al., 2021; Antoniou et al., 2018; Antoniou & Aretoulis, 2019; Aretoulis et al., 2016; Aretoulis, 2019; Titirla et al., 2021; Titirla & Aretoulis, 2019). The term Artificial Neural Networks (ANN) essentially describes several complex mathematical models, which are inspired by the corresponding biological ones. These models attempt to imitate the behavior of neurons in the human brain. Since the beginning of the 19th century, scientists have found that the brain consists of discrete elements, neurons, which communicate with each other and constitute its basic structural element. It is estimated that the brain contains approximately 10 billion neurons arranged in groups, each of which forms a natural neural network (Georgouli, 2015).

An additional definition by Aleksander & Morton (1991) states that: "An Artificial Neural Network is a vast parallel processor with distributed architecture, consisting of simple processing units and naturally capable of storing empirical knowledge and making it available for use." Of course, the way neural networks are used differs from that of classical computers. Their function is based on a combination of the methodology by which the human brain works and the way in which abstract mathematical thinking operates. The network is trained, learns, remembers numerical values, or forgets them, concepts that until now are characterized and concerned only by human thought (Argyrakis, 2001).

Neural networks first appeared about 50 years ago and became a separate interdisciplinary specialty from the mid-80s onwards, a fact that is verified by the large number of scientific publications and applications that began to diffuse in the market. The first artificial neural network built belongs to the neurophysiologist Warren McCulloch and Walter Pits in 1943, but the available technology of the time, put significant restrictions on its satisfactory development. The main reason for the development of neural networks from the moment of their first appearance, which attracted the interest of scientists, was the desire to construct machines and systems capable of carrying out complex operations, which computers based on the von Neumann model do not solve successfully due to their serial mode of operation (Siganos & Stergiou, n.d.). In the next sections the research methodology is highlighted. Then follows correlation analysis and ANN models' creation and conclusions along with future research.

2. Research Methodology and Sample Description

In order to apply artificial neural networks, it was needed to record a number of completed projects. The collection of data was based on several completed industrial projects with a variety of dimensions and uses. These projects were constructed in various regions of Greece and presented separate requirements depending on the desired result. The parameters examined included the type of installation (warehouse, refrigerator storage, freezer storage, offices), the building surface, the volume of earthworks, the surface of the asphalt pavements of the surrounding area, the amount of reinforced concrete, the weight of the metal bearing structure, the staff employed, the distance from the company, any contact with adjacent construction, the estimated duration and budget of the project. One critical factor was to ensure that the sample is as representative as possible. From the whole set of available data, special attention was provided to quantitative variables. The number and type of variables selected were defined by correlation analysis. Those variables that influenced the final cost were prioritized based on the degree of correlation. In this way, the input database was created to implement artificial neural networks.

The next stage included a series of tests to identify the most effective combination of input variables leading to a more accurate forecast of the actual cost. The main evaluation criterion for the accuracy of the prediction was the Sum of Squares Error and Relative Error for the Training and Testing samples, which calculate the difference between the actual result and the one predicted by the artificial neural network. Given the combination of variables, a series of tests followed based on various design options of the artificial neural networks, in an attempt to optimize the prediction.

Training of the ANN was based on the collection of data from 20 different projects. These specific projects were carried out by a single construction company, which is currently based in the city of Thessaloniki, Greece. The figures below (Figures 1-10) show some statistics regarding the projects in relation to the input variables used.

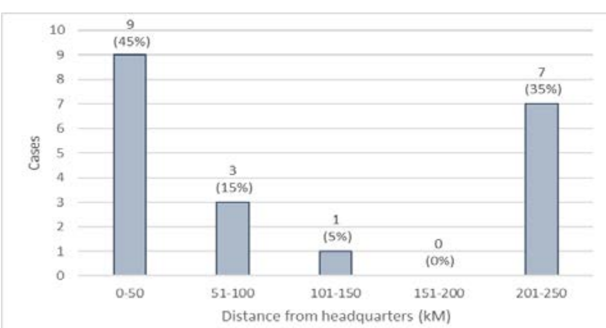

Fig. 47. Number of cases in relation to distance from enterprise headquarters

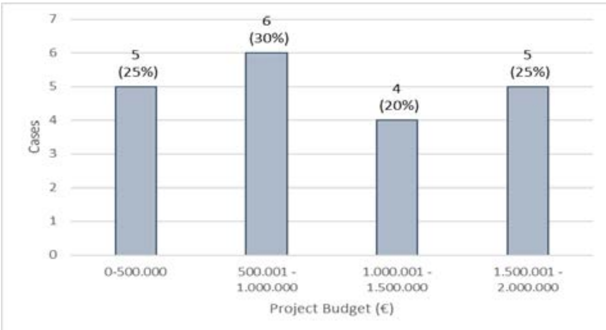

Fig. 48. Number of cases in relation to project budget

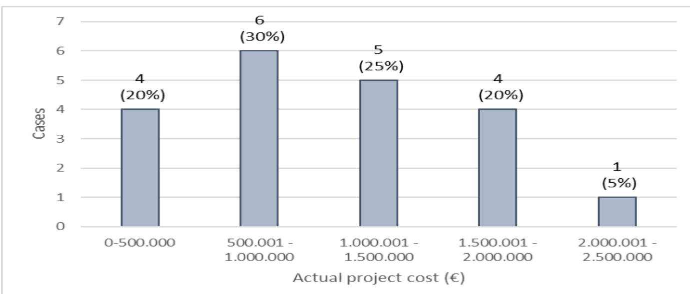

Fig. 49. Number of cases in relation to actual project cost

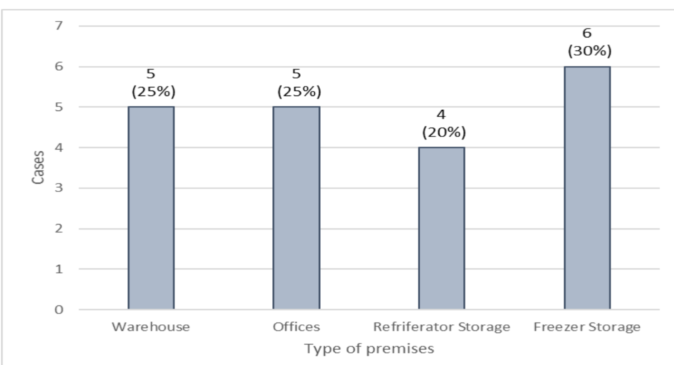

Fig. 4. Number of cases in relation to type of premises

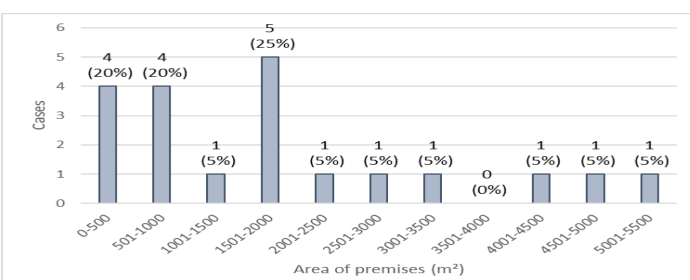

Fig. 5. Number of cases in relation to area of premises

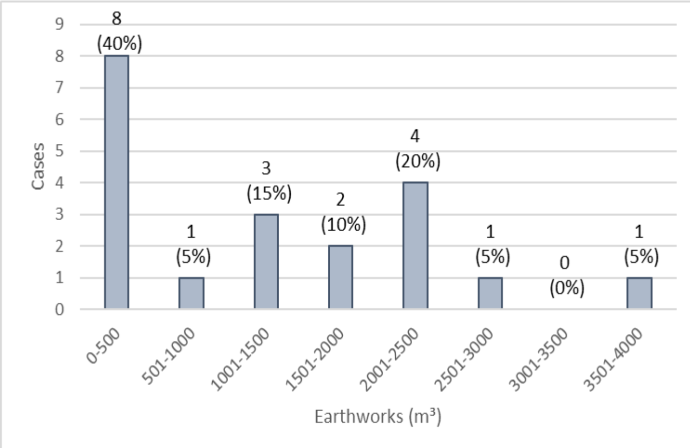

Fig. 6. Number of cases in relation to earthworks

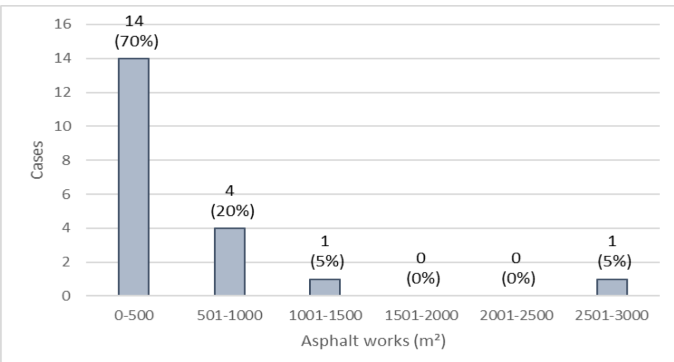

Fig. 7. Number of cases in relation to asphalt works

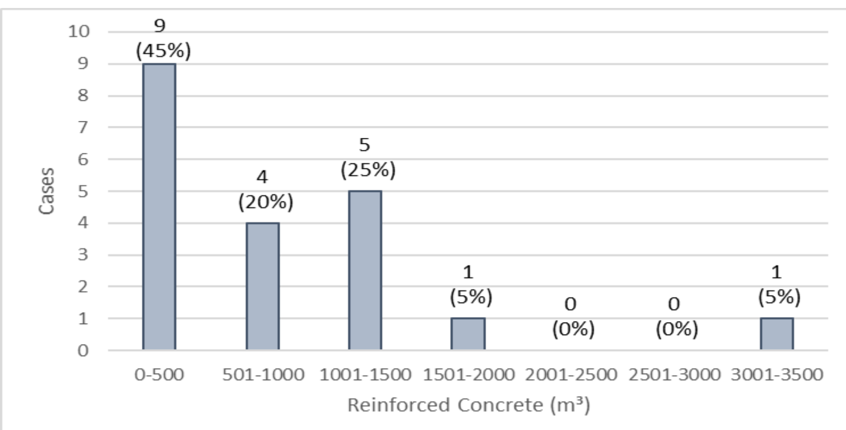

Fig. 8. Number of cases in relation to reinforced concrete

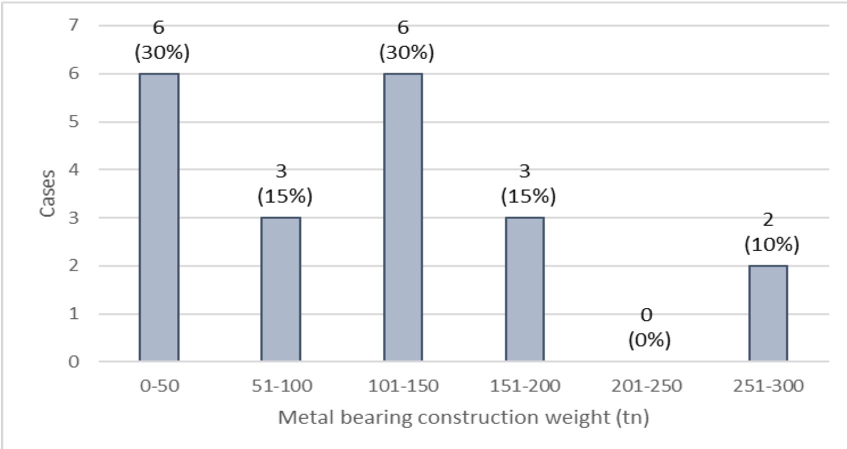

Fig. 9. Number of cases in relation to metal bearing construction weight

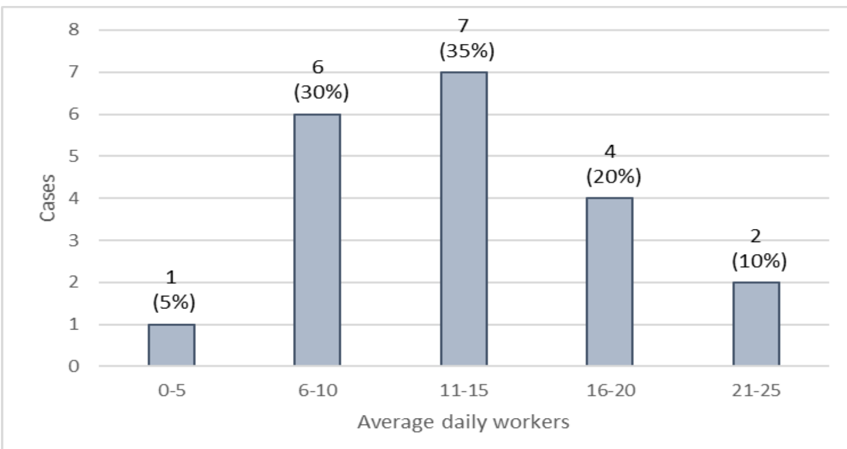

Fig. 50. Number of cases in relation to average daily workers

3. Results

3.1 Correlation Analysis

The correlation between two quantitative variables X and Y can be determined numerically using the correlation coefficient Pearson. The correlation coefficient Pearson r has no units of measurement and takes values in the interval from -1 to +1. Values close to one, positive or negative, are interpreted as almost perfect or very strong correlation, while values close to 0.5 are interpreted as moderate correlation. Values close to zero present a weak or absence of association (Field, 2009).

The following figure 11 presents the results from the correlation analysis, regarding cost. For an existence of correlation between two variables, the significance index Sig. (1- tailed) must be less than 0.05, while the hierarchy of the variables, which are related, is based on the Correlation Coefficient. Variables that show such a small significance index ($p < 0.05$) are shown in yellow, while if the value is even smaller ($p<0.01$) it is represented in green in the following Figure 11.

Actual Cost (€)		
	Pearson Correlation	Sig. (1-tailed)
Distance from Headquarters (km)	-0,338	0,100
Project Budget (€)	,995**	7,95E-16
Initial Project Duration (days)	,698**	0,001
Area of Premises (m^2)	,653**	0,003

Earthworks (m^3)	,543*	0,015
Asphalt Works (m^2)	-0,041	0,439
Reinforced Concrete (m^3)	,829**	3,57E-05
Metal Construction Bearing Weight (kg)	,723**	0,001
Average Number of Daily Workers	,850**	1,51E-05
Number of Different Personnel Disciplines	,657**	0,003

Fig. 11. Results of correlation analysis of quantitative variables with the Pearson correlation coefficient for actual cost

3.2 Application of Artificial Neural Networks

This section will present the results of the application of neural networks to predict the cost of the 20 industrial projects. In the effort to optimize the predictive capacity of the models, the results from the correlation analysis were used. Thus, various ANN's were constructed, with significant variations in the structure and the introduction of input variables. Hundreds of models were built with the help of the IBM SPSS 27 program using MLP (Multi-Layer Perceptron) which yielded better results than the corresponding RBF (Radial Basis Function). Both models presented in the current study are MLP. The first ANN for predicting actual cost and its parameters is detailed in Table 1 below. All available input variables have been used, regardless of correlation, in the order in which they are presented. The hidden level is divided into 8 units (neurons), while 70% of the sample is used for mini batch training and 30% for testing. Independent variables include: Type of premises, Contact with neighboring construction, Distance from headquarters (km), Project Budget (€), Predicted duration (days), Area of premises (m^2), Earthworks (m^3), Asphalt works (m^2), Reinforced concrete (m^3), Metal bearing construction weight (tn), Average daily workers, and number of different used disciplines per project. Details of the model regarding the hidden layer are the following:

- Number of Hidden Layers: 1
- Number of Units in Hidden Layer: 18
- Activation Function: Hyperbolic tangent

The output layer is the following:

- Dependent Variables: Actual Cost (€)
- Number of Units:1
- Activation Function: Identity
- Error Function: Sum of Squares

The deviation errors that occurred during training and testing are the following:

- Training Sum of Squares Error: 0,068
- Training Relative Error: 0,009
- Testing Sum of Squares Error: 0,148
- Testing Relative Error: 0,177

Figure 12 below sets out the diagrammatic representation of the actual and predicted cost for each of the 20 sample projects under consideration.

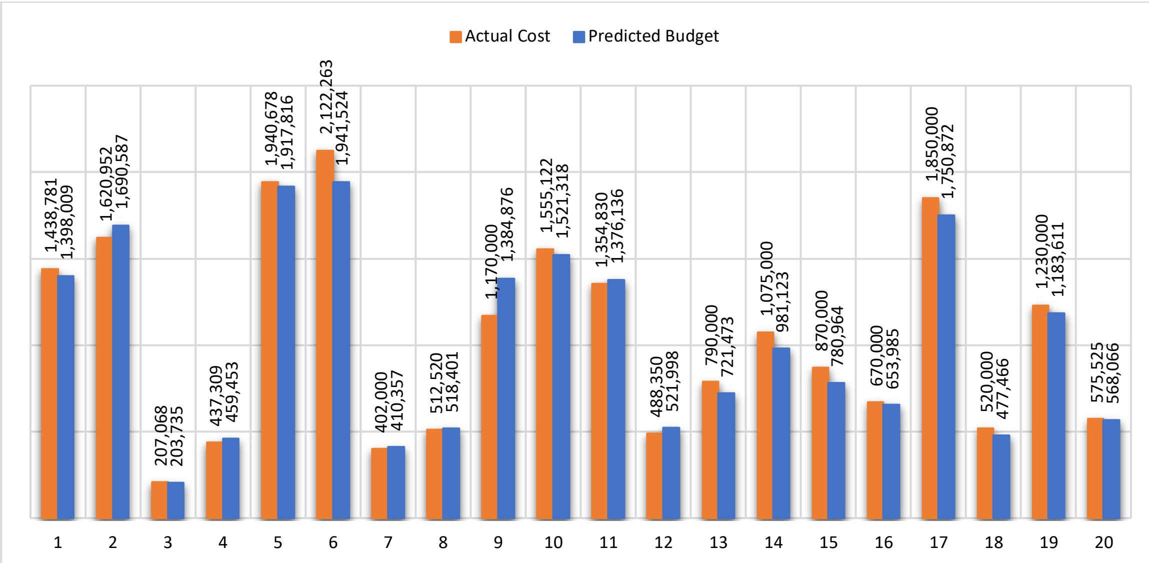

Fig. 12. Actual and predicted project cost according to the first forecasting model

Then follows the 2nd ANN for predicting actual cost. In comparison to the first model, the variable of asphalt works has been subtracted from the input variables, as correlation analysis shows that it does not play a significant role in predicting cost. The hidden level is divided into 7 units (neurons), while 70% of the sample is used for mini batch training and 30% for testing. The structure and variables of the second cost forecasting model include: Type of premises, Contact with neighboring construction, Distance from headquarters (km), Project Budget (€), Predicted duration (days), Area of premises (m^2), Earthworks (m^3), Reinforced concrete (m^3), Metal construction bearing weight (tn) and finally Average number of daily workers. The structure of the hidden layer is the following:

- Number of Hidden Layers:1
- Number of Units in Hidden Layer: 7
- Hidden Layer Activation Function: Hyperbolic tangent

The Output Layer includes:

- Dependent Variable: Actual Cost (€)
- Number of Units: 1
- Activation Function: Identity
- Error Function: Sum of Squares

The deviation errors for the second prediction model that occurred during training and testing are the following:

- Training Sum of Squares Error: 0,026
- Training Relative Error: 0,003
- Testing Sum of Squares Error: 0,011
- Testing Relative Error: 0,013

Figure 13 below sets out the diagrammatic representation of the actual and projected costs by the network for each of the 20 sample projects under consideration.

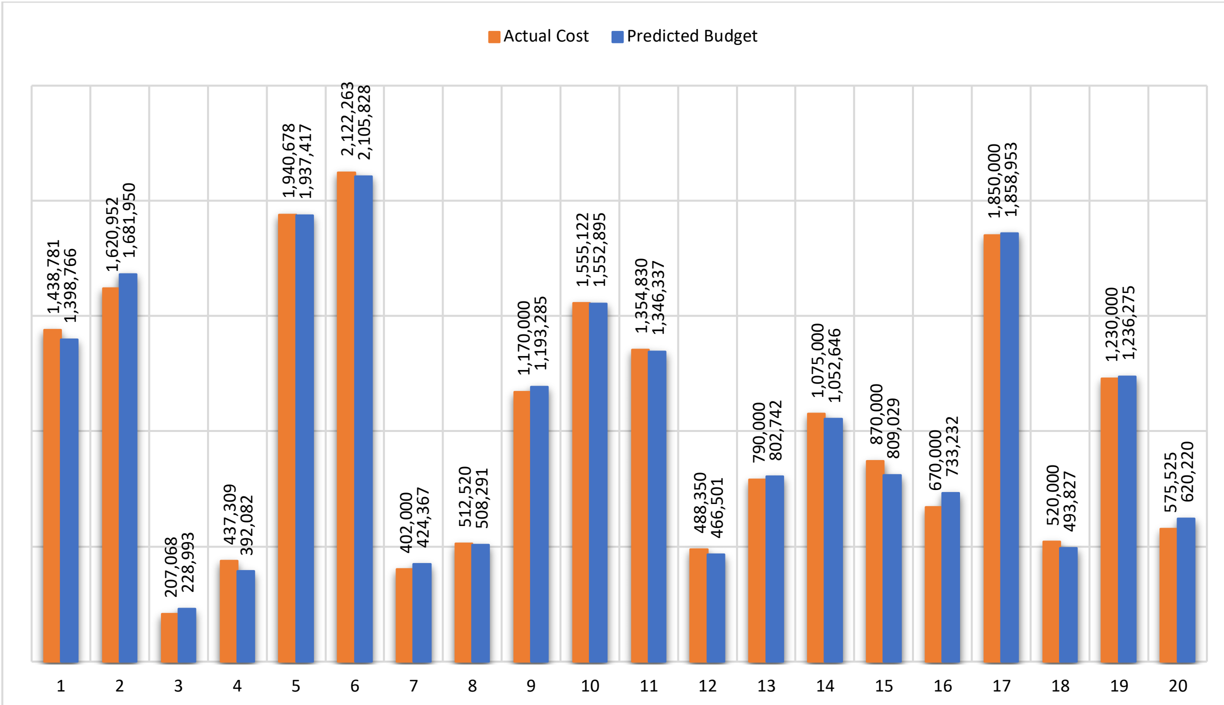

Fig. 13. Actual and predicted project costs according to the second forecasting model

5. Conclusions

In the current research, an attempt was made to predict the final cost of twenty industry-related construction projects, using neural networks. The results obtained showed that the neural network tool can also be applied to industrial projects, regardless of the type of variables used as input data. Although the number of projects was limited, the results were quite satisfactory.

The developed models showed sufficient accuracy based on the available data, and their estimates had errors with small differences between them. The second MLP model proved to be more accurate for cost forecasting, which did not include the quantity of "asphalt works" in the input variables and showed a total of 0.011 error and a relative error of 0.013. Also, a significant effect of categorical variables was observed which is particularly encouraging, as these variables are essentially the only way to distinguish the operation of installations. For neural network models, it was observed that the MLP method yielded better results than the Radial Basis Function model. It was also interesting that correlation analysis led to models with greater accuracy. Initially, all available input variables were used, and then taking into consideration the correlation analysis of variables, models with fewer variables, but with a greater impact on the output variable, were created. This resulted in greater accuracy of the produced models.

The sample size was an important parameter towards drawing more accurate conclusions. All the variables and their respective values were recorded with absolute reliability. Almost all the involved projects were managed by the authors. Also, an important limitation presented was the availability of options provided to the user by the software "IBM SPSS Statistics 27". With the use of the method "Multilayer Perceptron"(MLP) the options are comparatively more than the ones available within the "Radial Basis Function"(RBF) method. However, some options could be left to the user's discretion. Specifically, there is the possibility of selecting up to a maximum of two hidden layers, as well as specific activation functions and optimization algorithms. Also, the architecture of the network was clearly defined with simple feeding and learning under supervision. These limitations arose from the nature of the software and limited experimentation towards finding the optimal architectural structure of the neural network. One of the most important problems, which arises during the implementation of neural networks, is the choice of the appropriate training algorithm, as well as the overtraining of the network. In addition, due to the nature of the networks, the relationships between the parameters used for modelling are not sufficiently explained, making it difficult to explain how the network learns. Subsequently, a major problem during the development of artificial neural network models was the evaluation of their accuracy by the software based on the relevant error during training, which substantially influence the decisions made by both the software and the user.

The result of the forecast of the cost for industrial projects proved to be quite promising. The key and main element that should be considered at a later stage is the training of the model with a larger database in order to evaluate its effectiveness. Also, the wider environment of the projects should be considered, keeping in mind that the current data concerns the methodology and the production rates of a particular construction company. Another interesting approach to the problem would be to obtain more data during the progress of the execution of the project, in order to give more information about each input in the neural network and therefore to make a better categorization of the data. Of course, since the complexity of the network and neurons would increase at the input level, care should be taken to gather a much larger sample and produce more extensive database to train the ANN model, otherwise problems of under-training could occur in the network.

An additional proposal for future research is the element of the initial definition of the values of weights of synapses between neurons in the neural network. In the current software, this process was done automatically, but initial values could be assigned to the weights through some method of estimating the importance of each input, such as the method of hierarchical decision analysis or the tree decision method. A different neural network architecture with more hidden layers could also be tested, but this should be done in a programming environment. In addition, in terms of experimenting with the structure, a network with feedback could be tested, which again makes its structure more complex and perhaps more efficient, with proper training. To this end, it is recommended to use more flexible software environments (e.g., MATLAB). Finally, the same methodological approach could be followed to investigate the accuracy of forecasts in different types of construction projects, and a comparison could be made to examine whether the model structure and the use of these options produces better results.

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A Comparative Study on Dispute Resolution in Industry and the Departments of Transportation

Kasim Korkmaz[1], Raed Jarrah[1], Suleiman Ashur[1], Thomas Keranen[2], and Banu Colak[3]

[1] Eastern Michigan University, Ypsilanti MI 48197, USA
[2]Clark Hill, Detroit, MI, 48226, USA
[3] Dykema Gossett, Lansing, MI 48933
kkorkmaz@emich.edu

Abstract
Construction industry disputes are common, and the amounts in dispute generally tend to be high. Dispute Resolution (DR) helps the resolution of antagonisms between parties involved in the process. It can also be used interchangeably with conflict resolution when the conflicts are more profound and complex than disputes. Several DR methods can be implemented in construction projects. However, there are differences between the "industry" where arbitration is frequently utilized and the state Departments of Transportation (DOTs) where arbitration is not used as common. The reason is that DOT has an internal claims resolution process. When exhausted with an unacceptable result to the contractor, the contractor's only option to "appeal" the decision is to file suit against the DOT in the state's claims court. Several concepts have evolved to resolve claims on a relatively informal basis through early cooperative intervention. Standard practices in different states are seen under Negotiation, Mediation, Dispute Review Boards, Arbitration, and Litigation. This research provides a comparative study of arbitration and litigation on DOT projects among several states. The current dispute resolution methods utilized by various Departments of Transportation in the U.S. versus industry were examined with a particular focus on analyzing the use of arbitration and its outcomes compared to litigation. Arbitration can be more efficient in time and money, and therefore stands to be a valuable tool in dispute resolution for DOT construction projects; it is known that states function differently about arbitration resolution, but the need to analyze the variations exists if the industry is to identify a best practices approach that harmonizes the processes between the states and industry in the US.

Keywords
Disputes, Arbitration, Mediation, Negotiation, Litigation

1. Introduction
Arbitration can be a valuable tool to save time and money in resolving disputes concerning transportation construction projects and practices that differ between states. Therefore, this research is essential to investigating and identifying various types of practices across several state DOTs in the US. In the research, the differences between industry and DOT practices were investigated. The claim procedures are notorious for having complex and cumbersome requirements; short time limits for filing and documenting claims; penalties causing the claims to be waived if the contractor fails to follow the procedure strictly; with the process being deliberately biased in favor of the DOTs and structured to take a long time and impose a significant expense burden on the contractor when submitting the claim. The DOT claims process is viewed as a series of hurdles designed to discourage the contractor from making a claim. Failure to exhaust the DOT posture waives the claim and defeats the contractor's rights to sue the DOT in the state's claims court. Thus, the DOTs would be expected to oppose any action to enhance the process to deliver a more equitable result or allow the contractor less restrictive access to engaging the process. The research focuses on the differences between the DOT procedures and the "commonly accepted" mediation and arbitration process generally used by the rest of the industry. Since the feds are considering the use of ADR for federally funded DOT projects, this research aims to address if a similar shift has already started at the state DOT level or where individual states are in the process with the research question being whether the mediation /arbitration providing a better option than the current DOT practice involving litigation. The objective of

this research project is to investigate the utilization of Dispute Resolution methods in different states, including processes that DOTs use for the resolving disputes.

Various research work on dispute resolution and its standard practices in the construction industry. As with any contract between parties, disputes in construction are bound to occur. The traditional official approach to dispute resolution was directed through the judicial system, but parties have also sought ways to resolve disputes more amicable (Shrestha et al., 2017, 2019; 2022). Known as Alternative Dispute Resolution (ADR), methods include negotiation, mediation, and arbitration (Goldberg et al., 2012). There are also other forms of ADR, including minitrials and Summary Jury Trials (Stipanowich et al., 1996). Negotiation is a problem-solving process in which two or more participants attempt to reach an agreement on a disputed issue. Mediation is a process in which a neutral third party, called a mediator, assists people who have a dispute in resolving their differences to reach a compromise. Dispute Review Boards provide unique expertise that is kept up to date on the project to facilitate the timely and equitable resolution of disputes and claims in an effort to (1) avoid delays to the contract work; (2) minimize the expense of settlement; (3) avoid litigation, and (4) promote project partnering. Arbitration is a process in which a neutral third party, called an arbitrator, reviews all relevant items, including the contract documents, and produces a judgment. Litigation is the ultimate escalation on the DR scale, where the matter is put to trial through the public justice system. Dispute resolution methods have many levels of escalation. While negotiation and mediation aim to reach an amicable settlement between disputing parties, the resolution in arbitration and litigation is decided by an arbitrator or judge, respectively. Although similar and equally binding, arbitration differs from litigation in that it is a private process with little transparency and limited options to appeal. Arbitration initially developed as a consensual and non-binding dispute resolution process (Overcash, 2015), with "little or no discovery, motion practice, judicial review, or other trappings of litigation" (Stipanowich, 2010). However, as this dispute resolution method gained popularity and started to be enforced through statutes, there was more pressure to develop standard arbitration practices with time to align with the judicial process, including more extensive discovery and hearings (Stipanowich, 2010). Disputing parties may seek arbitration based on the perceived advantages over litigation, particularly regarding cost, speed, and privacy (Stipanowich, 2010). While arbitration has remained relatively popular, there is a criticism of the degree of cost and time savings it can provide (Kelleher & Smith, 2005). Particularly in the U.S., three trends are motivating the researchers to work on: 1) the legal workload is similar to litigation, 2) the more amicable and autonomous approach of mediation (mainly in construction disputes), and 3) the broad enforcement of arbitration in employment contracts and consumer/user agreements (Stipanowich, 2010). Claims arise when there are disagreements between the parties about the need for a change order or the cost of the change. In addition, the effects of disputes may cause new and more extensive arguments called Snowball effects, as seen in Figure 1 (Wallwork, 2003; Tazelaar and Snijders, 2010). Sarat (1984) lists a series of processes to be followed once a dispute arises, as seen in Figure 2.

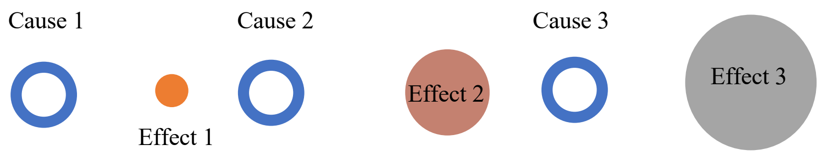

Fig. 1. Snowball Effect on Cause-and-Effect Relationship of Disputes

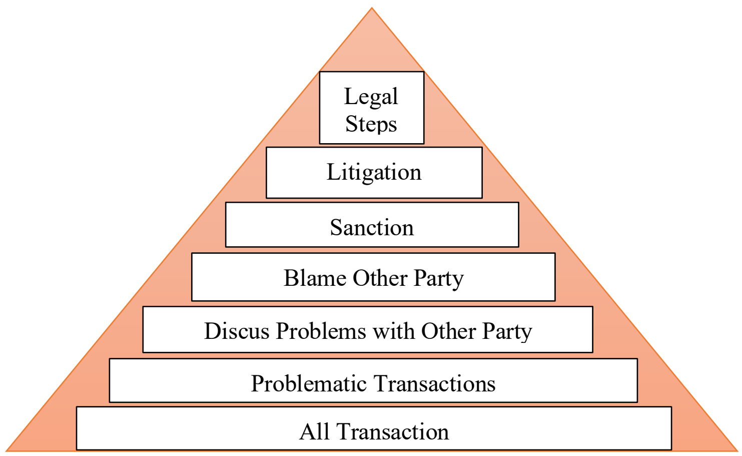

Fig. 2. The Pyramid of Series of Processes

2. Comparison of Industry and DOT Practices

Disputes on construction projects are a common occurrence. There have been times in the past, the 1980's for example, when the incident of disputes rose to an epidemic level. During that period, projects were wracked with disputes of all kinds, resulting in large financial losses, major disruptions and delays to work, and significant increases in risk associated with going forward with a project. Because of the complexity and technical nature of a typical construction dispute that often involves both design and construction considerations, litigation in the court system has proven inefficient and unreliable for resolving the controversy. Because of the volume and business of American trial courts, which are focused on the usual criminal and civil matters, but few construction disputes/contracts, the trial courts (and their civil juries) often lack the knowledge, experience, and expertise sufficient to render an equitable decision on a construction case. In the construction industry's eyes, the American judicial system does not work for the industry because it takes too long to reach a decision, the process costs too much, and the results are unreliable. The industry has recognized the limitations on litigation for resolving its disputes and has relied on binding arbitration as an alternative to litigation as its dispute resolution procedure of choice. The industry has also been employing non-binding strategies more recently to resolve disputes, including partnering, structured negotiations, dispute review boards, facilitated mediation, and other methods, with heavy preference towards facilitated mediation. Non-binding ADR has proven to effectively resolve construction disputes, short of arbitration or litigation on many occasions (AAA, 2015).

Industry form-contracts have adopted pairing a non-binding procedure in advance of arbitration as the preferred methodology for dispute resolution. By operation of the agreement, the parties to the dispute are obligated to first submit the dispute to mediation as a condition precedent to arbitration. If that fails, the argument is presented to arbitration for a binding decision. The specified process has proven effective for resolving construction disputes faster, more efficiently, and at a lesser cost than litigation. Most importantly, the arbitral decision is usually more consistent with the facts, circumstances, and governing law applicable to the project and dispute and is thus viewed as more equitable. The American Institute of

Architects ("AIA") family of contract documents have embraced the use of arbitration as the default binding dispute resolution procedure long ago. By operation of contract, when a dispute arose, by either the contractor or owner, it would first be referred to the project's architect for an "initial decision." More recently, to avoid complaints that the project's architect's initial decision was biased in favor of the Owner, the AIA now provides the option to appoint a neutral "Initial Decision Maker" to take the place of the project's architect for rendering the initial decision. If the parties accept the initial decision, the dispute is settled on its terms. If either party objects to the initial decision, the next step is to take the argument to non-binding facilitated mediation. If mediation fails to resolve the dispute, the parties are obligated to take the debate to arbitration. Recent revisions of the AIA contract documents allow the option to take the dispute to litigation instead of arbitration. Other industry-standard form-contract documents, such as those published by the Engineer's Joint Contract Documents Committee ("EJCDC") and Consensus DOCS, have followed suit to recognize the value and effectiveness of non-binding mediation and binding arbitration. Historically, the industry trend for many years has been to avoid litigation because of its shortcomings, and to rely, instead, on non-binding procedures like mediation, followed by arbitration to achieve a binding resolution of the dispute (Shahbaznezhadfard et al., 2021).

Contrary to the long-standing industry use of mediation and arbitration, the state "DOT" have not followed the industry standards. Most state DOTs rely on their own internal policies and procedures, which they have established to resolve "contractor claims." The process typically consists of a review and decision on the claim at one or more steps, administered and conducted by the DOT, who serves as the "judge" deciding the claim. There is no provision for mediation (only informal negotiation at most). If it disagrees with the DOT's final decision, the contractor's only option is to litigate in the state's claims court. The contractor community has widely criticized the DOT process because it is unwieldy, excessively procedural, time-consuming, and biased in favor of the DOT. Thus, the resulting decision is viewed as being unreasonable and inequitable. The contractor's option to "appeal" the decision is no better, since the contractor's only option is to take the dispute to litigation in the claims court, which imposes further excessive cost and delay on resolving the claim, and comes with unpredictable results, often in favor of the DOT under the rebuttable presumption the DOT's decision on the claim was made in good faith. Considering the DOT claim policy, the process has been intentionally structured to be cumbersome, costly, time-consuming, and challenging to manage to discourage contractors from making claims. Thus, the issue presents, and this paper addresses, whether the parties to the transportation construction project would benefit from following the construction industry's lead by adopting a similar dispute resolution process consisting of non-binding mediation followed by arbitration to resolve disputes more efficiently and equitably.

3. Mediation and Arbitration

The most recognized industry dispute resolution processes are facilitative mediation and arbitration. Both procedures have been administered over the years by the American Arbitration Association ("AAA") under its Construction Industry Mediation and Arbitration Rules (the "Rules"). In general, the AAA's Rules provide for the submission of the dispute to AAA for administration. For mediation, a process where the mediator works with the parties to achieve a mutually agreeable settlement of the conflict, the Rules provide for the parties to select the mediator from the AAA's Panel of Construction Mediators; administration of the mediation process by the Mediator once selected; little or no formal pre-hearing discovery; and, if a settlement is reached, the entry of a settlement agreement – binding on the parties – which resolves the dispute (Cheng et al., 2021).

For arbitration, where the arbitrator sits as a judge receiving evidence offered by the parties, and making a binding decision called an Award, the Rules provide for the administration of the case by AAA; selection of the arbitrator(s) by the parties from the AAA's Panel of Construction Arbitrators; the administration of the process by the arbitrator, including limited discovery and hearing procedures; the submission of evidence; and at the end of the hearing when the submission of evidence is closed, the arbitrator renders the award. Under federal and state law, the arbitrator's award can be confirmed as a judgment by a court of competent jurisdiction allowing the award to be enforced (Yuan et al., 2018).

Compared to DOT claims procedures and litigation, mediation and arbitration benefit from having the mediator and arbitrator selected from AAA's list of qualified Construction Mediators and Arbitrators consisting of pre-qualified persons familiar with the design and construction process. Panel members can include non-lawyer professionals, including architects, engineers, contractors and vendors/suppliers, and construction lawyers. AAA has a specialized Large Complex Case Arbitration Panel for significant complex cases to choose from. The obvious benefit to using the AAA system is selecting a qualified mediator or arbitrator who knows the industry. As one industry commentator has said, "in arbitration, we don't have to waste time educating the arbitrator on which end of the hammer to hold."

Under the AAA Arbitration Rules, further benefits include limited discovery and more streamlined procedures. Further, the arbitrator is dedicated to one case and does not have competing responsibilities for multiple issues as does a court. Thus, the arbitration case tends to proceed more directly, faster, and efficiently, and at the convenience of the parties as to time and date, without disruptions. Thus, in the end, the arbitration case typically proceeds more efficiently and at less cost and trouble than litigation and results in an award that is more representative of the circumstances surrounding the project and dispute (Oechler, et al., 2018).

Following graph of Figure 3 illustrates cost escalation based on actual project data as studied by DART. For all activity before mediation, the curve is flat, and it shows minimal cost or hassle with quality control, shop drawing review, etc. The angle then steps up for mediation and accelerates abruptly for arbitration and litigation.

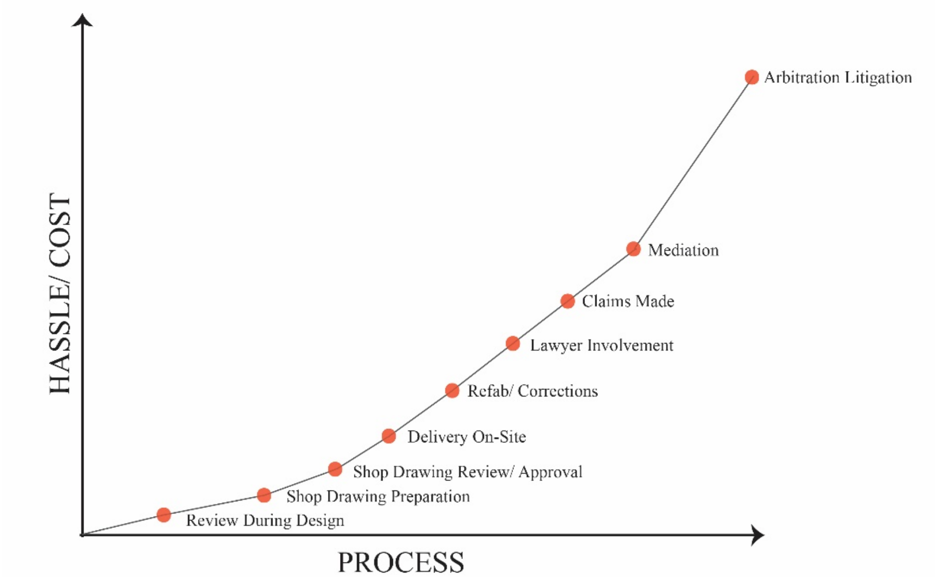

Fig. 3. Cost Escalation Graph for Dispute Resolution

4. Investigation of Different State Practices

The present research explores the current state laws on dispute resolution, mainly as they apply to DOT projects. In the study, standards from ten different states (Nevada, District of Columbia, Pennsylvania, Washington, Florida, Michigan, Illinois, New York, Ohio, and California) were investigated for a comparative understanding of the practices. Claims arise when there are disagreements between the owner and the contractor about the need for a change order and the cost. In Table 1, various practices from of those ten states are provided.

Table 1. Chronologic Orders in Legislations for the Selected States

Order	State	Legislation
1	Nevada	Nevada has been at the forefront of implementing forms of dispute resolution (DR) and continues to develop methods of resolving disputes without the cost of delay. The Dispute Resolution Program is a tool to assist stakeholders on NDOT projects to resolve conflicts at the lowest level possible.
2	District of Columbia	District of Columbia establishes and maintains dispute resolution procedures (DR) for transportation projects. The most common forms of DR are conciliation, mediation, arbitration, neutral evaluation, settlement conferences, and community dispute resolution programs.
3	Pennsylvania	In resolving disputes in the procurement, management, and administration, the Contracting Officer, at their discretion, may conduct a claim review meeting to attempt to settle and resolve a dispute or claim with the Contractor.
4	Washington	DR is a collaborative, consensual dispute resolution approach. It describes various problem-solving processes used instead of litigation or other adversarial proceedings to resolve disagreements. The Department of Transportation agrees that DR is voluntary, and there must be a mutual agreement to use it.
5	Florida	The Disputes Review Board (DRB), founded to be flexible to meet unexpected life circumstances during the project's life, runs the process for the dispute resolution. As referenced in this procedure, a Dispute is defined as a disagreement between the Florida Department of Transportation and the Contractor.
6	Michigan	When the Contractor disagrees with the engineer's decision regarding compensation for work performed and the time required to complete work operations, including requests for extension of time, action is initiated upon the Contractor filing a Notice of Intent to File Claim. At this time, the Contractor and the Engineer will work to resolve the potential claim issue before (if possible) the disputed work begins.
7	Illinois	IDOT advises and supports management by investigating the complaints, documenting the facts, presenting the findings, and making recommendations to resolve the dispute.
8	New York	Department of Transportation (DOT) provides interested parties with an opportunity to administratively resolve disputes, complaints, or inquiries related to work. Interested parties are encouraged to seek the resolution of conflicts through consultation with DOT staff. All such matters will be accorded complete, impartial, and timely consideration. Interested parties may also file a formal written dispute according to the DOT procedures.
9	Ohio	ODOT may choose to utilize a Dispute Resolution Board (DRB) process on massive projects instead of the standard dispute resolution process. If a DRB is utilized, Proposal Note 108 will be included in the Proposal, and an Item Special, Dispute Review Board, will be included as a pay item.

10	California	Dispute Resolution Process (DRP) is an appeal process for local agencies to use when they disagree with the decision, they receive from the district office concerning their local assistance funded project on or off the State Highway System (SHS).

Many states have "enabling legislation" that allows a contractor to claim a case/complaint. The legislation typically defines the type of claims brought and provides the procedure for doing so. In the absence of the enabling legislation, the state would enjoy the defense of governmental immunity to avoid the claim despite the law allowing the contractor to bring a claim as the exclusive remedy. Using Michigan as an example, Michigan law requires a contractor to sue its DOT ("MDOT") in the Michigan Court of Claims. It is not clear if while the Court of Claims has exclusive jurisdiction over the claim and is the only course for resolution, whether MDOT, by contract or policy, can separately agree to resolve claims against it by other binding alternative dispute resolution methods such as arbitration. MDOT does have a non-binding "Contractor Claims Procedure" that it has adopted by policy and contract term. The contractor must exhaust the Contractor Claims Procedure as a condition precedent to suing in the Michigan Court of Claims. The causes of disputes can be categorized as follows:

- The construction projects take a relatively long time to complete; the drawings and specifications are often revised because of changes in the owner's needs and requirements.
- Some architects, who prepare the drawings and specifications, do not have adequate know-how about installation details for successful application on the job site.
- Construction issues are generally not detected and solved at early stages of the design.
- Construction documents that regulate the contractor's on-site performance are faulty or do not have an adequate level of detail.

Claims arise when there are disagreements between the owner and the contractor about the need for a change order and the cost. Decisions and most of the pleadings on cases submitted to court are available for public view and evaluation. On the other hand, arbitration proceedings are confidential and are not reviewable unless the parties to the arbitration agree. The non-binding procedures, MDOT's Claims Procedure, mediation, and other procedures are personal. Thus, it is unclear if pleadings, orders and opinions, decisions, and additional information would be available for analysis when arbitrating and submitting the dispute under the non-binding procedure. Table 2 briefly discusses each practice (MDOT, 2012 and 2019; Mc Crary et al., 2010).

Table 2. Practices and Terms for Construction Projects with Explanations

Practices	**Definitions**
Design/Build (D/B)	Design/Build process with a single point of design and construction responsibility.
Build-Own-Operate-Transfer (BOOT)	A form of project delivery method for large-scale infrastructure projects.
Partnering (P)	A relationship between the owner and the contractor, including the elements of long-term commitment to achievements.
Performance Specifications (PS)	Project Performance-Related Specifications.

Prequalification (P)	A process for screening prospective contractors according to predetermined criteria of the project.
Subcontractor Approval (SA)	The owner approves the subcontractors of the project.
Guarantee (G)	An assurance by the contractor for the final product that meets the specifications for the project period.
Quality Assurance/Quality Control (QA/QC)	The contractor's control is to get the expected quality in the project.
Cost Plus Time (CPT)	The constructor is paid the cost of the materials and time, plus a flat fee on top of the costs.
Value engineering (VE)	A concept for alternate designs construction procedures in materials to be considered before the notice of bidding.
Quality Incentives (QI)	The owner provides the contractor with stipulations for the increased or decreased compensation.
Time Incentives (TI)	Time-based Incentives/Disincentives provide bonuses for attaining contract time objectives and deductions for not achieving those objectives.

5. Utilization and Outcomes of DR Methods

From a legal point of view, in the absence of enabling legislation that allows the claim to be presented, there would be an immunity development from the suit. Thus, legislation created the contractor claims from both federal and in the states that allow the claims to be presented and adjudicated by the contractor claims. In such cases, practices become more important to analyze to understand the outcomes. The Michigan Department of Transportation (MDOT) Construction Contractor Claims Procedure provides a formalized, tiered process for submitting and reviewing a contractor's claim. MDOT has been experimenting with a Dispute Review Board mechanism to resolve disputes. The claim review process involves a formalized administrative procedure. Most DRB, mediation, arbitration, and other forms of non-litigation dispute resolution procedures are typically considered "private and confidential." The goal of both processes is to resolve claims at the lowest possible level. The time durations within the guidelines are intended to be maximum timeframes with any request for an extension to the duration, whether by the contractor. The DOTs are obligated to allow access to case outcomes under their ADR procedure(s) – assuming they have an ADR procedure. Construction Field Services (CFS) and Region Construction Engineers will monitor all claims. The procedures for reporting of claims are as follows (MDOT, 2012 and 2019):

- A copy of all notices of intent to file claims (local agency) must be provided to TSC Managers and Region Construction Engineers as noted in the procedures.
- The Federal Highway Administration (FHWA) Area Engineer must be notified on all Projects of Division Interest (PODI) when a claim meeting is scheduled, or an issue is scheduled to be presented to a Dispute Review Board (DRB). A copy of the DRB claim package will be provided to the FHWA Area Engineer. FHWA participation in claim payment is not guaranteed. FHWA must be notified of the claim before settlement and have the opportunity to review claim documentation before settlement.
- All claim decision letters from the Region Office Review hearings are copied to both the Region Construction Engineer and the CFS Construction Contracts Engineer.

Only the US Court of Federal Claims can render a binding decision against the federal government by statute for construction claims involving the federal government. Since it is a crucial procedure, arbitration is precluded by the law. Thus, any non-binding procedures, such as mediation, dispute review board, etc.

Because of the federal involvement with funding, most of the state DOT projects and the federal rules and regulations that come with the money, the states have adopted a claims/disputes procedure that's somewhat similar to the Contract Disputes Act of 1978, 41 USC 7101 et seq., ("CDA") and the applicable code of Federal Acquisition Regulations (FAR 52.233-1). Claims made by contractors working directly for the federal government on federally funded projects are regulated by the CDA and FARs. The DOTs have adopted similar, but, when comparing MDOT to the CDA and FAR 52.233-1 for example, MDOT's process is different from the federal procedure.

6. Conclusions

The overall objective of this research project is to provide a comprehensive investigation of Dispute Resolution methods in different states, including processes that DOTs use for the resolution of construction disputes. The study also investigates the other processes' rules and analyzes the contract provisions in binding dispute process decisions. The result of this research facilitates a deeper understanding of:

1) The various current state laws on Dispute Resolution and identify the best practices among them as well as any existing conflicts between such laws.
2) The current utilization of various dispute resolution methods and whether there is a correlation to different resolution outcomes.
3) The utilization of arbitration vs. litigation and the factors that may influence arbitration rulings (mainly contract terms, following precedence, and evidentiary standards).

On the other hand, arbitration became a popular method to resolve transportation agencies' construction disputes. Arbitration has many advantages over litigation. Arbitration is also ideal for resolving construction disputes. One is its ability to be customized by the agency putting out the contract. The benefits outweigh the disadvantages and, with some customization, address the public entities' concerns.

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Evaluating the Benefits Experienced by Professional Women Working in the Construction Industry in South Africa

Langanani Muthambi[1] and Justus Ngala Agumba[2]

[1] Tshwane University of Technology, Pretoria, Gauteng Province, South Africa
[2] Tshwane University of Technology, Pretoria, Gauteng Province, South Africa
Langi1229m@gmail.com

Abstract
The construction industry is male-dominated and has been viewed as a hostile environment for women to work and thrive in it. However, despite its hostility towards the female gender, some women have thrived and are successful in the construction industry. Therefore, the aim of this study was to determine the benefits the professional women working in the construction industry in South Africa have experienced while they continue to work in a male-dominated construction industry. To achieve the purpose of this study, a deductive research approach was adopted. An electronic questionnaire survey was used to collect the data. An exploratory factor analysis and reliability analysis was conducted to determine the validity and consistency respectively of the questionnaire. A total of 110 respondents participated in the research study. The findings deduced indicate that the professional women have gained confidence which has enabled them to manage construction projects, gained technical skills and are able to mentor other candidates in the field.

Keywords
Benefits, Career, Construction Industry, Gaining Skills, Professional Women

1. Introduction

The construction industry is an enormous field which includes engineering and the built environment. The professionals can be on-site or office based, working as contractors or consultants in different civil infrastructure and building projects. The professionals that can be appointed to perform relevant construction duties in different project stages are engineers, architects, project managers including construction related, construction managers and quantity surveyors which include women. In Europe, the construction industry employed 15 million people but only 1.5 million women were employed as indicated by Liebus, (2016). Statistics of women who were employed from 2018 data in South Africa indicated that only 32% of women are managers, 49% are professionals, 55% are technicians and the total of women employed in South Africa in all fields was 43,8% (Stats SA, 2018). Statistics SA (2018) also revealed that in the informal sector of the construction industry more men are working in it than women.

Despite professional women working in male-dominated industry, they can still acquire various benefits. Literature suggests a number of the benefits that women in the construction industry can acquire. These are:

Gaining construction skills and experience: The construction industry is a fast-growing industry that is advancing technologically, thus, one has to adapt to the change and gain more knowledge through training programmes (Patel and Pitroda, 2016). In-spite of the knowledge required due to advancement of technology, construction professionals working in project management division in the construction industry, acquire direct and indirect skills. Hence, women who are project managers can gain technical skills which are direct and indirect skills through managing a project and a project team. These skills have an impact on a construction project's success according to Hwang and Ng (2012). Further, leadership skills in the construction industry is imperative. The women that took part in Wesley (2012) study revealed that leadership development in employees is encouraged by the supervisor and the leader. Furthermore, leadership development classes are encouraged in order for women to be able to gain skills on how to interact with different types of people. Such leadership classes are said to be helpful to the employees and it boosts their confidence (Wesley, 2012).

Career advancement: Although women still face gender inequality in employment opportunities. There are companies that are male-dominated which ensure an equal workplace by providing networking opportunities, support groups, good communication methods, being able to balance work and life and changing the male-domination mindset of the company (Gaines, 2017). It has been established that women network better than men as they concentrate more on creating long term friendships or personal connections, making them want to get advice for professional benefits (Castrillon, 2019), hence advancing there career. Despite the percentage of women in high ranking positions in the construction industry are under-represented according to Fernando, Amaratunga and Haigh, (2014). The implementation of training and development for women in the construction industry could be a solution to increase the representation of women in higher management positions in the industry (Fernando, Amaratunga and Haigh, 2014). In order for women to advance their careers, it is revealed that having educational and professional qualifications that are recognised, for example by Royal Institute of Chartered Surveyors (RICS), is a benefit for the success of career women in the construction industry. This has enabled women to occupy top management positions in the construction industry (Fernando, Amaratunga and Haigh, 2014). Thus, career women can consider getting professional qualifications that are an advantage to them in the construction industry, apart from the academic qualifications they have obtained. This may mean a better financial reward.

Financial reward: The construction industry is known to pay its employees well, although women and men are still not paid the same. Male-dominated occupations are considered to pay more than female-dominated occupations. Therefore, women choose careers that are male-dominated (England, 2010). Remuneration in the construction industry certainly differs based on position, experience and qualification. It is deemed that female project managers that have more construction experience get paid more salary compared to those with little experience in construction (Bilbo *et al*., 2014). In the United States of America, Bilbo et al., (2014) found that project managers who are women earn more than $95000 per year depending on their experience level. In South Africa, according to CareerJunction (2018) in the building and construction field, an individual who is in a senior position in building project management, can be paid between R40,465 to R53,527 per month, in civil engineering they can be paid between R50,525 to R65,621 per month and in quantity surveying they can be paid between R31,417 to R43,083 per month. In a research study by Worku (2017), it revealed that civil engineers that work in the local municipalities in South Africa are paid R15,000 to R45,000 per month, some were also able to negotiate their own salary instead of getting a fixed one that has been set. Project managers are usually rewarded with a salary that is high in order for them to move around and want to relocate (Bilbo *et al*., 2014). However, from South Africa point of view it is not clear what women professionals are paid compared to their male counterparts.

Apart from getting a salary, work benefits have a big impact on the goals of an employee, and this can also attract good and competent employees (Song, Wang and Cheng, 2018). Some organisations have employee benefits which include pension funds, medical aid, housing allowance, insurance, vacation, lunch, transport and entertainment for employees (Song, Wang and Cheng, 2018). However, the benefits the construction professional women have acquired in the South African context has not been adequately researched. Therefore, the aim of this paper is to empirically determine these benefits and inform the construction industry stakeholders the benefits construction professional women have attained in this male dominated industry, despite the challenges they encounter.

2. Methodology

The epistemology of the research is a positivist philosophy approach used to determine the benefits that professional women who have worked for five and more years, experience in the construction industry in South Africa. A positivism philosophy study relates to a quantitative study (Saunders *et al.*, 2016). The approach of the study is deductive as the data found, explored a known theory and answered questions of the research. A quantitative methodological choice was used, and an electronic questionnaire survey was used to collect the data. The questionnaire was distributed using LinkedIn (social media tool) and the website of South African Council for the Project and Construction Management Professions (SACPCMP) professional council.

The number of participants who responded were 110 professional women working. They completed the survey using Google Forms survey link provided to them. The professional women are professionally registered either as: professional construction manager (Pr. CM) or professional construction project manager (Pr. CPM) with the South

African Council for the Project and Construction Management Professions (SACPCMP). Furthermore, registered as professional engineer (Pr. Eng.) with the Engineering Council of South Africa (ECSA) or professional quantity surveyor (Pr. QS) with the South African Council for the Quantity Surveying Profession (SACQSP). The data analysis was undertaken using Stata version 17.

The results are presented using descriptive and inferential statistics. The descriptive statistics are presented using the mean values and the standard deviation. The inferential statistics was determined using construct validity and internal reliability of the questionnaire items based on the 5 point Likert scale. To achieve the construct validity, the exploratory factor analysis (EFA) was used to determine the factor loadings of each item in the construct. The factor loading accepted should be equal to or greater than 0.30. The reliability of the study was established using Cronbach's alpha at a cut-off point of 0.70. The section below represents the discussion of the analysed data of the study.

3. Discussion of Results

The validity and the reliability results were discussed before the descriptive statistics results were presented. The following section discusses the results of the benefits professional women attained in the construction industry despite the challenges they encounter.

3.1. Exploratory factor analysis (EFA) for benefits

The exploratory factor analysis (EFA) is usually used when a research has a sample size that is large. Factor loading measures what a variable makes on a factor. Therefore, a factor loading that is high will show that the variables need to account for the factors (Yong and Pearce, 2013). The EFA on this research was based on the factor analysis, Eigenvalue, factor loadings and Kaiser-Meyer-Olkin (KMO) measure of the benefits experienced by professional construction women for persevering in the construction industry. The Eigenvalue cut off is set at 1, therefore Eigenvalue in the data had to be less than 1 (Eigenvalue < 1). During data analysis, the Varimax rotation blank used was 0.30 for factor loadings. Thus, the EFA for each benefits has been discussed below.

Gaining skills and experience exploratory factor analysis (EFA)

The EFA for gaining skills and experience in **Table 1** has shown that an Eigenvalue greater than 1 is depicted by Factor 1 (2.68196), the other Factors (2-4) were less than 1. Further, the factor loadings for gaining skills and experience variables (GSE-1, GSE-2, GSE-3 and GSE-4), were all above 0.30 using varimax rotation, as 0.7222 was the minimum value. The overall Kaiser-Meyer-Olkin (KMO) of 0.6448 was greater than 0.50 suggesting that the data was suitable for factor analysis (Alabdulkarim, 2021). The results infers that gaining skills and experience is a one factor model and the measures are valid in measuring this construct.

Table 1: Gaining skills and experience EFA

Gaining skills and experience					
Item	Factor	Eigenvalue	Factor loadings		KMO
			Variable	Factor 1	
Working with different stakeholders improved my soft skills	Factor 1	2.68196	GSE-1	0.8261	0.6516
I achieved technical skills	Factor 2	0.73566	GSE-2	0.8744	0.6124
I am able to manage a project and project team	Factor 3	0.40621	GSE-3	0.8447	0.6608
I gained confidence through leadership training	Factor 4	0.17617	GSE-4	0.7222	0.6693
Overall					**0.6448**

Career advancement EFA

The EFA for career advancement in **Table 2** has shown that an Eigenvalue for Factor 1 (2.09596) is greater than 1, and the other Factors (2-4) were less than 1. The factor loadings for the career advancement variables (CA-1, CA-2, CA-3 and CA-4), were all above 0.30 using varimax rotation, as 0.6467 was the minimum factor loading value. The overall KMO of 0.7033 was greater than 0.50, indicating that the data was suitable for factor analysis (Alabdulkarim, 2021). The results deduce that career advancement is a one factor model and the measures are valid in measuring this construct.

Table 2: Career advancement EFA

Career advancement					
Item	Factor	Eigenvalue	Factor loadings		KMO
			Variable	Factor 1	
I was able to mentor other women in their career	Factor 1	2.09596	CA-1	0.7981	0.6733
I was recognised of my achievement in the workplace	Factor 2	0.77338	CA-2	0.7348	0.6819
I created friendships in the workplace with colleagues to get professional advice	Factor 3	0.65817	CA-3	0.7077	0.7617
I was able to register as a professional	Factor 4	0.47249	CA-4	0.6467	0.7223
Overall					**0.7033**

Financial reward EFA

The EFA for financial reward in **Table 3** infers that one Eigenvalue is greater than 1 i.e. Factor 1 (2.73686) which indicates that the component is a one factor model. The other Factors (2-4) were less than 1. The factor loadings for the financial reward variables (FR-1, FR-2, FR-3 and FR-4), were all above 0.30 using varimax rotation. The overall KMO of 0.6180 was greater than 0.50, indicating that the data was suitable for factor analysis (Alabdulkarim, 2021). The results deduce that career advancement is a one factor model and the measures are valid in measuring this construct.

Table 3: Financial reward EFA

Financial reward					
Item	Factor	Eigenvalue	Factor loadings		KMO
			Variable	Factor 1	
I received performance bonus	Factor 1	2.73686	FR-1	0.7836	0.7183
I am paid a salary that equates to my experience	Factor 2	0.69137	FR-2	0.8770	0.5795
I received benefits in my package: medical aid, pension fund, bonus, etc	Factor 3	0.46455	FR-3	0.7375	0.6249
I am paid a salary that matches my qualification	Factor 4	0.10722	FR-4	0.8999	0.5953
Overall					**0.6180**

3.2. Reliability analysis for benefits

After attaining the construct validity of the factors describing benefits, the reliability analysis was conducted to determine the internal consistency of the data using Cronbach α. The acceptable coefficient of internal reliability was 0.70 and higher as per literature by (Heale and Twycross, 2015). **Table 4** represents the results of the internal consistency using Cronbach's α of the statements (items) describing benefits the construction professional women have experienced working in the construction industry. The reliability exceeded the minimum acceptable Cronbach's α result required of 0.70 apart from career advancement. The 0.6763 – career advancement test scale was below 0.70 which is suggested to be moderately acceptable. A Cronbach's α that is 0.60 - 0.70 shows a reliability that is moderately acceptable (Ursachi, Horodnic and Zait, 2015).

Table 4: Reliability statistics of benefits

Benefits					
Items	Observe	Item-test correlation	Item-test correlation	Average inter-item covariance	Cronbach's α
Gaining skills and experience					
GSE-1	110	0.7952	0.6483	0.417181	0.7794
GSE-2	110	0.8349	0.7143	0.3933834	0.7534
GSE-3	110	0.8506	0.7159	0.3566861	0.7450
GSE-4	110	0.7823	0.5564	0.3960523	0.8351
Test scale				**0.3908257**	**0.8234**
Career advancement					

CA-1	110	0.7592	0.5741	0.3074507	0.5480
CA-2	110	0.7391	0.4610	0.312844	0.6115
CA-3	110	0.6704	0.4633	0.383792	0.6164
CA-4	110	0.7113	0.3917	0.347206	0.6700
Test scale				**0.3378232**	**0.6763**
Financial reward					
FR-1	110	0.7870	0.6192	0.990165	0.8178
FR-2	109	0.8527	0.7312	0.8804837	0.7714
FR-3	110	0.7715	0.5737	0.9963196	0.8438
FR-4	110	0.8816	0.7749	0.822358	0.7517
Test scale				**0.9222679**	**0.8399**

3.3. Benefits of persevering in the construction industry

The construct validity (section 3.1) and reliability (section 3.2) results found that the factors describing benefits i.e. gaining skills and experience, career advancement, and financial reward were valid and reliable. This empirical finding enabled the central tendency of the descriptive statistics i.e. mean and standard deviation (Std. Dev) of these benefits to be computed, interpreted and the findings discussed to determine the main benefits obtained by construction professional women.

In order to discuss the mean value results appropriately, a scale with ranges used by Renault, Agumba and Ansary (2018) was adopted, where 1 = Strongly disagree ($\geqslant$ 1.00 and $\leqslant$ 1.80), 2 = Disagree ($\geqslant$ 1.81 and $\leqslant$ 2.60), 3 = Neutral ($\geqslant$ 2.61 and $\leqslant$ 3.40), 4 = Agree ($\geqslant$ 3.41 and $\leqslant$ 4.20), and 5 = Strongly agree ($\geqslant$ 4.21 and $\leqslant$ 5.00). The variables are ranked using mean value and to some extent, considering the standard deviation. These results are presented and discussed herein.

Gaining skills and experience

The results in **Table 5** shows that the overall mean value for the benefit of gaining skills and experience was ranked first with a mean value of 4.08. This suggests that the respondents agreed that they gained skills and experience while working in the construction industry. To buttress this result, GSE-1 measure (working with different stakeholders improved my soft skills) was ranked first and rated as agreed with a mean of 4.18 and a standard deviation (SD) of 0.77. GSE-2 (I achieved technical skills) was rated as agree and ranked number 2 with a mean score of 4.15 and a SD of 0.75. To support this finding technical skills are significant in construction for project management in planning phase, which can also make an individual to provide knowledge and expertise in the construction industry (Hwang and Ng, 2012). Construction professional women are able to oversee a project and different teams as they have been working in construction industry for more than five years and are registered as professionals with the built environment councils in South Africa. They are able to ensure that a construction project is successful throughout its duration. Therefore, GSE-3 (I am able to manage a project and project team) resulted in agreed rating of the mean and ranked number 3. The mean score was 4.13 and a SD of 0.86.

The measure GSE-4 (I gained confidence through leadership training) was ranked fourth with a mean of 3.82 and a standard deviation of 1.01. The result suggested that the respondents agreed they gained confidence through leadership training. From previous studies leadership is a project management requirement of making sure that a project is completed on time (Hwang and Ng, 2012). Leadership is a significant soft skill that is required in project management (Zuo et al., 2018). When training women in construction, it helps them to come up with new ideas which can assist them to get promoted in their positions (Fernando, Amaratunga and Haigh, 2014). Career success can be enhanced when a person is able to lead (Fernando, Amaratunga and Haigh, 2014).

Career advancement

Table 5 indicates that the overall mean value for career advancement was ranked second with a mean value of 3.83. The respondents agreed that they had benefited in relation to career advancement while working in the construction industry. Furthermore, the measures defining career advancement were agreed upon by the respondents as benefits. The mean values were in the range of agreed (≥3.41 and ≤4.20). CA-1 (I was able to mentor other women in their career) was ranked 1st and rated as agreed with a mean of 3.90 and standard deviation of 0.86. Fouad et al., (2017) revealed that participants required a female mentor whom they would be able to talk to about the difficulties they experience while working in a male-dominated industry such as engineering.

In addition, a good mentor enhances the success of an individual's career (Fernando, Amaratunga and Haigh, 2014) and can provide a good working environment (Moncaster and Dillon, 2018). CA-4 (I was able to register as a professional) was ranked 2nd with a mean of 3.90 and a SD of 1.16, resulting in agreed rating. CA-4 was to find out if registering as a professional with the built environment councils was indeed a benefit the women attained during the years they had been working in construction, although this is a requirement for the study. It is important to be registered as professional in South Africa's construction industry in order to work in certain types of projects, which enhances the career success of one.

CA-3 (I created friendships in the workplace with colleagues to get professional advice) was ranked 3rd and resulted in agreed rating, with a mean of 3.88 and SD of 0.80. Creating friendships at work is like networking internally which can be seen as an advantage for increasing career success. Creating friendships at work helps with creating a personal and professional support network (Bicer and Buyukyilmaz, 2017). Good friendships at work can increase the performance of employees and the goals of a company (Bicer and Buyukyilmaz, 2017). Recognition greatly enhances the success of an individuals' career. Employees expect to usually be given feedback, wherein their efforts are appreciated (Coffey, 2013). When an employee is recognised in the workplace it also motivates them to perform their job better and this increases productivity in the organisation (Coffey, 2013). Therefore, CA-2 (I was recognised of my achievement in the workplace) was ranked 4th and rated as agreed. This measure had a mean of 3.62 and SD of 1.10.

Financial reward

Table 5 also indicates the responses with regards to financial reward are in the neutral range (≥2.61 and ≤3.40) including the overall mean value which was established as 2.89. In relation to the individual measures FR-1 (I received performance bonus) was ranked 1st with a mean of 3.06 and a SD of 1.24, however the respondents were neutral on their response. Literature indicates that it is perceived that receiving a reward for performance at work enhances the job performance of an employee. Hence an employee is recognised in the workplace. Employees that perform well as stated by Jongo *et al*., (2019) are the ones that get more rewards and makes them to be satisfied, unlike those with low work performance.

Benefits that employees get are attached to the values a company has to the employee skills. When the employees do not receive benefits they see it as a company not valuing them (Song, Wang and Cheng, 2018). The civil engineers that work in South Africa's municipalities stated that they had no interest in registering as a professional, due to insufficient benefits they get from the workplace when they are registered as professionals. In addition, the public sector had insufficient benefits compared to the private sector (Worku, 2017). Based on the aforementioned FR-3 (I received benefits in my package: medical aid, pension fund, bonus, etc.) was ranked 2nd with a mean of 3.02 and a SD of 1.36, resulting in a neutral feedback from the respondents.

Improving knowledge through improving qualifications is found to be a career enhancement by getting a work promotion (Fernando, Amaratunga and Haigh, 2014). Participants in (Fernando, Amaratunga and Haigh, 2014) revealed that having a qualification had increased their career success. Therefore, FR-4 (I am paid a salary that matches my qualification) was ranked 3rd with a mean of 2.77 and a SD of 1.26, which was rated as neutral. FR-2 (I am paid a salary that equates to my experience) was asked in order to find out if the construction professional women are paid a salary that equates to their experience. In relation to the results, FR-2 was in the neutral range and was ranked 4th with a mean of 2.73 and a SD of 1.23.

Table 5: Benefits experienced by construction professional women participants

Code	Benefits	N	Min	Max	Mean	Std Dev	Rank
Gaining skills and experience		**110**	**1**	**5**	**4.07**	**0.69**	**1**
GSE-1	Working with different stakeholders improved my soft skills	110	1	5	4.18	0.77	1
GSE-2	I achieved technical skills	110	1	5	4.15	0.75	2
GSE-3	I am able to manage a project and project team	110	1	5	4.12	0.86	3
GSE-4	I gained confidence through leadership training	110	1	5	3.82	1.01	4
Career advancement		**110**	**1**	**5**	**3.83**	**0.71**	**2**
CA-1	I was able to mentor other women in their career	110	2	5	3.90	0.86	1
CA-4	I was able to register as a professional	110	1	5	3.90	1.16	2
CA-3	I created friendships in the workplace with colleagues to get professional advice	110	2	5	3.88	0.80	3
CA-2	I was recognised of my achievement in the workplace	110	1	5	3.62	1.10	4
Financial reward		**109**	**1**	**5**	**2.89**	**1.05**	**3**

FR-1	I received performance bonus	110	1	5	3.06	1.24	1
FR-3	I received benefits in my package: medical aid, pension fund, bonus, etc	110	1	5	3.02	1.36	2
FR-4	I am paid a salary that matches my qualification	110	1	5	2.77	1.26	3
FR-2	I am paid a salary that equates to my experience	109	1	5	2.73	1.23	4

4. Conclusion

The soft skills and technical skills of the professional women's have been enhanced while working in the construction industry. This also enables them to able to be in charge of a project, supervise a project team and work with other stakeholders. The soft skills they gain are beneficial to their everyday lives and interactions with other people. The self-esteem of professional women whom have attended leadership skills training through the construction industry has increased. This could perhaps allowed them to be confident while in being charge of construction projects, even though they are in a male-dominated field.

The professional women working in the construction field for more than five years are able to mentor other construction candidates. This has been revealed by the empirical data which indicated that the women are able to improve the construction careers of other construction women through offering mentorship. Mentorship and networking in the construction industry can assist with forming meaningful friendships that are beneficial to the women professions and growth of the career. Thus, more construction women should seek mentorship from their seniors or colleagues. It can further be indicated that some of the professional women in construction are recognised for the work they do in their workplaces and construction projects they work in.

The literature has revealed the significance of being registered as a professional in the construction industry. The construction professional women in the study were able to register as professionals throughout the years they have been working in the construction industry. Registering as a professional, for example: Pr. Eng, Pr. QS, Pr. CM or Pr. CPM with either ECSA, SACPCMP or SACQSP (one of the three built environment councils) in South Africa has assisted the construction professional women to move in different work positions. Furthermore, it has made the women to gain more skills required in their construction positions and projects. In relation to the individual measures results discussed above. The overall benefits results indicated that gaining skills and experience, and career advancement were benefits for this cohort of construction stakeholders. They were found to be the main benefits that the professional women had obtained while working for five years and above in the construction industry. However, financial reward was not deduced as a benefit as the respondents were neutral in their response.

5. Recommendation

Any female who wants to venture into the construction industry should bear in mind that they are rewards gained while working in the construction despite the challenges women experience. These benefits are career advancement and, gaining skills and experience. Furthermore, companies that are in the engineering and built environment should revise their financial reward structures towards construction women employees.

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Reengineering Project Management Processes for EPC Contractors: A Saudi Arabia Case Study

Muhammad Sami Ur Rehman[1] and Muhammad Tariq Shafiq[1]

[1] Department of Architectural Engineering, College of Engineering, United Arab Emirates University, 15551, Al Ain, Abu Dhabi, UAE

muhammad.tariq@uaeu.ac.ae

Abstract

Engineering Procurement Construction (EPC) contracts provide an effective framework for projects where integrated interdisciplinary engineering expertise is required for large-scale industrial projects such as power generation, processing plants, oil and gas sector, and mining development projects. However, project management processes in EPCs contracts are complex due to overlapping project phases, interface management among the project stakeholders, and specific requirements of various industrial sectors. Hence a complex and well-integrated project management process is required to deal with the structural, technical, directional, and temporal complexities of EPC projects. This paper presents research findings of a study that investigated the project management performance of an EPC contractor on a large power transmission revamps project in Saudi Arabia. The research findings are based on a single case study research methodology that investigated EPC contractor's project management processes using a detailed project audit including site visits, document review, team interviews and focus group sessions with various project stakeholders. This paper presents the overall case study, identified gaps in capacity and competencies of the EPC contractor in various project management areas, i.e., initial planning and proposal development, engineering management, procurement management, etc., and presented recommendations to enhance the project performance of the EPC organization.

Keywords

EPC; Case study; Project management; Process reengineering; Performance improvement; Saudi Arabia

1. Introduction

Successful projects are usually the result of efficient and robust project management processes (PMI, 2013). There are five distinct project management processes i.e., project initiation, project planning, project execution, project monitoring and control, and project closing (Mantel & Meredith, 2009). These project management processes further require a specific configuration that comprises of project management method, project plans, project documentation, information exchange protocols, and the resources required for the project planning and execution.

Engineering, Procurement, Construction (EPC) is one of the well-known contracting methods used for large and complex projects and is widely used in complex industrial projects (Guo et al., 2010). A key intention of an EPC contract is to employ a single contractor to deliver the complete facility to the employer by coordinating all design, procurement, and construction work using a front-end engineering design (FEED) approach. The FEED process is typically completed before the EPC contract which encapsulates the project specifications, technical details, cost estimates, and performance requirements, yet the detailed engineering design is completed within the EPC contract. Inherently, the EPC contracts involve much higher risk than traditional Design-Bid-Build (DBB) or Design-Build (DB) methods (Galloway, 2008). Efficient project management is the utmost requirement in EPC contracts as these projects are ultra-large and large sums of money are at stake (Ballesteros, 2019). EPC contractors devise their project management processes as per the type of project and their respective industries. Their project management processes are also highly influenced by the requirements of their client or respective funding agency (Yeo & Ning, 2002). However, when an EPC contractor intends to take projects in a different industry with similar approaches and techniques, they might face hurdles in the successful delivery of the said projects. This arises the need for re-engineered project management processes and related techniques according to the type of the industry and as per the requirements from the owner/client/funding agency which require a serious effort, commitment, and a major overhaul of their existing processes across all project management areas (Al-Hajji & Khan, 2016). Several EPC contractors working in different industries at once experience difficulties and one such example is selected for this research study.

This paper presents a case study where an EPC contractor with a well-established track record of executing power up-gradation projects with the Saudi Electric Company (SEC) moved to expand its client base by exploring similar work opportunities within the Oil and Gas sector. The EPC contractor faced several difficulties and challenges in executing the project and opted for a detailed project management audit to reengineer its project management processes for better performance in the understudy and future projects within the Oil and Gas sector. This paper presents partial findings of the project management audit by discussing gaps in the current project organization and processes to propose recommendations for improved project performance in this project and the overall EPC organization for future projects.

2. Research Methodology

This single case study research strategy was adopted within which several data collection tools, such as documents review, field visits, and in-depth interviews were used (Yin, 2009). The first step in this study was to collect all the relevant information about the status of the project, understand the current project origination, manpower, and resources, identify key challenges of the project, and review the cost, time, and quality variance in the project delivery. This preamble step enabled the research team to develop an understanding of the project and design an efficient strategy for a more in-depth analysis of the project in the next steps.

In the second step, the study investigated project management practices in the key areas identified which were not efficiently contributing to the planned execution of the EPC project. For each of the identified areas, the study analyzed the current organization and role in supporting the project line organization or functional services to the project. The investigations for each area were conducted using in-depth open-ended interviews with key project personnel in each area, details of interviewees are given in Table 1.

Table 43. Method of data collection and participant's detail

Sr. No.	Method	Project role
1	One to one Interviews	Project Director
2		Project Manager
3		Construction Manager (s)
4		HSE Manager (s)
5		Project Controls Manager
6		QA/QC Manager (s)
7		Procurement Manager
8		Engineering Manager
9		Commercial and Contracts
10		HR Manager

In the Analysis step, the study analyzed the collected data from the in-depth interviews by tabulating the information and arguments received in each area to identify information that reflects gaps in the project line organization and the supporting functional organization. The study proposed recommendations for the identified gaps in each area of the project management process.

3. Results and Discussion

The adopted research methodology was carefully executed to understand the difficulties being faced by the EPC contractor and provide useful recommendations to improve the project management processes for successful management and delivery of the case study project. The first step of the research methodology helped researchers understand the management process and organizational policies being followed. The second step, in-depth one-to-one interviews with key project roles, identified key project management areas which were causing hindrances in the smooth delivery of the EPC project and remained the focus of this research study. This preliminary investigation identified 11 key project management areas i.e., Overall project management, Initial planning and proposal development, HSE Management, Engineering management, procurement management, subcontractor management, construction management, project controls, QA/QC management, interface management, and HR management. The following sections discussed the gaps identified within each project management area and presented improvement strategies to address the identified gaps.

3.1 Overall project management

The overall project organization suffered from a lack of clarity regarding roles and responsibilities, missing key roles, and inadequate delegation of authority for effective project delivery. This study identified that there was a general lack of accountability across the project organization and a general perception prevailed that key decision-making rests outside the line of project organization. Furthermore, key service organization functions were not integrated, for example, the Engineering design team was not co-located with the line project organization along with some key management roles missing. As a result, design changes were not effectively managed on the project which resulted in information bottlenecks in shop drawings production at the site and caused significant delays. The key contributor to this situation was the absence of a formal change management process that resulted in a long and time-consuming process to formulize the proper approval within the organization before it can be incorporated. Moreover, there was no formal risk management process in the project and thus the project had no risk management charter, or a risk register to effectively manage the risks involved in such a complex project.

This study proposed suggestions to improve the overall effectiveness of the project organization which is critical in determining a project's success or failure. It proposed the creation of a common vision and mission for the project and advised its communication across the project team and overall organization along with the identification of all key roles and positions and assigning qualified and competent members of the project team. It also emphasized defining the Key Performance Indicators (KPIs) and empowering the project team with an adequate delegation of authority to control all aspects of the project. Furthermore, it also suggested the definition and creation of change and risk management processes and the assignment of clear responsible roles to manage change and risk on the project.

3.2 Initial planning and proposal development

The study identified that the project bid did not adequately evaluate the scope and risk associated with this kind of project and client. As the contractor's strategy revolved around securing and sustaining the business with the proponent, so the project evaluation and bid preparation development process in the initial phases of the project did not benefit from the long and successful experiences of the contractor. Furthermore, the contractor did not have in-house engineering capabilities which contributed to the reason for underperformance from the early stages of the project. As the Engineering subcontractor was not involved in the bid evaluation and proposal development stage, therefore Engineering related contingencies in the bid were greatly reduced without strong evaluation and knowledge of the subject matter.

Since the main aim was to sustain the business with the proponent in this industry, this study recommended the establishment of a dedicated team for effective proposal development for projects with this specific client. It also emphasized ensuring that the initial bid evaluation and development process must benefit from the experience of key project stakeholders with relevant technical and commercial experience. A clear and precise subcontracting strategy and the prequalification of suppliers and subcontractors must be developed. Lastly, a risk assessment must be performed in the initial bid development stage to incorporate contingencies based on the results of the risk assessment process.

3.3 HSE management

The study identified that the overall performance of the HSE management was satisfactory and met the requirements of the project. However, the HSE practices were generally disconnected from the overall project management and require integration and collaboration with other disciplines to improve overall project performance. Overall safety culture in the organization was weak and lacked companywide cohesion. The safety program was not very well communicated and adhered to by the construction and subcontractors. Inadequate safety training was offered to overcome fragmented site locations and the high turnover of subcontractors. Not enough focus was put on leading indicators to measure safety performance on the overall project. An in-depth assessment of HSE practices and management indicated that although recorded incidences were generally low, there were however indications that data collection and preventive actions were lacking.

This study recommended that the EPC contractor must define and communicate clear corporate safety objectives and strongly communicate its vision for HSE management on the project. Also, direct serious efforts towards defining companywide safety KPIs and performance measures. Furthermore, the subcontractor selection and hiring process should be updated to include safety performance prerequisites to enhance HSE performance on the project. Lastly, this study advised actively addressing any training deficiencies in the HSE performance and management of the project on all levels.

3.4 Engineering management

Engineering management was a critical area of this revamp EPC project, as the EPC contractor did not have any in-house Engineering capabilities and the project design package was completely subcontracted. This study identified several issues hindering the project performance where a trickledown effect of inadequate engineering management caused several other issues. The engineering organization on the project suffered from a lack of integration, inadequate staffing, and a late engagement in the project. The project suffered heavily from the deficient design due to inappropriate engineering practices in detail design development, revamping work processes, team capability, and management ability to resolve issues. The engineering management process was not tailored to suit the specific needs of the proponent's revamp project and lacked clarity regarding issues resolution. Engineering deficiencies had major negative impacts on procurement, construction, and overall project planning and integration.

This study recommended an urgent restructuring of the engineering organization. The engineering organization must be realigned with the construction organization, attending to urgent construction priorities. It is further advised to strengthen and align field engineering roles with the overall engineering to effectively respond to immediate construction needs and missing roles in the engineering organization shall be filled with qualified and experienced staff. Furthermore, to proactively resolve engineering issues and quality deficiencies, this study recommended the agile response from engineering to improve the quality of engineering, develop and follow up a corrective action plan and incorporate lessons learned throughout the lifecycle of the project.

3.5 Procurement management

This study observed that Procurement performance did not meet the project requirements and was hampered by incomplete information from Engineering and caused regular delays. It was observed that the procurement on this project underperformed due to its rigid process and suffered from poor quality of engineering information. An in-depth investigation revealed that the critical material deliveries were delayed 60% of the time throughout the project. The procurement organization lacked the integration and flexibility needed to deal with the specific requirements of this project. The procurement process was utilizing a paper delivery system, which must go through the head office for approval. However, the actual procurement process was ambiguous and was not fully understood by the project management. The procurement process on the project was not efficient, did not consider execution requirements for contracts, and was not integrated with the project team as the procurement process was developed earlier in the project but was not followed later.

This study recommended that the project procurement needs to improve its response to meet the requirements of the proponent and it must be streamlined with all stakeholders to reduce the overall process duration. It also emphasized the need for digitizing and automating the procurement process to reduce the limitations and restrictions posed by the paper-based system and improve the workflow and tracking of procurement-related inquiries. Furthermore, this project organization was in dire need of a strategic long-term relationship with key suppliers to establish reliable and timely delivery of materials. Finally, the procurement department needs to be consistently engaging with project control to further streamline the procurement process with planned and ongoing project activities.

3.6 Subcontractor management

In general, the contracting strategy adopted for the project was not a good fit for the requirements of the project. The key strategy of the EPC contractor was to subcontract the key work packages including "Engineering" and "Construction". However, selected subcontractors underperformed which prompted the contractor to deploy its resources pulled from other projects. The contracts for the subcontracts were all "Unit Rate" which is in contrast to the actual Lump sum contract between the EPC contractor and the proponent. Pre-qualification process was not sufficient to confirm the qualification of subcontractors. As observed, the subcontractor selection was done based on the recommendations instead of a proper selection process by following standard prequalification procedures which resulted in the selection of subcontractors without adequate experience and required capabilities to execute this project. The ineffective subcontractor management process failed to influence performance, frequent turnovers, and commercial disputes throughout the lifecycle of the project.

This study recommended that the strategy for contracting the under-defined work needs to be revised and subcontractor performance metrics need to be developed along with clear work requirements to manage subcontractor's quality. It is also directed toward the establishment of clear requirements for subcontractors and measuring their performance against clearly defined and communicated performance metrics. Furthermore, the subcontractor prequalification process needs to be revamped to include past performance, quality performance, safety performance, and quality of key personnel along with the resolution of issues hampering the retention of subcontractors such as assurance of timely remunerations, addressing mobilization delays, and ensuring all project condition requirements laid out in contracts.

3.7 Construction management

The project site construction organization was fragmented, inexperienced in revamping projects of this nature, unfamiliar with the proponent's requirements, and lacked adequate authority and drive. This study identified that the increased turnover in key executive positions was hurting the overall performance of the construction organization. Important roles including Project Director and Construction Managers had remained vacant for a longer period. Moreover, the overall scope of the project was challenging as this project spanned the country with 36 site locations which posed a significant challenge for construction management organizations. Site work execution management did not adopt appropriate management processes, particularly for this type of project and client. Incomplete engineering had hindered construction works and the construction work planning was also disconnected from the overall project plan and schedules thus creating delays.

For strengthening the construction organization roles and processes this study recommended the addition of a Project Engineer role to strengthen the integration and delivery focus. Moreover, it emphasized the improvement and integration of engineering support for the construction process and adequate availability of resources, and a dedicated process of distribution of resources across all construction sites. Furthermore, it also suggested rethinking the requirements of key roles for constriction organization as team capabilities not only require technical skills but also management knowledge and experience to develop and implement effective processes. Lastly, this study emphasized the development of KPIs to monitor and control progress and efficiency.

3.8 Project controls

The investigation of project controls revealed the key hindrances occurring due to inadequate staffing and lack of clarity of role, responsibility, and reporting. The project team had communication and integration gaps with the project leadership. Moreover, the team that developed the baseline schedule for this project was different from the team that was managing the schedule during the construction phase. Project control plans were unrealistic and not integrated well with the proponent and other project disciplines and lacked corrective actions plans. This study identified that the baseline project schedule was developed focusing on fulfilling the requirements of the contract and forecasts were largely dictated by the proponent without considering realistic planning making the baseline schedule highly unrealistic. The current planning process was deficient in focusing the project team on critical activities/issues of the project. Even though the project schedule was approved by the proponent, there was no great value in the critical path process in the project and the critical path was never reviewed.

This study emphasized addressing deficiencies in the project control organization by employing adequate staff under experienced leadership to manage the project controls department. This study also highlighted the fact that there was a general need for the whole organization to educate on the importance of project control and provide essential support to keep the project on track. The current project team needed to improve their technical competencies, especially in planning, scheduling, and cost management. Moreover, the planning process should be clear with assigned roles and responsibilities. It should be aligned with all key stakeholders in all disciplines to support the planning process. Project control needs to include assessment of variances, reporting, and advising on action plans along with key stakeholders.

3.9 QA/QC management

This investigative study revealed that the presence and influence of QA/QC in engineering and procurement were not adequate. Overall QA/QC procedures on the project were adequate and met the minimum requirements of the proponent. However, this was observed that QA/QC procedures were not integrated with other project disciplines, as well as with subcontractors, for better performance and results. Further investigation revealed that QA/QC procedures were not properly applied in Engineering quality during the design development stage. Similarly, these procedures in procurement were not timely highlighted and resolved as well. Resultantly, the QA/QC plans and procedures were not followed adequately by the project team and subcontractors during the construction phase.

This study recommended empowering the QA/QC department to better integrate with other disciplines. Also, engage the executive management support for the QA manager role by emphasizing the importance of QA/QC procedures for engineering and procurement.

3.10 Interface management

This study identified that the project did not have a formally structured interface management process to manage the complex interfacing involved in this project. Due to the complex nature of this project, it required substantial efforts to manage interface points with external stakeholders. For example, this project involved a requirement of a Shutdown to complete the works on live substations that required an extensive effort to manage the interfacing between various external stakeholders. Moreover, there was no documented process, the project team was managing interfacing on an ad-hoc basis and there was no ownership of the interface management process. Furthermore, the details of interface management were not identified early, and issues were not addressed in time. Similarly, engineering interface management was under the responsibility of the Engineering Manager, but it was not integrated with the construction and project management as well.

This study put forwarded several recommendations to address this critical area of project management and emphasized the need for dedicated support to identify and resolve issues to enhance project performance. It is also advised to develop a clear process for interface management by clarifying roles and responsibilities for all participants and stakeholders. Lastly, it advised the utilization of state-of-the-art tools available for interface management.

3.11 HR management

In summary, the HR management processes were not timely resolving the issues and concerns of the project. This study identified that the HR management on the project was not systematic, but rather followed ad-hoc methods to handle any issues and challenges, which usually took a long time. Moreover, the HR processes on the project were generally disconnected from other project disciplines which also added to the prolongation or resolving HR issues. Overall, the project was understaffed and suffered from recruitment delays for new appointments. Due to the absence of formal HR procedures, the morale of project staff was low and disputes on overtime compensations, poor conditions of site facilities, lack of recognition and reward, and poor management of staff commute from accommodation to work site and back were frequent.

This study recommended the development of a clear corporate-level policy for HR resource development and implement it on each project. Also, provide additional expertise and resources in HR development and training. Furthermore, revisit the recruitment process and procedures to optimize the overall duration of new employee recruitment and remove bottlenecks in the process. Lastly, it advised investigating root causes for morale and turnover issues and implementing corrective action plans.

4. Conclusions

This paper presents the findings of a study conducted to improve the project performance of an EPC contractor on a large revamp project in the power transmission sector. The study adopted a single case study approach with data collection tools ranging from document reviews, physical site visits, meetings, and one-to-interviews. Initially, a detailed review of existing processes was conducted to understand the prevailing processes and build an understanding of prevailing policies and practices. Later, in-depth interviews were conducted to investigate the phenomenon and identify gaps in current practices, policies, and processes. Based on the standard project management practices and theories, recommendations were provided, across all project management areas, to improve the overall project management process for the EPC contractor. The findings of this study will guide the EPC contractors to review their existing practices and processes and improve shortcomings to improve overall project management and increase project performance on complex EPC projects.

This study also contributed to the existing body of knowledge by investigating the overall project management process for an EPC contractor, which is a complex endeavor. Also, this study identified a wide variety of factors that hinders smooth and effective project performance across all aspects of an EPC project. This wide range of causes and factors will pave the way for future studies to further investigate and improve the project performance across all the phases of the EPC project and associate project management areas. Moreover, key recommendations provided for every project management area will also serve as a valuable resource for performance improvement research studies and will provide a guided direction to achieve their research ambitions.

Future research can explore the prioritization of recommendations made in this study and explore effective organizational structures which are aligned with the requirements of EPC contracts and will improve overall project management processes in EPC projects.

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Automated Construction Progress Monitoring – Industry Perspective

Muhammad Sami Ur Rehman[1] and Muhammad Tariq Shafiq[1]

[1] Department of Architectural Engineering, College of Engineering, United Arab Emirates University, 15551, Al Ain, Abu Dhabi, UAE.
202090209@uaeu.ac.ae

Abstract
The project schedule is an important control mechanism, yet the construction schedule monitoring practices are largely manual and document-centric. This leads to poor tracking of project progress, resulting in delays, cost overruns, bitter stakeholder relationships, schedule changes, and legislative proceedings to settle construction claims. Advancements in technology (such as Building Information Models, Cloud Computing, Sensors, Computer Vision, IoT, etc.) have shown the potential to automate construction progress monitoring (ACPM) with real-time data tracking and reporting for effective decision making in managing construction projects. However, applications of these technologies are largely experimental and have yet not been adopted in the construction industry. The objectives of this paper are to summarise the potential of available technologies for automated CPM (ACPM), examine the current industry needs, and present the industry perspective on adopting ACPM. This paper presents the findings of a survey that assessed the awareness of the construction industry (CI) professionals regarding the available technologies and techniques which enable and facilitate ACPM. The research limitations and future work directions are also discussed.

Keywords
Construction Progress, Progress Monitoring, Automation, Awareness, Construction Industry.

1. Introduction

Construction projects are complex and dynamic, and the process is considered one of the most complex undertakings in any industry. The associated complexity of construction projects depends on multiple factors i.e., uncertainty, involvement of technology, inherent complexity, the rigidity of sequence, overlapping activities, and concurrency among many others (Wood and Ashton, 2010). Generally, project success is associated with the successful completion of the project within its planned cost and time by achieving an acceptable level of project specifications (Bannerman, 2008). To ensure success and stay aware of the status of the project at any given time, construction project management teams conduct continuous worksite inspections throughout the lifecycle of the project; usually termed 'construction progress monitoring' or 'construction progress tracking' (Mantel and Meredith, 2009). Traditional CPM techniques depend on manual and subjective interactions, which lack accuracy and consume more time and human resources. Such an approach has been recognized as one of the major problems that cause project delays and cost overruns (Omar and Nehdi, 2016). For the past few years, many attempts have been made to automate the CPM process and have shown the potential for effective construction project control (Kopsida *et al.*, 2015). The literature has explored a plethora of technology-enabled techniques to automate the CPM process i.e., Global Positioning System (GPS), Radio Frequency Identification (RFID), sensors, and Computer Vision (CV) based techniques (Navon and Sacks, 2007). Moreover, the CI is adopting a highly integrated project management environment throughout the lifecycle of the project in a vision for the future of the fully automated construction industry (Omar and Nehdi, 2016).

The process of CPM can be divided into four distinct categories or sub-processes i.e., data acquisition, information retrieval, progress estimation, and output visualization (Kopsida *et al.*, 2015; Sami Ur Rehman and Tariq Shafiq, 2021). Data acquisition refers to the means of collecting the as-built information from the construction worksite throughout the lifecycle of the project. The information retrieval process can also be termed as the organization of the as-built data, which refers to the retrieval of useful information regarding ongoing work processes. This information can be in the form of percent completion of individual activities, incremental milestones associated with larger activities or work packages, start or finish dates, weighed or equivalent units, subjective observations on pace or quality from the members of the project management office (Hegazy, 2013). The process of progress estimation corresponds to the comparison of as-built vs as-planned information. As-planned information is usually in the form of a baseline schedule and the as-built information is compared to it periodically to access the current state of the project and forecast the ending concerning time and cost. This process can also be termed the analysis of the as-built data or information (Omar and Nehdi, 2016). Many contracts require a periodic submission of project status reports to all the stakeholders, after performing various analyses the output visualization marks the final process of the overall CPM process. These reports can be in the form of S-curves, double S-curves, updated schedules, tracking Gantt charts, or other formats of written or visual reports (Hegazy, 2013).

In this paper, the authors aimed at summarizing tools and techniques presented in the literature to automate the CPM process, getting the perspective of the construction industry over the adoption of available tools and techniques, and identifying opportunities and challenges. Firstly, all available techniques were summarized and categorized based on their usefulness throughout the process of CPM Secondly, the responses of the concerned industry representatives over current practices being followed in the CI for progress data recording, reporting, and analysis. Furthermore, this study presented the views of CI professionals on the need for ACPM to be integrated into traditional practices or replaced with advanced techniques for effective decision-making. Lastly, this study presented the level of awareness of CI practitioners regarding the available technologies and techniques that enable ACPM, discussed the results, presented a concise conclusion, and laid down future research directions.

2. Literature Review

The success of any construction project heavily relies on timely and accurate information regarding the progress of all the activities involved in the construction project (Omar and Nehdi, 2016). All the phases of a construction project comprise many complex activities and their continuous monitoring and management have always been difficult tasks for the construction industry (Pučko *et al.*, 2018). The accuracy of CPM relies on the experience and capabilities of the field personnel who collects the required information based on manual visual observations and traditional practices (Golparvar-Fard *et al.*, 2009). However, manual visual practices and traditional CPM practices are inefficient, error-prone, and time-consuming (Navon and Sacks, 2007).

Information Technology (IT) has dominated every sector of life and brought revolutionary changes to information processing (Deb, 2014). To address the challenges faced by construction progress monitoring and management, researchers have studied IT-based tools and provided various useful methods to gather and process the required information (El-Omari and Moselhi, 2009; Tsai, 2009). Various types of multimedia such as photographs, audio, and video recordings have been used by many researchers to create information management models and enable information visualization for the critical path method using cameras and audio recording devices (Abeid and Arditi, 2002; Abudayyeh, 1997). The email has been a very effective mode to collect data, keep a follow-up, and store the necessary information regarding construction progress by initiating communication to request periodic updates and generating full schedule reports with a visual representation on a bar chart (Ahsan *et al.*, 2009; Hegazy and Abdel-Monem, 2012).

Geospatial tools help project management teams to visualize, track, control, monitor, and manage various aspects of construction projects (Cheng and Chen, 2002). Barcoding has been in use for years due to its low cost and accuracy; can be scanned using various wireless bar code readers or handheld devices; such as mobile devices; which allows the construction teams to keep track of materials, labor, and project progress especially in prefabricated construction (Lin *et al.*, 2014; Navon and Sacks, 2007). Radio Frequency Identification (RFID) has the capability of capturing and transmitting data over bigger ranges; hence many research studies identified its potential benefits in safety management, material management, and progress measurement at various types of construction projects (Jiménez *et al.*, 2013; Li *et al.*, 2012). Geographic Information System (GIS) allows the construction management teams to integrate project-specific spatial and non-spatial data to collect, analyze and manage a large amount of data. In recent years, research focus has shifted toward the use of imaging technologies to collect, analyze, store and manage important information for construction management purposes. Most research studies focused on generating the 3D models or Point Cloud Models (PCM) from digital visual datasets. Photogrammetry is an accurate method to create 3D models using digital photos of construction sites taken through various modes e.g., smartphones, digital cameras, surveillance cameras, or Unmanned Aerial Vehicles (UAV). This technique is being used in estimating the quantities of work done, geometric measurement of various building elements, and for various surveying-related purposes (Ahmed *et al.*, 2012; El-Omari and Moselhi, 2008). Videogrammetry is also a very robust tool to generate as-built models more accurately. Studies have shown its effectiveness in safety management, damage detection, and progress monitoring (Brilakis *et al.*, 2010; Zhu and Brilakis, 2010). Photogrammetry and Videogrammetry are affordable, portable, and take less processing time than 3D laser scanning; however, 3D laser scanning is among the most accurate. However, initial research has focused on data collection through various techniques. No research study has successfully automated or integrated the complete scope of the CPM. A summary of available techniques and their capabilities is presented in Table 1.

Table 44. Summary of available techniques and their capabilities.

Sr. No.	Category	Technology	Data Acquisition	Information Retrieval	Progress Monitoring	Output Visualization
1	Enhanced IT	Email	✓			
		Voice Notes	✓			
		Multimedia	✓			
		Construction Software (CDE)	✓	✓	✓	✓
2	Geospatial Tools	Barcoding	✓	✓		
		RFID	✓	✓		
		Ultra-wide Band	✓	✓		
		GIS and GPS	✓	✓	✓	
3	Imaging Technologies	Photogrammetry	✓	✓	✓	✓
		Videogrammetry	✓	✓	✓	✓
		Laser Scanning	✓	✓	✓	✓
		Range Images	✓	✓	✓	✓
4	Reality Technologies	Augmented Reality	✓	✓	✓	✓
		Virtual Reality	✓	✓	✓	✓
		Mixed Reality	✓	✓	✓	✓
5	Artificial Intelligence & Machine Learning	Computer Vision	✓	✓	✓	✓

3. Methodology

A quantitative research methodology was adopted to fulfill the objectives of this research study. A survey-based research strategy was adopted using a web-based questionnaire as a data collection tool, also adopted by (Sami Ur Rehman *et al.*, 2020).

The questionnaire was designed to collect the responses of the CI practitioners regarding the existing practices for CPM and their awareness of the available techniques for ACPM. The survey questionnaire was divided into three (03) sections. The question types were multiple-choice questions with an allowance for selecting a single answer choice or checklist type one or more choices depending on the objective of the question. The first section of the questionnaire aimed at collecting the demographic information of CI practitioners including years of experience, type of organization, current position, department, and size of their organization. The second section aimed at exploring existing practices and problems associated with them. The third and final section listed all available techniques that enable all four sub-processes i.e., data acquisition, information retrieval, progress estimation, and output visualization; and ask for their awareness of these techniques in enabling sub-processes of the ACPM.

The questionnaire was developed using a cloud-based survey tool i.e., SurveyMonkey. The link to the survey questionnaire was circulated among personal industry connections and CI practitioners identified and shortlisted through the online professional platform LinkedIn. A total of 100 responses were received to date and were being considered for the analysis to report the findings through this research study.

4. Findings

4.1 Demographic Analysis

Most of the respondents belonged to the client organization representing 36% of the total respondents. The respondents belonged to general contractors and consultants comprising 25% and 20% respectively. A significant number i.e., 10%

of respondents belonged to academia as well. The rest of the respondents were associated with architect organizations, designers, sub-contractors, and personal businesses. For the current position of the respondents, 20% of the respondents were project engineers followed by project managers and planning engineers with a contribution of 14% and 10% respectively. The rest of the respondents held a wide array of job titles including but not limited to assistant project managers, construction managers, resident engineers, site engineers, CEOs, managing directors, executive engineers, etc. Furthermore, 49% of the respondents held the experience between 4 to 6 years followed by 26% and 13% of the respondents belonged to the 7 to 10 years and 0 to 3 years bracket respectively. Also, 7% of the respondents held more than 20 years of construction-related experience. For their current department within the organization, 24% belonged to the general management of construction projects followed by construction execution, planning and estimation, and consultancy with 21%, 17%, and 14% respectively. Lastly, 56% of the respondents belonged to large-scale organizations with more than 250 employees.

Overview of Existing Practices

This section explored the input of the CI practitioners on existing CPM practices in the industry. The inquiry started from the type of instrument or data collection tool being used in the industry i.e., verbal, paper-based forms/templates, photos/videos, emails, etc. Furthermore, their opinion was explored by asking whether they think that current practices are timely and comprehensive progress-related information. Later, they were asked to identify the problem associated with traditional CPM practices and provide their opinion if any. Lastly, they were asked whether they think that there is a need to automate the existing CPM process or not using a simple Yes/No type of question.

The prevailing progress-related data collection instrument or tool was reported as paper-based forms/templates. Over 86% of the respondents selected this option confirming the use of paper-based templates during the execution of the project to collect progress-related information from the construction site. A significant number of respondents also selected the use of photos and videos as a progress recording, reporting, and analysis tool and as evidence of the construction progress. Moreover, 36% and 33% of respondents also identified the use of emails and verbal communication as a tool for CPM respectively. Apart from these options, individual respondents also highlighted several other tools for CPM i.e., the progress measurement system (PMS), Whatsapp, ERP solutions like Procore and Plangrid, and letters. Figure 1 summarizes the responses associated with this question.

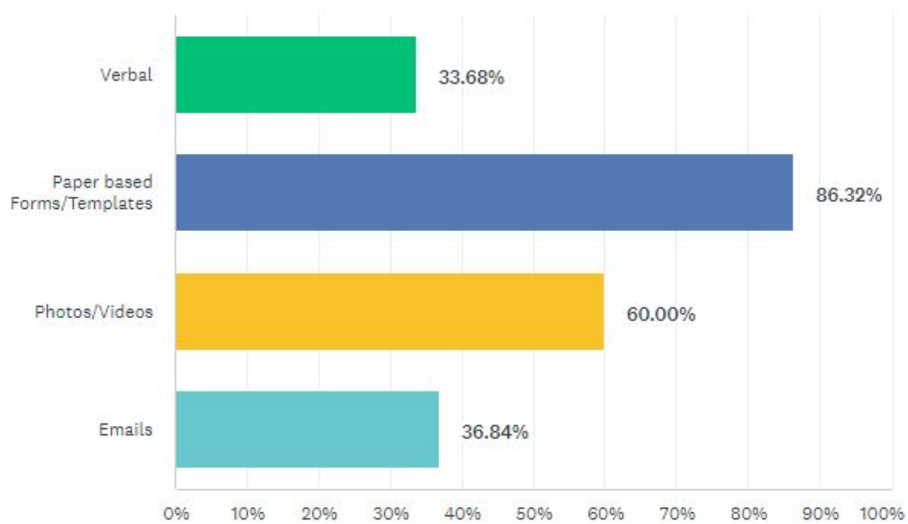

Fig. 51. Summary of responses associated with the type of CPM tool currently being used in the CI.

In response to the inquiry over the effectiveness of existing practices for providing timely and comprehensive progress-related information, over 64% of respondents chose Yes, and the rest selected No as an answer. This represented that in one way or the other traditional CPM practices seemed to be working for the CI in fulfilling their contractual requirements regarding project tracking and updating the client or consultant.

Although traditional CPM practices were enough to fulfill the requirements of the construction contracts, the respondents also identified several problems associated with traditional CPM practices. Over 66% of the respondents identified that traditional practice involved manual activities throughout the process. Furthermore, over 54% of the respondents labeled the current practice as a time-consuming activity and over 52% identified that the outcome of the traditional practice lacked accuracy and was not useful for effective decision-making. Moreover, the respondents highlighted several other problems as well i.e., the erroneous nature of the progress data, labor-intensiveness of the overall process, difficulty in analyzing and understanding the information, and the progress data being least meaningful. Figure 2 summarizes the responses associated with this question.

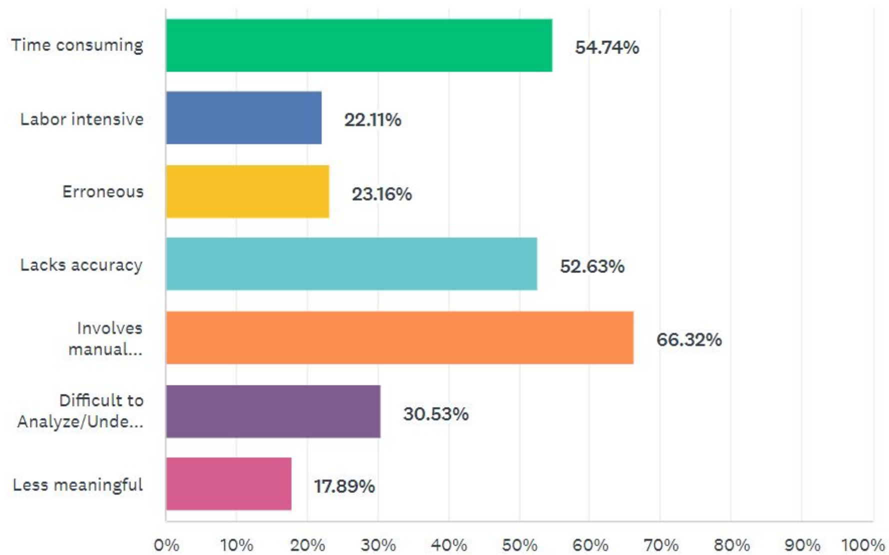

Fig. 2. Summary of responses associated with the problems with traditional CPM practices.

After giving their opinion on the problems associated with the traditional CPM practices, the CI practitioners were asked whether there is a need of automating the CPM process or not, and in response to this question, almost all of the respondents i.e, over 96% selected Yes as an answer. Figure 3 highlights the need for automating the CPM practices.

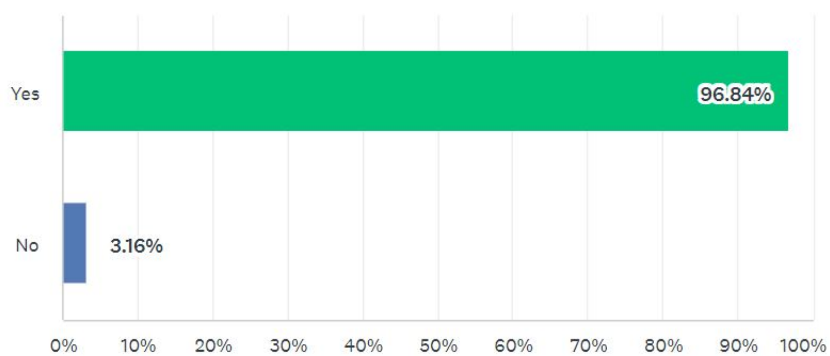

Fig. 3. Summary of responses associated with the need for automating the CPM practices.

4.3 Awareness Regarding Available Technologies and their Capabilities

This section summarized the responses received for section 3 of the survey questionnaire which aimed at assessing the awareness of CI practitioners regarding the available techniques that enable ACPM and their capabilities in enabling sub-processes of the ACPM process. The respondents were asked questions to gauge their awareness regarding the available techniques as identified by the literature across all sub-processes of the ACPM. An example of the questions in this section is as follows: "*Do you agree that the Computer Vision technique can perform 1) data acquisition (collection of as-built data) 2) information retrieval (extracting useful as-built information) 3) progress* *estimation (comparing as-built vs as-planned), 4) output visualization (generation of useful reports), 5) Not aware at all.*" Figure 4 summarizes the responses regarding the awareness of available techniques

In response to the opinions about enhanced IT tools which comprise Construction Software, 43% of the respondents agreed that it can perform data acquisition from the work site via the inputs from site engineers or supervisors. Moreover, 41% agreed to its ability for retrieving useful information from the acquired data, 56% agreed that it can efficiently perform the comparison between as-built and as-planned, and 43% agreed that it can help in the visualization of progress information. Only 17% of the overall respondents showed their unawareness of this tool.

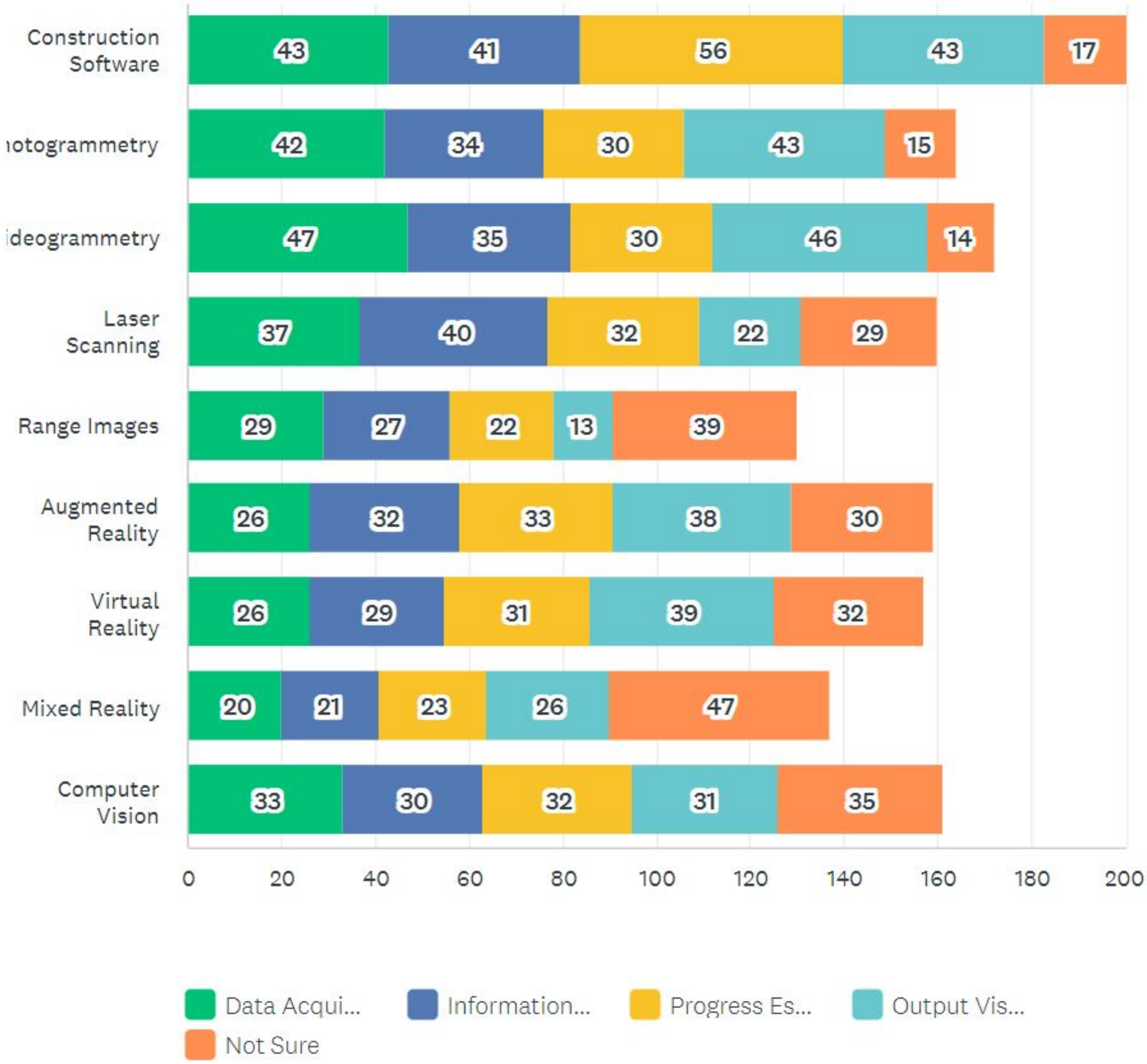

Fig. 4. Summary of responses associated with the awareness of available techniques.

The category of imaging technologies comprises photogrammetry, videogrammetry, range images, and laser scanning. Overall 42% of the respondents were aware of the capabilities of the photogrammetry technique to perform data acquisition, 34% to perform information retrieval, 30% to estimate progress by comparing as-built and as-planned and 43% to visualize the output effectively. Only 15% were unaware of this technique and its capabilities. Similarly, in the case of videogrammetry, 47%, 35%, 30% and 46% of the respondents were aware of its capability to perform data acquisition, information retrieval, progress estimation, and output visualization respectively. Moreover, 29% of the respondents were aware of the capability of range images to collect as-built data from the construction environment, 27% were aware of its capability to retrieve information, 22% of its capability to perform progress estimation and only 13% agreed to its capability to produce useful results for effective decision making during the execution phase of the project. However, 39% were unaware of the capabilities of range images to enable the ACPM process. Lastly, 37% of the respondents were aware of the capability of laser scanning to enable as-built data acquisition, 40%, 32%, and 22% of the respondents were aware of its capability for information retrieval, progress estimation, output visualization respectively. A significant number i.e., 29% of the respondents were unaware of the capabilities of laser scanning for progress monitoring.

In the category of reality technologies, 26%, 26% and 20% of the respondents were aware of the data acquisition capabilities of Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) respectively. Similarly, 32%, 29%, and 21% were aware of the information retrieval capabilities of AR, VR, and MR. Moreover, regarding AR, VR, and MR, 33%, 31%, and 23% of the respondents were aware of their capabilities to enable progress estimation, and 38%, 39%, and 26% of their capabilities for output visualization respectively. However, a significant number of respondents were unaware of these technologies and their contributions to enabling the ACPM process.

CV lies under the category of Artificial Intelligence and Machine Learning. Overall 33% of the respondents were aware of its capabilities to effectively collect data from the construction environment regarding construction progress and only 30% agreed to their awareness regarding the capabilities of CV to retrieve progress-related information from acquired data in the form of point cloud models. Moreover, 32% and 31% of the respondents were aware of CV's capabilities to efficiently compare as-built and as-planned to estimate the progress of the construction project and extract useful reports to visualize the outcome of progress estimation to enable project management teams to use the information and take important decisions to keep the project on track and deliver the desired project deliverables within the planned time and cost targets. However, a significant number i.e., 35% were unaware of its capabilities to perform ACPM.

4. Conclusions

This research study aimed at summarizing the techniques which enable ACPM and their capabilities in enabling sub-processes of the ACPM process i.e., data acquisition, information retrieval, progress estimation, and output visualization. Moreover, it aimed at exploring the existing CPM practices being followed in the CI and associated problems. Lastly, assessing the awareness of CI practitioners regarding the techniques available to enable the ACPM process. A comprehensive review of the available literature revealed several techniques across five major categories i.e., Enhanced IT, Geospatial tools, Imaging technologies, Reality technologies, and Artificial Intelligence & Machine Learning. A web-based closed-ended questionnaire survey revealed that prevailing CPM practices in the CI were labor-intensive, erroneous, time-consuming, and involves manual activities. The feedback of the CI practitioners suggested that the industry requires the ACPM practices either to be integrated within existing practices or replace the traditional CPM practices. The results showed that the majority of the CI practitioners were not aware of the ACPM techniques identified through the literature review and also they were not aware of the capabilities of these techniques in enabling the overall ACPM process. This study highlighted the need for educating the CI practitioners regarding all the technological advancements in the field of construction innovation and involving them in the process of the research to be able to effectively design methods and techniques according to the requirements of the CI. The end-users of all ACPM technologies and techniques are CI practitioners only their awareness will lead to experimentation with such technologies and eventually their adoption by the CI.

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ID 129

3D Concrete Printing; The Material Point

Frank Marquette[1]

[1] Troy University, Troy, AL,
fmarquette@troy.edu

Abstract
The growing application of automation in manufacturing and construction processes, leveraged by advances in computer aided design, presents a growing opportunity for 3D Concrete Printing technology (3DCP). This sector of additive manufacturing is receiving considerable attention with social and traditional media references to projects by companies achieving certain levels of efficacy generating a high level of public awareness of its potential. Our estimation is there's an emphasis on projects and equipment over 3DCP material science, and at this time open collaboration in research will support the development of the material science central to this technology.

Keywords
3DCP, 3D Concrete Printing, 3DCP Mix Design, 3DCP Mortar Mix Design, Open Source 3DCP, Mortar Rehology, Mortar Pumpability, Mortar Extrudability, Mortar Printability, Portland Cement, CSA Cement.

1. Introduction
3DCP technology remains at relatively early stages of development in all aspects of design and implementation. The ambition of designers utilizing CAD and parametric software outpaces the present deposition technology for automated 3DCP manufacturing. The additive manufacturing slogan "complexity is free" is yet to be realized in 3DCP without significant investment in proprietary equipment and material; even with these constraints are limiting.

Much of 3DCP focus to date has been on large format 3D concrete printing machines over a greater understanding of the printing material. This paper posits the industry will benefit from an emphasis on the material science of 3DCP first, and how this offers the greatest potential for advancing this manufacturing and construction technology.

Additive Manufacturing has its origins and growth in "open source" sharing of R&D, and we envision 3DCP benefiting from the same. Outstanding research has been completed and made available addressing several aspects of 3DCP mix designs including:

- Rehology Characteristics
- Structural Performance
- Interlayer Bonding
- Effective Extrusion
- Structural Stability
- Cement Hydration
- Fiber Reinforcement
- Polymer Admixtures

Still, those approaching the industry anew find that 3DCP mix designs are not readily shared, and companies that have developed designs for proprietary use are understandably protective of their intellectual property.

3DCP starting point scratch mix designs supported by an open source collaboration between industry and education will accelerate the range, advancement, and uptake of concrete printing. Examples and learnings gained will be shared from research in our university lab setting and working with industry.

2.1. What Comes First?
Usually, a machine. A machine that can print a house as a solution to the housing supply and construction labor shortages. This prospect has been a primary fuel for early investment in equipment and industry positioning.

It's understandable, someone sees a large printer extruding the walls of a house. The machine is printing a house, we need a machine. The machine is printing an engineered mortar, that may or may not be available or ultimately effective. With an effective and readily available 3DCP mortar mix a printer can manufacture house walls and a lot more, not before.

What if the first question when witnessing a machine print concrete was: "What mortar mix can we obtain to achieve our 3DCP vision"?

Concrete is among the most common, inexpensive, tested, and understood building materials in modern history. The assumption that a typical concrete mortar could be effectively printed is a blindside and gross oversimplification.

Performance criteria of 3D printed concrete is perhaps one of the least common, tested, inexpensive, and understood applications of concrete or mortar to date.

Can we effectively batch and mix an available 3DCP mortar? Do we have a pump and extrusion system to deposit this? Can the material perform to our production and design needs? Our research informed us the material comes first.

3DCP technical nomenclature is emerging and beginning to articulate the fundamental aspects of mix design performances. The following constitute the primary characteristics, challenges, and needs discovered in our experiments.

2.3.1. Lack of mix Designs and Sources

The ability to source materials is clearly essential, yet often over looked. Proprietary mixes are evolving and often difficult to obtain, and in many cases have exclusive distribution. Identifying supply chains and the required logistics is essential and often carries hidden expenses and other practical challenges.

2.3.2. Material Mixability

The ability to mix and hydrate the material, especially in instances of continuous supply on large scale projects, is often underestimated. Proprietary mixes may have particular needs, i.e. high-shear mixing, and may or may not be compatible with automated mixing equipment commonly utilized. An understanding of the chemistry of admixtures and their activation needs is also central to workflow of the mixing process.

2.3.3. Mix Pot-Life and Open-Time

These reference the amount of time available after mixing and before deposition; how long an activated mix can be effectively pumped or extruded. Pot-life and open-time are affected by atmospheric conditions, mixing procedure, and pumping technology. The ability to work within or adjust pot-life and open-time requires material chemistry understanding and dynamic management options.

2.3.4. Pumpability

The ability to pump and convey the mortar to an extruder is fundamental to the printing process. Precise control of over delivery rates and integration into the printer control system is required. Concrete and mortar pumps can induce surging of material supply and/or shearing and heating that are not favorable in most 3DCP applications. Pump, mortar, extruder, and control system alignment is critical.

2.3.5. Extrudability

Two types of extrusion are commonly used presently: Continuous Feed and Controlled Feed systems. Continuous feed, wherein the material is extruded through and aperture with little control over placement at the nozzle. With Controlled feed the material is pumped into a hopper that feeds an extruder with the ability to control the speed and pausing at the nozzle. Different extruder and nozzle designs require different mix designs for optimum performance.

2.3.6. Buildability

This is the ability of the material to develop sufficient yield strength to support subsequent layer deposition while maintaining layer bond. Time required between each layer deposition, the nature of the hydration or other reactive properties of the mix design, sufficient open-time to maintain effective bond between layers, and the level of complexity of forms that can be printed define good buildability.

2.4. Fundamental and Practical Requirements

Mix design affects and governs the efficacy of all phases of 3DCP production. Access to formulations, accurate and consistent batching of materials, effective and consistent mixability, material delivery and pumpability, material extrudability, material deposition and buildability, material durability and structural performance - all of these are inherent in the mix design.

3DCP mix designs require rigorous consistency and often paradoxical performance parameters, i.e. pumpability of mix and controlled hydration of set has effectively the opposite performance needs of buildability and early strength. All of these factors and how they respond in an applied environment are central to the effective placement of 3DCP concrete and mortar.

The utility of portland, calcium sulphoaluminate, geopolymer, and other cement binders have revealed unique strengths and weaknesses striving to address these demanding requirements. In the lab, several mix formulations have demonstrated efficacy in small batches and experiments. Applying the same formulas in the field at larger scales reveal other fundamental and practical needs.

Material availability, logistics, and general material handling during implementation are other fundamentals required for application success. Extrinsic factors affecting the utility and placement of mixes include atmospheric, mechanical handling, and human skills sets. Failure in any of these areas will be expressed in the product appearance, production rates, and final mechanical properties.

2.5. Rehology and Accelerated Reaction

The buildability of 3DCP mortar is delivered by the rehology and acceleration of early set in the mix. Rehology and Acceleration work in concert to make a buildable mix while meeting the other needs of successful 3DCP deposition.

Though these two work together to achieve buildablilty, at present mix designs emphasize one of these as primary. We will describe these as Rheology Build Mortar and Accelerated Build Mortar.

Rehology Build Mortar is a mix design activated by water, or another type of reagent, to create a homogenous mix that delivers a limited degree of buildability through integral yield stress for successive layer deposition. However, this is limiting to build speed and draft or incline of vertical surfaces. These mixes are relatively simple formulations and can be batched with commonly available materials.

Accelerated Build Mortars are typically proprietary mixes that have evolved through significant investment in development that allows for high levels of control over deposition rate and material set time. This technology typically injects and mixes a secondary catalyst to the mix at the print nozzle immediately preceding extrusion. This can be one or a combination of accelerators of different chemistry that are adjustable to realize the most complex and rapid build in 3DCP to date.

CSA cement can be utilized as a binder for Accelerated Build Mortar as this material offers high early strength, typically with minutes, developing enough yield stress resistance to build as high as the printer build volume allows. This is a less forgiving approach as the reaction of the mix originates at the first stage of mixing and dynamic control of reaction is limited compared to multi-part designs that can be accelerated at different rates to service a range of buildability needs.

The range of hybrids of rehology and reaction blends is effectively innumerable. We will share the hybrid formulation we have developed in our lab and an indication of the performance of this mix design.

2.6. Material Delivery: Controlled or Continuous

Continuous material feed is effectively an extrusion through the print nozzle that is controlled by the pump delivering the material. The ability to pause and restart the print is compromised due to pressures in the pump line and any control over the material at the nozzle. These mixes generally begin extruding before beginning the print profile and continue after the print is completed. This lack of material feed control limits the deposition and design of the layer geometry. Continuous feed works best with "spiral" printing geometry as the extrusion is continual and does not require the ability to pause for Z height or point to point nozzle position changes.

Controlled material feed utilizes an extruder immediately preceding the print nozzle. This is a combination of a hopper to accumulate material and an auger to extrude and control the flow of material. The extruder allows good control of the volume of material delivery and has the ability to pause or even retract material to allow the print nozzle to be repositioned either on Z axis or to other locations.

Both material delivery systems have application advantages, however the controlled method is most commonly utilized especially in large format 3DCP.

3. 3DCP Lab Results

Here we share the results of our lab experiments with 3DCP mix designs and deposition techniques.

3.1. 3DCP Experiment Goal

Our project goal was to learn more about 3DCP at small to medium scale application. The students decided upon printing a vase of approximately 400mm diameter as high as possible with the given equipment and material performance constraints.

3.2. Binder

Resources limited our choice to hybrid rehology build mortar mix designs. We began with OPC binder, and due to the scale and limited time between layer deposition we could not achieve more than 6" of Z height on our prints. This was affected by the small scale of our prints, typically shapes less than 500mm in diameter, which resulted in successive layers being placed within 20- 40 seconds. This did not allow enough time for OPC mixes to develop yield strength.

We began formulations blending CSA and OPC binders to create a hybrid mix that offered both pot-life and different degrees of early strength.

3.3. CSA/OPC 3DCP Mix Design

This table defines our scratch mix design that utilizes CSA binder, polymer, VMA, fiber, and pH adjusted potable water.

Material	Parts by batch weight
Washed and graded 30-120 mesh silica sand	1.0
Ordinary Portland cement	0.9
CSA Cement	0.3
Dry Polymer Admix	0.2
Hydroxyethylcellulose	0.03
PVA Fiber, 6mm	0.05
Water	0.3
Citric Acid	As needed to achieve 2.5 pH in batching water

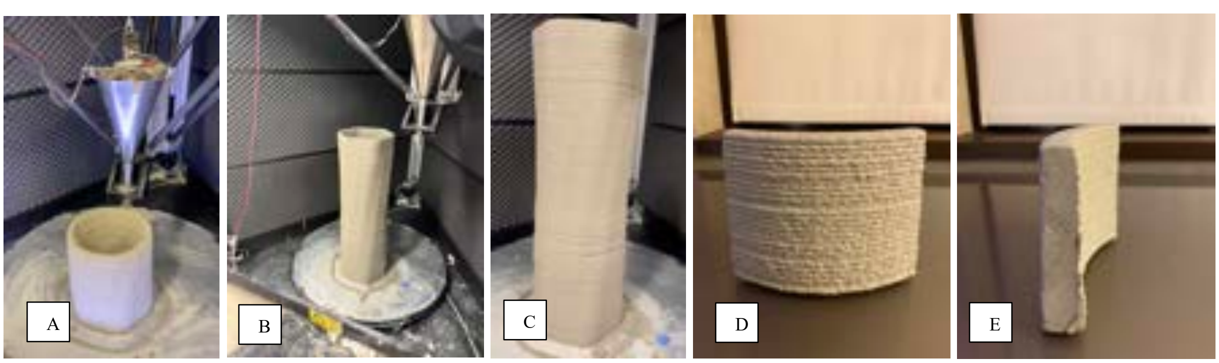
The consistency of the mix will vary and the water content adjusted to achieve the desired viscosity.

3.4. Mix Deposition

We experimented with both continuous-feed pumping the material and with controlled deposition utilizing an auger extruder and manual feed material hopper.

3.5. Print Results

With the formula and deposition described above we achieved a build of 400mm diameter at 900mm high. The layer height was 4mm. The nominal print speed was 40mm/sec. The extruder rate was adjusted to deliver a wall thickness of nominally 20mm.



A: First attempts to achieve 300mm Z height. B: Achievement of 900mm Z height with more complex shape geometry. C: Completed 900mm Z height print at specs defined above. D: Detail of layer heights. E: Cross section showing interlayer adhesion and integration.

4. Discussion

The recent growth in awareness of 3DCP, especially in large format for printing walls for residential applications, we were inspired to begin the journey of experimenting with this technology. We found proprietary material supply companies supportive and continue in these relationships sharing outcomes and general learnings of 3DCP technology. However, we also found that other proprietary 3DCP companies remain protective of their material innovations, and understandably so. However, our intention was to develop and share starting point mix designs as perhaps the most central element for successful 3DCP.

This is clearly a much broader technology than can be addressed in this paper. However, in our estimation, all progress and success in 3DCP will revolve around more effective 3DCP mix designs. Material science first, product design and electromechanical engineering second.

5. Conclusions

It is possible to create a scratch mix for 3DCP that meets all of the primary performance criteria with readily available materials. With access to starting point mix designs locally available materials and regionally available admixtures can yield a mix design with predictable results.

Open sharing and collaboration of mix designs will accelerate the adoption of 3DCP and make possible applications and utility of design and deposition technology accessible. Industry-wide adoption of 3D Printing was greatly accelerated when open source sharing was facilitated and the same is possible for this sector, 3DCP.

Going forward our research will continue to enhance the performance of 3DCP mix designs with an emphasis on buildability and form complexity, making these findings available open source. This will include:

- R&D modifying and controlling hydration rates
- R&D of dynamically adjusting mix designs to compensate for environmental changes
- Flexural and compression testing of 3DCP mix designs for small scale structural elements
- Exploration of “1.5K” mix designs for greater complexity of print designs and increased printing speed
- Development of an open source library of design files for 3DCP that align with scratch mix design performance criteria.

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ID 130

Analysis of Personnel retention Strategies within South African Construction Industry A Case Study Of Gauteng Province

Morena William Nkomo[1], Wellington Didibhuku Thwala [2], Emmanuel Emem-Obong Agbenyeku[3] and Molusiwa Stephan Ramabodu [4]

[1] University of Johannesburg, Department of Construction Management and Quantity Surveying, Beit Street., 2094 Doornfontein, South Africa
[2] University of South Africa, Pretoria
[3] University of Johannesburg, Department of Construction Management and Quantity Surveying, Beit Street., 2094 Doornfontein, South Africa
[4] University of Johannesburg, Department of Construction Management and Quantity Surveying, Beit Street., 2094 Doornfontein, South Africa
mnkomo@uj.ac.za

Abstract
Globally, the retention of skilled workers in the construction industry has been a serious concern to management due to higher turnover of professionals in the construction industry. The desired critical measures for retention strategies of skilled workers need to be done to sustain competition among construction professionals. This paved way for the study to analyze the current retention strategies within the construction industry in South Africa. The study adopted a source technique with the administration of a well-structured questionnaire to active stakeholders and professionals in the construction industry as well as interviewing human resource managers in the Gauteng Province of the South African construction industry. Data for this study was obtained through primary and secondary sources. The primary data collected was achieved through administering a well-structured questionnaire to 100 respondent professionals in the construction industry, in which 75 respondents completed and returned the questionnaires. Data for this study were analyzed by percentage distribution. The questionnaires were administered to active professionals in the construction industry in the Gauteng Province of the South Africa. The findings of the study revealed that the significant retention strategies within the construction industry in South Africa are performance appraisal bonuses, training, also by Construction Education Training Authority (CETA), recognition, good working conditions and competitive salaries in some companies outside South Africa. The study concluded that all the retention strategies need to be improved because they have been found to have a positive and significant effect on organizational performance. The study recommended that stakeholders in the construction industry and management of construction organizations should improve on retention strategies because they have been found by this study to have a positive effect on the organizational performance and by extension, the construction industry.

Keywords
Retention, Training, Strategies, Organizational Performance, Construction Industry.

1. Introduction

Talent management is the use of an integrated set of activities to ensure that the organization attracts, retains, motivates and develops the talented people it needs now and in the future. The aim is to secure the flow of talent, bearing in mind that talent is major corporate resource. It is sometimes assumed that talent management is only concerned with key people the high flyers. For example it is aimed at improving the calibre, availability and flexible utilization of exceptionally capable (high potential) employees who can have a disproportionate impact on business performance.' (Smilansky, 2005). Talent management is concerned with the roles people carry out. This involves role development, ensuring that roles provide the responsibility, challenge and autonomy required to create role engagement and motivation. It also involves taking steps to ensure that people have the opportunity and are given the encouragement to learn and develop their roles. Talent management policies also focus on flexibility giving people the chance to develop their roles by making better and extended use of their talents.

But everyone in an organization has talent, even if some have more talents than others. Talent management processes should not be limited to the favoured few; heroes of corporate performance are the capable, steady performers (deLong and Vijayaraghavan, 2003). Talent management starts with the business strategy and what it signifies in terms of the talented people required by the organization. Ultimately its aim is to develop and maintain a talent pool consisting of a skilled, engaged and committed workforce.

In South Africa, construction is the one of the largest economic activities. Currently, the investment in construction accounts to approximately 83 billion rand (roughly 5.4 billion US dollars) to the South Africa's gross domestic product (GDP) (Statista, 2022). With increasing workload and complexity of projects, the stakeholders of the industry are very conscious of the need to employ skilled personnel. As a result, a number of professionals have started to look outside their company for growth. Retention of professionals is a critical aspect for every organization because they are the most critical asset of today's modern construction industry.

Hiring and retaining efficient professionals are the most difficult tasks. Developing retention strategies for retaining construction professionals has the potential of providing large cost savings to an organization associated with employee turnover. Therefore, this study analyzes the current retention strategies within the construction industry in South Africa.

2. Current retention strategies: Attraction strategies and Employer of choice

The overall strategy of most companies is to become an employer of choice. The recruitment of key individuals who will contribute significantly to the value-creating capacity of the firm is crucial to success. The aims are to establish the brand image of the organization: how others perceive it (employee branding), to become an employer of choice, and to target recruitment and selection to obtain the kind of people the organization needs (Scarborough, 2003).
Employer branding is the creation of a brand image of the organization for prospective employees. It will be influenced by the reputation of the organization as a business or provider of service as well as its reputation as an employer. Employer branding is a concept of applying to the recruitment process the same marketing coherence used in the management of customers (Reed, 2001). The approaches required to develop an employer brand are:

- Analyse what ideal candidates need and want and take this into account in deciding what should be offered and how it should be offered.
- Establish how far the core values of the organization support the creation of an attractive brand and ensure that these are incorporated in the presentation of the brand as long as they are values in use (lived by members of the organization) rather than simply espoused.
- Define the features of the brand on the basis of an examination and review of each of the areas that affect the perceptions of people about the organization as a great place to work- the way people are treated, the provision of a fair deal, opportunities for growth, work life balance, leadership, the quality of management, involvement with colleagues and how and why the organization is successful.
- Benchmark the approaches of other organizations (the *Sunday Times* list of the 100 best companies to work for is useful) to obtain ideas about what can be done to enhance the brand
- Be honest and realistic

Looking at the events around the world, especially, in the international companies, their aim is to become an employer of choice for the most talented and good employees, a place where employees prefer to work. This means developing a value proposition, which communicates what the organization, can offer its employees as a great place to work (Sears, 2003). The factors that contribute to being an employer of choice are the provision of:

- Interesting and rewarding work
- Opportunities for learning, development and career progression.
- A reasonable degree of security
- Enhanced future employability because of the reputation of the organization as one that employs and develops high quality people, as well as the learning opportunities it provides
- Better facilities and scope for knowledge workers, for example, research and development for engineers and IT specialist

- Employment conditions that satisfy work life balance needs
- A reward system that recognizes and values contribution and provides competitive pay and benefits.

All these add up to an employee value proposition which, as a means of attracting and retaining high-potential employees, recognizes that they will be looking for strong values and expecting to be well managed, to have freedom and autonomy, high job challenge and career opportunities. A powerful method of retaining employees is simply to ensure that people feel they are valued.

Employer of choice plans should include plans for attracting good candidates by ensuring that the organization will become an employer of choice. This could be achieved by generally improving the image of the company as an employer (the employer brand) and by offering:

- Better remuneration packages
- More opportunities for learning, development and careers
- Enhanced future employability because of the reputation of the organization as one that employs and develops high-quality people, well as the learning opportunities it provides.
- Employment conditions which address work/life balance issues by, for example, adapting working hours and arrangements and leave policies, and providing child-care facilities or vouchers to meet the needs of those with domestic responsibilities.
- Better facilities and scope for knowledge workers, such as research and development scientists or engineers or IT specialists.
- Golden hellos (sum of money paid upfront to recruits).
- Generous relocation payments

3. Research Methodology

3. 1 Sampling and sample population

The population for this study were active stakeholders and construction professionals as well as human resource managers in the Gauteng Province of the South African construction industry. These construction professionals were chosen because, in the pilot study, they indicated knowledgeable contributions to meeting the objective of the study. The standard for selecting respondents for this study was that participants had to be actively involved in the South African construction industry from the Gauteng Province of the country. This study employed self-selection and random sampling which gives all participants an equal chance of being selected for the study. Data for this study was obtained through primary and secondary sources. The primary data collated for this study was achieved through administering of a well-structured questionnaire, which is mostly used for quantitative research (McDaniel and Gate, 2012). The questionnaire was designed based on the review of related literature. Secondary data used in this study was derived from existing literature published in government reports, conference papers and journal articles. As appraised by Kumar (2011), literature review expands the knowledge base of the researcher and helps in integrating the findings with the existing body of knowledge.

This study used closed-ended questions based on literature reviewed. Data for this study was collected with the aid of a well-structured questionnaire to analyze the current retention strategies within the construction industry in South Africa. The respondents were given an average of fifteen minutes to complete the questionnaire without any form of coercion. 75 questionnaires were retrieved from a total of 100 administered. The questionnaires were administered to 21 female and 54 male participants who are actively involved in construction activities in Gauteng Province. It is important to note that these numbers were highly based on the availability, willingness, and consent of the candidates to partake in the study. From the pilot study, there were signs that indigenes of the Gauteng Province are liberal. As such, their cultural, traditional, or religious predispositions did not seem to have posed a barrier or limitation to their willingness to partake in the study nor did it hinder them from freely disclosing their opinions and sharing their knowledge with respect to the subject matter. Nonetheless, the general knowledge base and opinions of the male and female respondents in this study are considered vital as they offer a basis for comparison between respondents, providing crucial insights to the subject matter and indicate pertinent dynamics on the study of the current retention strategies within the construction industry in South Africa through the Gauteng Province.

Data analysis

Data analysis is the process implemented by the researcher to give structure and meaning to the vast amount of data collected (Strydom and Delport, 2002). The handling of information needs to happen creatively and meaning must be given to the vast amount of information. The study employed descriptive analysis for its data analysis. Descriptive analysis used frequency distribution to measure the significance of all the variables and to rank them. The questionnaire consisted of questions that were ranked using frequency distribution to analyze and acquire the respondents' opinion on the current retention strategies within the South Africa construction industry in the Gauteng Province. This made it possible to determine the rank of each item. The comparison of the frequency distribution of the items as judged by the respondents was easy because the items were ranked. This helped in analyzing data collected from the survey questionnaire. After the mathematical computations were done, the individual criteria were ranked in descending order of their frequency distribution (from the highest to the lowest).

3.3 Results

Table 1 presents the current retention strategies within the construction industry in South Africa, the variables and the respondents' ranking. The study revealed that, with a frequency distribution (FD) of 51, performance appraisal bonuses, training, recognition and competitive salaries in some companies is the current retention strategy perceived by respondents within the construction industry in South Africa.

Table 1: Current retention strategies within the construction industry in South Africa

3. **Current retention strategies by respondents**	4. **Frequency distribution (FD)**	5. **Percentage (%)**
6. Performance appraisal bonuses, training, recognition and competitive salaries in some companies	7. 38	8. 51
9. No retention strategies that I know of	10. 37	11. 49
12. **Total**	13. **75**	14. **100**

51% of the respondents felt that the current retention strategies within the construction industry in South Africa are performance appraisal bonuses, training, also by Construction Education Training Authority (CETA), recognition, and competitive salaries in some companies outside South Africa. Some answers that were received from other respondents were good working conditions within the organization, which as a result, assist the organization in improving on its organizational performance. 47% of the respondents felt that they have no answer to give as regards the retention strategies within the construction industry in South Africa as they perceive the South Africa construction industry as being biased because an employee or a professional can only be retained if he or she is related to a stakeholder of the industry or management of the organization.

4. Discussion

With regard to determining the current retention strategies of companies, the following were found to be in place: benefits that the participants emphasized they were given based on the position they hold within the company; followed by competitive salaries that are paid, although not offered by all companies; also depending on how well they know you in the company; and the opportunities for promotions in their career. The strategy supports the construction industry's strategic business objective to be 'a place where people are proud to work and feel supported and valued so that the industry can iron out the problems/barriers and employees feel empowered and own the services they deliver and that diversity is valued'. This strategy operates within the context of a range of associated policies in relation to recruitment, retention, development and discipline. Allowances must be made to any changes required to existing policies or the introduction of new policies to implement this strategy.

Hire the right people in the first place . Quality of the right people is one of the single biggest factors affecting future success in today's business world. The success of the construction industry is very much dependent on the quality of their employees. Employee commitment and ownership and the emotional and psychological attachment to an industry are the qualities that deliver high performance, as employees are prepared to put in an effort and go that extra mile. The construction industry understands that the right people are important and they know what they want.

A sense of direction: people want to know where they are going and where their employer is going. Younger people, for example, young employees are probably more vocal about this, but we all like to know what we are working towards.

5. Conclusions

This study focused on the current retention strategies within the construction industry in South Africa. The study sought the views of active stakeholders and construction professionals in the Gauteng Province of the South African construction industry. The study revealed that the current retention strategies within the construction industry in South Africa are performance appraisal bonuses, training, also by Construction Education Training Authority (CETA), recognition, and competitive salaries in some companies outside South Africa. The results also indicated that good working conditions within the organization is also a retention strategy, that helps the organization and the industry at large to improve its organizational performance. Based on the findings of the study, the study recommends that management and stakeholders within South Africa construction industry should improve on its retention strategies as it has been found by this study to have a positive effect on the organizational performance. Additionally, the study recommends good treatment of professionals and good working conditions for professionals to enable them deliver good services in their respective duties.

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An Investigation into the Causes of Job Hopping within South African Construction Industry A Case Study Of Gauteng Province

Morena William Nkomo[1], Wellington Didibhuku Thwala [2], Emmanuel Emem-Obong Agbenyeku[3] and Molusiwa Stephan Ramabodu [4]

[1] University of Johannesburg, Department of Construction Management and Quantity Surveying, Beit Street., 2094 Doornfontein, South Africa
[2] University of South Africa, Pretoria
[3] University of Johannesburg, Department of Construction Management and Quantity Surveying, Beit Street., 2094 Doornfontein, South Africa
[4] University of Johannesburg, Department of Construction Management and Quantity Surveying, Beit Street., 2094 Doornfontein, South Africa
mnkomo@uj.ac.za

Abstract

This study was carried out to investigate the causes of job hopping within the construction industry in South Africa. The study adopted a source technique with the administration of a well-structured questionnaire to active stakeholders and construction professionals as well as interviewing human resource managers in the Gauteng Province of the South African construction industry. Data for this study was obtained through primary and secondary sources. The primary data collected was achieved through administering a well-structured questionnaire to 100 respondent professionals in the construction industry, in which 75 respondent professionals completed and returned the questionnaires. Data for this study were analyzed by percentage distribution. The questionnaires were administered to active professionals in the construction industry in the Gauteng Province of the South Africa. The findings of the study revealed that the significant causes of job hopping within the construction industry in South Africa are money and recognition, personal growth and new challenges, lack of experience and bad treatment from managers, not working as a team, and circumstances surrounding the individual that requires him or her to job hop. The study therefore suggests that to drastically reduce the causes of job hopping within the construction industry in South Africa, stakeholders in the construction industry must come up with strategies used as retention strategies by companies from a neutral or fair extent and hence, its practicality and effectiveness to retain employees.

Keywords

Job Hopping, Causes, Strategy, Construction

1. Introduction

There is a high rate of job hopping within the construction companies in South Africa. This has led to increased expenditure by employers as a result of lower productivity, failure to meet deadlines, and the costs associated with re-training of newly hired workers. In line with Ryan (2016), employees in the construction industry leave their current jobs and relocate abroad, or jump from one company to the next, to look for better remuneration and opportunities. This results in lower productivity at various projects. When an employee leaves an organization, efficiency is expected to fall due to the learning curve involved in knowing the job and the organization. To this effect, lack of intellectual capital adds. Not only do organizations lose the human and relational capital of the departing employee, competitors are also potentially gaining these assets (Stovel and Bontis, 2012). Therefore, this study investigated the causes of job hopping within the construction industry in South Africa.

2. Factors influencing job hopping

There are several factors that influence job hopping among employees. Typically, a combination of factors influences job hopping. The table 1 shows the factors influencing job hopping among employees documented by several authors. Employees can be demotivated when other factors are unsatisfactory, these being termed hygiene factors, and mainly related to:

- Working conditions
- Salary
- Relations with superiors
- Company policy

Importantly, the hygiene factors apparently had little positive effect on job attitudes but served primarily to prevent job dissatisfaction. For instance, if a company fails to provide adequate hygiene factors the worker will become dissatisfied, no matter how adequate the salaries, working conditions, etc., the worker will remain unsatisfied unless the job has the intrinsic motivation elements.

The two-factor model of satisfiers and dissatisfiers was developed following an investigation into the sources of job satisfaction and dissatisfaction of construction employees, for example engineers. It was assumed that people have the capacity to report accurately the conditions that made them satisfied and dissatisfied with their jobs. Accordingly, the subjects were asked to tell interviewers about the times during which they felt exceptionally good and exceptionally bad about their jobs and how long their feelings persisted (Herzberg, 1957).

It was found that the accounts of good periods most frequently concerned the content of the job, particularly achievement, recognition, advancement, autonomy, responsibility, and the work itself. On the other hand, accounts of bad periods most frequently concerned the context of the job. Company policy and administration, supervision, salary and working conditions more frequently appeared in these accounts than in those told about good periods. The main implications of this research were that:

The wants of employees are divided into two groups. One group revolves around the need for personal growth to develop in one's occupation. The second group operates as an essential base to the first and is associated with fair treatment in compensation, supervision, working conditions and administrative practices. The fulfilment of the needs of the second group does not motivate the individual to high levels of job satisfaction and to extra performance on the job. All we can accept from satisfying this second group of needs is the prevention of dissatisfaction and poor job performance.

These groups form the two factors (Herzberg, 1957). One consists of the satisfiers or motivators, because they are seen to be effective in motivating the individual to superior performance and effort. The other consists of the dissatisfies, which essentially describe the environment and serve primarily to prevent job dissatisfaction, while having little effect on positive job attitude. The latter were named the hygiene factors in the medical use of the term, meaning preventive and environmental. The following are some of the causes of employee dissatisfaction within the working environment, which eventually will lead to or result in job hopping: The employees of today are working to meet their needs and to achieve their own goals (Drafke and Kossen, 2002: 10); they no longer want to have a long-term relationship with the company. On average, employees used to have 3 or 4 jobs during their careers, but now this number has increased to 7 or 8 jobs. This number grows as employees become more mobile (Gubman, 2003: 32). Employees are keen but employers struggle to retain, attract and develop talent, according to a recent national survey of the South African workforce. Local employers are failing to attract, retain and develop their employees. The research findings are based on more than 21 000 responses to a 70 question survey conducted among a broad spectrum of industries and employees at various job levels (Blue River Stone Research, 2008). South Africa's fastest growing jobs portal the second annual *Careers 24* Salary Survey was conducted between October and November, 2008. Some of the key findings of the study include: organizations implement and respond to performance reviews poorly, despite having proud and willing employees; as a result employees move from one company to the next; companies fail to invest sufficiently in skills development; due to this recruitment tends to happen outside the organization rather than developing and promoting employees internally; this also tends to lead to job dissatisfaction of employees within the organization. Men earn more than women and the wage gap widens with age and business; management expertise is the most sought-after skill across most industries (*Careers 24*, 2008). The true root causes of voluntary employee job hopping are hiding in plain sight. If we really think about it, we already know what they are: lack of recognition (including low pay), unfulfilling jobs, limited career advancement, poor management practices, untrustworthy leadership, and dysfunctional work cultures. So in what way are these root causes hidden, and from whom? Surveys tell us that they are hidden from the very people who need to be most aware of them, namely the line managers within companies who are charged with engaging and keeping valued employees in every organization. The vast majority of line managers in fact believe that most employees leave because they are pulled away by better offers. Of course most do leave for better offers, but it is simplistic and superficial to accept pull factors as the root causes. What these managers fail to perceive is that push factors, mostly within their own power, are the initial stimuli, the first causes that open the door to the pull of outside opportunities. The important question that remains unasked in so many exit interview is not 'Why are you leaving?' but 'Why are you not staying?' (Branham, 2005).

Table 1 Factors influencing job hopping

Authors	Factors influencing job hopping
Firth, David, Kathleen, and Loquet (2004)	Lack of commitment in organization Job stress/dissatisfaction
Pee, Woon, and Kankanhalli (2008)	Alternative employment opportunities
Schaefer, Terlutter, and Diehl (2019)	Economic reason
Sharabi (2008)	Large organization provide employees with better chance of advancement and higher wage
Reardon and Barrett (2000)	Increased international capital flow (globalization)
Meek, Roberts, and Gray (2005)	Company size
George, Gow, and Bachoo (2013)	Training opportunities
Gberevbie, D. (2010)	High performers insufficiently rewarded
Ghosh, Satyawadi, Joshi, and Shadman (2013)	Managerial style Poor hiring practice Lack of recognition Toxic workplace environment Lack of competitive compensation system
Songstad, Lindkvist, Moland, Chimhutu, and Blystad (2012)	Inadequate job training Lack of financial support to new agent/employee Lack of involvement in decision making Poor supervision Lack of good career policy Dissatisfaction with remuneration method
Lombardi, Verma, Brennan, and Perry (2009)	Wrong fit
Egan, Yang, and Bartlett (2004)	Job not standardized Procedure does not exist for transmitting knowledge to new member
Kok, Kane, Tulloch, Ormel, Theobald, Dieleman (2015)	Poor supervisory practices, Poor recruitment policies, Poor personnel policies, Poor grievance procedure, Lack of motivation
Xiong, Wang, Cheng, and Yu (2018)	High level of inefficiency
Tsai, Yen, Huang, and Huang (2007)	Needs to cut cost Restructure/ downsize
Rose, Mallinson, and Gerson (2006)	Resigning to take care of terminally ill family member Accompanying spouse to another area
Andrews and Dziegielewski (2005)	Lack of job satisfaction Job stress Alternative opportunities
Lu, Barriball, Zhang, and While (2012)	Age Gender Role conflict Co-worker support Job opportunity Organizational commitment

	Intent to leave Kinship responsibility
Pfeiffer and Reize, (2000)	State of the economy Unemployment level Size of firm Job design Family responsibility Expectations and abilities
Wong (2008)	Length of time in job Age
Ghignoni and Verashchagina (2014)	Qualification of the employees
Rad and Yarmohammadian (2006)	Work repetitiveness Perception of co-workers Intention to leave Importance of improvement
Kultalahti and Viitala (2014)	Motivated by higher pay Not engaged Bored Poorly managed

(Source, Author's own)

3. Research Methodology

3. 1 Sampling and sample population

The population for this study were active stakeholders and construction professionals as well as human resource managers in the Gauteng Province of the South African construction industry. These construction professionals were chosen because, in the pilot study, they indicated knowledgeable contributions to meeting the objective of the study. The standard for selecting respondents for this study was that participants had to be actively involved in the South African construction industry from the Gauteng Province of the country. This study employed self-selection and random sampling which gives all participants an equal chance of being selected for the study. Data for this study was obtained through primary and secondary sources. The primary data collated for this study was achieved through administering of a well-structured questionnaire, which is mostly used for quantitative research (McDaniel and Gate, 2012).

The questionnaire was designed based on the review of related literature. Secondary data used in this study was derived from existing literature published in government reports, conference papers and journal articles. As appraised by Kumar (2011), literature review expands the knowledge base of the researcher and helps in integrating the findings with the existing body of knowledge. This study used closed-ended questions based on literature reviewed. Data for this study was collected with the aid of a well-structured questionnaire to investigate the cause of job hopping within the construction industry in South Africa and its subject matter. The respondents were given an average of fifteen minutes to complete the questionnaire without any form of coercion. 75 questionnaires were retrieved from a total of 100 administered. The questionnaires were administered to 21 female and 54 male participants who are actively involved in construction operations in Gauteng Province. It is important to note that these numbers were highly based on the availability, willingness, and consent of the candidates to partake in the study. From the pilot study, there were signs that indigenes of the Gauteng Province are liberal. As such, their cultural, traditional, or religious predispositions did not seem to have posed a barrier or limitation to their willingness to partake in the study nor did it hinder them from freely disclosing their opinions and sharing their knowledge with respect to the subject matter. Nonetheless, the general knowledge base and opinions of the male and female respondents in this study are considered vital as they offer a basis for comparison between respondents, providing crucial insights to the subject matter and indicate pertinent dynamics on the study of the causes of job hopping in South African construction industry through the Gauteng Province.

Data analysis

Strydom and Delport (2002) opined that data analysis is the process implemented by the researcher to give structure and meaning to the vast amount of data collected. The handling of information needs to happen creatively and meaning must be given to the vast amount of information. The study employed descriptive analysis for its data analysis. Descriptive analysis used frequency distribution to measure the significance of all the variables and to rank them. The questionnaire consisted of questions that were ranked using frequency distribution to examine and acquire the respondents' opinion on the causes of job hopping in South African construction industry in the Gauteng Province. This made it possible to determine the rank of each item. The comparison of the frequency distribution of the items as judged by the respondents was easy because the items were ranked. This helped in analyzing data collected from the survey questionnaire. After the mathematical computations were done, the individual criteria were ranked in descending order of their frequency distribution (from the highest to the lowest).

3.3 Results

Table 2 shows the main causes of job hopping within the construction industry in South Africa, the variables and the respondents' ranking. The study revealed that, with a frequency distribution (FD) of 41, 'money and recognition' is the leading factor influencing job hopping within construction industry in South Africa. 'Personal growth and new challenges' were ranked second with (FD = 17); 'lack of experience' was ranked third with (FD = 8); and 'ill-treatment from managers' was ranked fourth with (FD = 7). The table further shows that 'not working as a team' was ranked fifth with (FD = 1); and 'individual circumstances' was ranked sixth with (FD = 1).

Table 2: Main causes of job hopping within the construction industry in South Africa.

Job hopping related causes	Frequency distribution (FD)	Percentage (%)
Money and recognition	41	55
Personal growth and new challenges	17	23
Lack of experience.	8	11
Ill-treatment from managers	7	9
Not working as a team	1	1
Individual circumstances	1	1

In brief, 55% of respondents felt that money and recognition cause job hopping, whereas 23% of the respondents ascribed job hopping to not being given an opportunity to grow, with the least of the causes of job hopping being 1% for both not working as a team, and individual circumstances. Recognition that is valued in terms of financial rewards is the biggest single cause of job hopping; for instance, if you are a worker, you need to be recognized in your job so that you are able to be motivated in your job and get promoted. If this were to be done, there would be no job hopping within the construction industry. Employees move from one company to the next in the hope of gaining experience to enable them to earn more money. Others say that there are no fringe benefits in the company so they do not see the point of being in such a company. Unfairness, racism, sexism, political appointments, racial appointments, appointments based on colour, and appointing non-skilled employees with irrelevant experience and qualifications in specialized skills jobs – all of these factors also contribute to employees resorting to job hopping. Some workers are not well-trained in what they do and they are under pressure as they are not performing well in what they are required to do, resulting in job hopping. There is still much training to be done, especially on the White employees (Afrikaners). Participants said that they (the Whites) still believe that they own the building industry and personally participants said they would prefer to work in an environment with fewer Afrikaners.

4. Discussion

The main causes of job hopping within construction is the fact that candidates are more skilled today and tend to play the field when looking for work, which allows them to negotiate for higher packages and more benefits. Two years ago, employees in generally were most concerned about the location and the name of the company in the job advertisements, but now it is all about the money. The strong focus on salary is often at the expense of long- term security. Therefore, the decision to stay with a company or to resign involves evaluating costs and benefits, and if the present value of the returns associated with turnover exceeds both monetary and psychological costs of leaving, workers will be motivated to change jobs. If the discounted stream of benefits is not as high as the costs, workers will resist changing jobs **(Ehrenberg and Smith, 1994).** The explicit and implicit benefits associated with staying or retaining a job will be reduced if a worker is unhappy, if the immediate cost of leaving is low, if the utility of the new job is great, or if the new job offers a comparable compensation package.

5. Conclusions

This study focused on the causes of job hopping within the construction industry in South Africa. The study sought the views of active stakeholders and construction professionals in the Gauteng Province of the South African construction industry. The study revealed that, out of the list of main causes of job hopping within the construction industry identified, the top three most severe causes as recorded by the respondents are as follows: money and recognition, personal growth and new challenges, and lack of experience. The results also indicated that, money and recognition is the leading factor/cause influencing job hopping within the construction industry in South Africa, based on respondents' viewpoint. Personal growth and new challenges, is considered the second most severe factor/cause influencing job hopping within the construction industry in South Africa. There is a pressing need for the government and all parties involved in the construction industry to intervene in order reduce employee turnover in South Africa. The study therefore suggests that to drastically reduce the causes of job hopping within the construction industry in South Africa, the South African government and stakeholders in the construction industry must come up with strategies used as retention strategies by companies from a neutral or fair extent and hence, its practicality and effectiveness to retain employees. *Rewards and recognition* are yet another crucial component to the success of a company's retention programme because they confirm to the employees that their efforts are meaningful, acknowledged and appreciated. One of the easiest and best ways to reward employees is to simply congratulate employees on a job well done. Long hours and hard work that go unnoticed will leave employees feeling deflated. Other forms of recognition include service awards, congratulatory or promotion letters signed by top executive, promotion announcements on the company intranet, in a company newsletter or in a trade publication and public accolades at company meetings. Companies might consider a systematic compensation/bonus programme designed to establish milestones and to reward top performers.

Companies that establish a clear, definitive strategy for retention will benefit tremendously. The following are some strategies that are invaluable in current retention strategies:

Culture and commitment: It is a common misconception that retention is the sole responsibility of a company's HR department. In practice, a successful programme includes buy-in from all departments and levels of an organization. Owners, top executives and managers must jointly establish company operating principles that define its value system. Further, these leaders must take an active role in promoting, communicating and practising this culture. A strong company culture is one that places value on people, fosters teamwork, is forwarding-thinking, and encourages open communication.

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Perspectives of Women in Construction to Encourage More Women to Join Construction

Anoop Sattineni[1] and Yolanda Ikner[1]

[1] McWhorter School of Building Science at Auburn University, Auburn, AL, 36849, USA
sattian@auburn.edu

Abstract
Despite a range of equality legislation and initiatives in the United States Congress, the construction industry remains one of the most male-dominated sectors. The construction industry is one of the largest job providers in the U.S., and the construction industry suffers from critical labor shortages in the workforce. Research shows that women are significantly underrepresented in all the construction occupations and professions in the United States construction industry. For years, there has been a wealth of research and many initiatives to tackle equality and diversity in the construction industry, specifically concerning female representation. In this research a quantitative study was conducted using an online survey. Results indicate that there is a significant level of dissatisfaction within the female workforce in the construction industry. Opinions of a significant percentage of respondents indicate that they feel overlooked, that their opinions are considered and that they are underpaid. However, the respondents also provided valuable feedback to include more women to participate in the construction industry. Mentoring and equal pay were prominent answers to the question of empowering more women to join the construction industry.

Keywords
Women in Construction, Survey, Diversity and Inclusion

1. Introduction
The construction industry is one of the most male-oriented industries. Construction has always had a 'macho, male-dominated connotation. There remains a pressing need to do more to encourage a commitment to gender diversity in the workplace, thereby attracting more women into the construction industry and enabling women the opportunity for senior-level positions. The status quo needs to shift, enabling a more inclusive, diverse, and gender-equal workforce in the years to come, with women comprising of just under 20% of the directly employed construction workforce. Research reflects that women get passed over for the top jobs in construction. However, a diverse workforce allows the best talent to rise to the top, regardless of gender, race, ethnicity, cultural background, or beliefs.

Of all the people working in construction, women comprise only 10.3 percent. Even smaller is the number of women on the front lines of a job site. Out of 100 employees in the field, only one is female. Considering that women make up 47 percent of all employed individuals, this means that the construction industry is only benefitting from about 1.25 percent of women in the workforce (*Women in Construction: The State of the Industry in 2022 | BigRentz*, n.d.). The gender gap in the construction workforce persists, despite efforts to close it over the past several decades. Increasing gender diversity is a critical strategy for strengthening the supply of engineering professionals required to meet current and future public and private demands. Female construction workers appear underrepresented in supervisory positions as compared to their male counterparts. Female construction workers are also much more likely to leave their jobs than male supervisors. Their departure rate is higher in both the private and public sectors (*Women Construction Owners & Executives – We Create Opportunities for Women*, n.d.). These results illustrate the advancement challenges women encounter on their career paths and the consequences of these barriers. This includes less gender diversity in the pool of civil engineers available to meet the growing demand in the construction industry and fewer women available for promotion into leadership positions (Choi et al., 2022).

Rapid growth in the construction industry in the U.S. has driven increasing workforce demand. In 1998, construction spending in the United States was $689 billion (private sector: $534 billion; public sector: $155 billion);

in 2019, it was $1,326 billion (private: $997 billion; public: $329 billion) (Branch, n.d.). According to the U.S. Department of Labor's Bureau of Labor Statistics (BLS), the annual hiring rate grew by 20.1% between 2015 and 2019, increasing from 3,982 to 4,981 hires per year (*Table 1. Job Openings Levels and Rates by Industry and Region, Seasonally Adjusted - 2022 M02 Results*, n.d.). In addition, the construction industry has played an important role in the nation's economy, contributing 4.1% to the U.S. gross domestic product (GDP) in 2019. As the number of workers has increased in this sector, so has the job turnover rate. In 2015 the turnover rate was 21%, but it increased to 27.6% in 2019.

While the odds seem stacked against women in construction management, the outlook for female representation and opportunity in construction has improved in other areas. Social attitudes and organizational cultures are becoming more accepting of women in male-dominated fields such as construction and other science, technology, engineering, and mathematics (STEAM) fields (Norberg & Johansson, 2021). Since 2002, there has been evidence that the industry values and desires women's diverse capabilities and perspectives in construction management (Agapiou, 2002). A 2013 study in Sweden found that women scored equal to or higher in 17 out of 20 project management competencies than their male counterparts (Arditi et al., 2013), concluding that project managers are as competent as their male counterparts. Universities recruit more female construction management students (Moore and Gloeckner 2007; Sewalk and Nietfeld 2013).

2. Research Methodology

This research study was conducted through the utilization of a quantitative approach. Quantitative data was obtained and analyzed by surveying women working in the construction sector. A standardized survey with multiple choice and short answers was conducted electronically over the internet. The survey sought to discover the female responses to 35 questions ranging from demographics to current working conditions and what can be done to improve the numbers of women working in the construction industry. Quantitative methods were used to analyze the survey data. The survey was sent to 73 female participants, 31 of whom completed the survey, resulting in a response rate of 42.5%. This is less than desirable and the authors intend to further distribute the survey to elicit a greater response rate.

3. Results

The survey was completed from women in the construction industry working in the United States. Women were asked about their experiences in the construction industry. The data reveals a dark experience for a majority of the women working in the industry, as shown in Table 1.

3.1 Quantitative Results

The data reveals a dark experience for a majority of the women working in the industry, as shown in Table 1. Some of the highlights of the data include:

- Only 55% of the women agreed that women have good opportunities to advance in the construction industry
- 30% of the respondents do not agree that the situation in the construction industry is improving for women
- 45% of the respondents believe that men were respected more than women
- Only 35% of the respondents thought that their leadership team encouraged women to participate in decision making process
- 38% of the respondents did not believe that their opinions, ideas and suggestions were genuinely considered by others in the company
- Only 50% of the respondents believed that their company's leadership listens to them compared to men within the company
- Only 50% of the respondents believed that their company valued them as their male counterparts
- Only 55% of the respondents believed that their company paid them the same as men within the company

Taken as an aggregate, this data points to deep dissatisfaction amongst the respondents about how valued they feel with their companies. Additional comments for these questions also suggested the same, as evidenced by one respondents comment *"I have worked in the field and in construction offices for over 2 decades. I have been talked over and over-looked more times than I can count. If I could change one thing, it would be to be heard."*

Table 1. Opinions of female workers in construction industry about treatment and in comparison to men

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Do you feel women have good opportunities for advancement in the construction industry?	0.00%	55.17%	20.69%	24.14%	0.00%
Do you feel the role of women in construction is changing for the better?	10.34%	58.62%	24.14%	6.90%	0.00%
More coworkers are respectful towards their male counterparts, then female counterparts.	13.79%	31.03%	24.14%	27.59%	3.45%
People in leadership encourage more women to participate in the decision making process.	10.34%	24.14%	31.03%	34.48%	0.00%
My opinions, ideas, and suggestions are genuinely considered.	20.69%	41.38%	31.03%	6.90%	0.00%
My company's leadership listens to women the same as they listen to men?	20.69%	27.59%	27.59%	24.14%	0.00%
I feel respected and valued as much as my male counterparts.	24.14%	27.59%	20.69%	27.59%	0.00%
At my company, men and women are paid equally for the same work?	20.69%	34.48%	24.14%	13.79%	6.90%

Respondents were further probed on these matters to include issues of discrimination, unwanted attention and growth opportunities. Some key findings related to this issues are:

- Only 30% of the respondents disagreed that they were discriminated against due to their gender
- Only 35% of the respondents mentioned they hear inappropriate comments from customers and clients
- 32% of the respondents did not agree that they had mentors within their company
- 25% of the respondents did not agree that they had an opportunity to advance within their company
- Only 47% of the respondents thought that women had good opportunities in the construction industry

Once again this data paints a bleak picture for women to advance in the construction industry. It appears that to incorporate more women to enter the construction industry, perceptions of women already in the construction industry must change. This preliminary data suggests that much remains to be done to encourage more female participation in the construction industry.

In an effort to validate the internal consistency of the survey instrument, respondents were asked a few questions where the possible answers were 'Yes', 'No' and 'Uncertain'. Respondents were allowed to provide verbal answers to qualify their response. The results from this data presented in Table 3 correspond to the findings presented in Tables 1 and 2. Key findings from this data indicates:

- Only 32% of the women disagreed that they were given different jobs compared to men
- Only 29% of the women disagreed they have had a negative experience in the construction industry due to their gender
- Only 32% of the participants felt that they were not disadvantaged in the construction industry due to their gender
- Only 29% of the female participants agreed that they feel that they are treated the same as men at work

Table 2. Opinions of female workers in construction industry about treatment and opportunity

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
During my career in construction, I have been discriminated against because of my gender	20.69%	31.03%	20.69%	24.14%	3.45%

I have received inappropriate comments or unwanted attention from customers or clients.	17.24%	37.93%	10.34%	27.59%	6.90%
I have access to mentors in the industry or in my company.	21.43%	46.43%	17.86%	7.14%	7.14%
I have the opportunity to advance in my company.	25.00%	50.00%	7.14%	14.29%	3.57%
There are good opportunities for women in construction.	10.71%	35.71%	46.43%	3.57%	3.57%

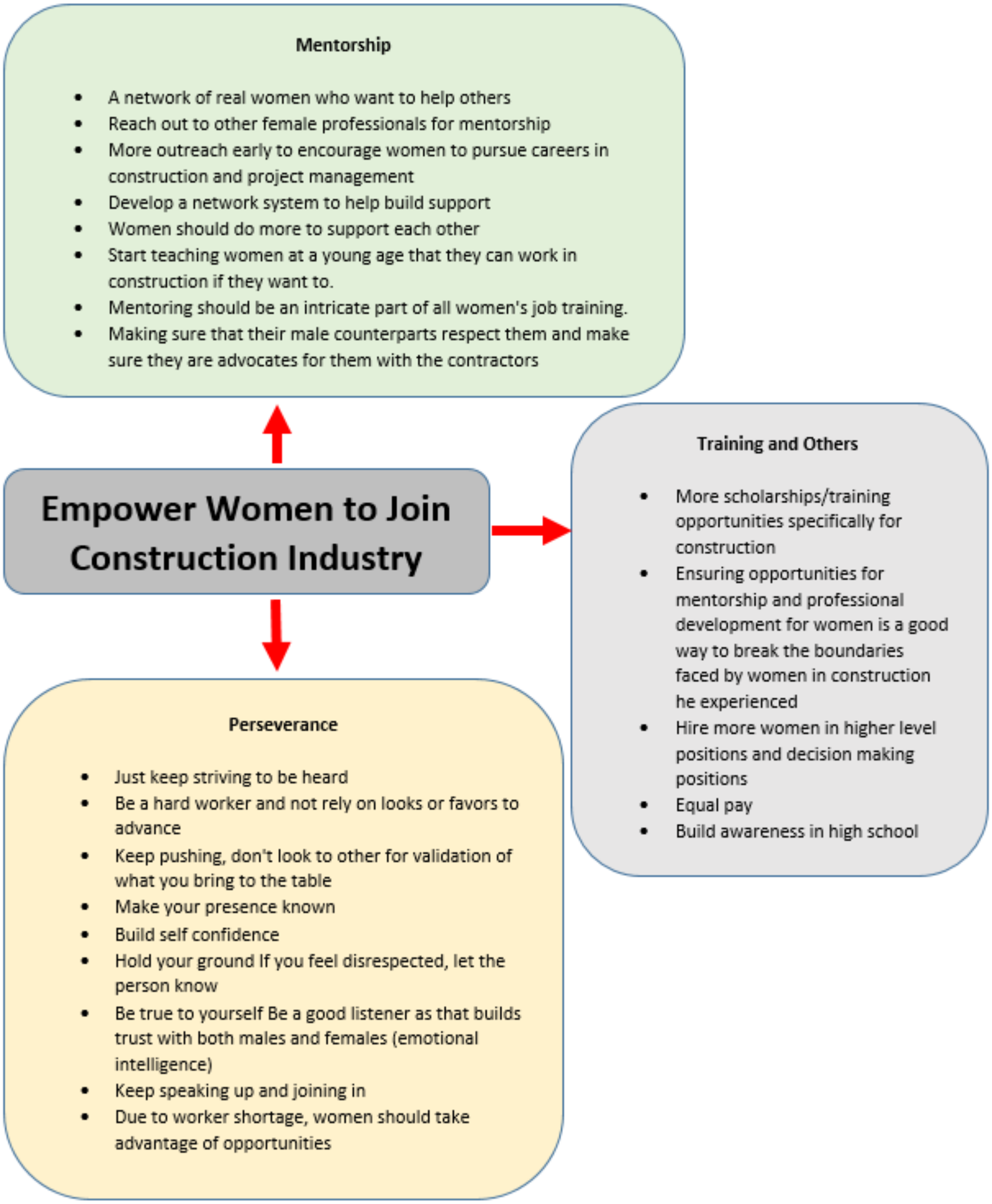
The results shown in Table 3 once again point to a significant level of dissatisfaction of working in the construction industry. These descriptive statistics are similar to those presented in Table 1 and Table 2 indicating that more needs to be done to make women feel included and appreciated within the construction industry.

Table 3. Opinions of female workers in construction industry about treatment and opportunity

	Yes	No	Uncertain
Are you sometimes given different jobs or tasks to do, compared with the men you work with?	53.57%	32.14%	14.29%
Have you ever had any negative experiences being a woman working in the construction industry?	57.14%	28.57%	14.29%
Have you ever felt disadvantaged in the construction industry because of your gender?	50.00%	32.14%	17.86%
Do you feel you are treated the same as men at work?	28.57%	46.43%	25.00%

3.2 Qualitative Results

Finally, respondents were asked about how more women can be empowered to participate in the construction industry. This question required the participants to provide a verbal answer so that they may offer some overarching thoughts about the topic. The results were analyzed using thematic analysis techniques and are presented in Figure 1. The main themes that emerged were grouped under 'Mentorship', 'Perseverance' and 'Training and Others'. Responses indicate that participants encouraged female professionals in the industry to mentor junior members as they enter. Respondents suggested that women should build a professional network to help build a support system and to be advocates for each, as evidenced by the comment *"One of the greatest ways for women in the construction industry to be empowered is for other women to empower them"*. Another issues mentioned was how the construction industry was inherently male focused and that issues pertaining to women must be considered, as evidence by the comment *"Jobsites are set up generally with men in mind; more thought to what women need would be good"*. Participants also encouraged women to persevere in the industry despite the obstacles as evidenced the comment *"Ignore the stigma people may have related to women in construction and keep moving forward. The more women enter the construction industry the lower the stigma will become"*. Participants encouraged women to take personal responsibility despite obstacles to grow within the construction industry. Participants also mentioned that women should be provided with more scholarship and training opportunities to advance within the industry. They also recommended the companies should do more to hire more women in higher positions to serve as role-models to others. It was also brought up that women are not advancing as fast as they could be, as evidenced by the comment *"Allowing higher graded positions to be readily available. We are losing many great people because they are topping out at a flat ceiling of advancement"*.



4. Conclusions and Recommendations

This research sought to gather the opinions of women working in the construction industry with the intention of increasing numbers of women working in the industry. Results from the online survey indicate that there is significant amount of dissatisfaction in the female workforce regarding current working conditions. The results from the survey conducted has 31 respondents from the 73 respondents invited to participate. The authors acknowledge that these results are preliminary and that further efforts will be made to include opinions from a wider audience of female construction professionals. The preliminary results, however, indicate that nearly 50% of the respondents felt that they were treated differently than men, more than 50% have been made to feel uncomfortable at some point in their careers and more than 50% of them felt disadvantaged working in the industry due to their gender. This paints a dark picture for women in the industry and shows that in order to bring more women in to construction, we have to improve the perception of women already working in the industry. Participants did have several suggestions to increase the number of women to enter the construction industry. These suggestions included thoughts such as female professionals mentoring women entering the construction industry, providing more training opportunities for women, recruiting more women to decision making roles to serve as role-models for women entering the industry and females entering the industry to persevere and continue on the path forward.

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Fatalities and their Root Causes in Pakistani Construction Industry

Mustafa Shabbir[1], Rizwan U. Farooqui[1], Muhammad Saqib[1]

[1] NED University of Engineering & Technology, Karachi, Pakistan
mustafa.shabbir126@gmail.com

Abstract

The Pakistani Construction industry is known to be second hazardous industry after our agriculture industry; reputed highly for its peculiar high rate of injuries, fatalities and deaths on construction sites. ILO (International Labor Office) report such incidences and identifies the type of accidents and their impact on the Labor Safety policies as it estimates 25-40% of occupational fatalities (rounding upto 60,000 fatalities occur on construction sites in industrialized countries which takes place each year throughout the world (ILO, 2005). Similarly, a questionnaire survey was conducted to determine the multiple accidents occurring at construction sites where the data was collected from multiple stakeholders. This research identified multiple occupational accidents like burning, structural failures, falling from height, struck by heavy objects, electrocution from faulty tools and many more; occurring on construction sites with high impact within the Pakistan Construction industry.

Keywords

Fatalities, Root Causes, Labor Safety Policies, occupational hazards, high impact, Pakistan Construction industry.

1. Introduction

The importance of construction industry has been acknowledged by various studies as it plays an imperative part in affecting the financial advancement of any nation. However, it cannot be denied that this industry also one of the perilous business due to its high rate of fatalities, wounds, laborers pay expense and loss of work hours (Amjad, 2005; ADB-WB, 2005). This industry recorded most elevated mishaps on the planet when contrasted with other work escalated commercial ventures (Amjad, 2007). The laborers of this industry are presented to perils as there are various variables like getting slip, trip, struck by/ against heavy items, tumble from stature and electrical perils etc. which are well-known sorts of mishaps occurring at construction site (Amjad., 2007; ADB-WB, 2005), which are very hard to evaluate for various reasons nearly connected with the way development exercises are performed. That is the reason the accidents/ mishaps information is not at all recorded in multiple developing nations including Pakistan (PBC, 2007; PBC 1989).

The developing nations like Pakistan have yet to react to late mechanical enhancements (Yuan et al., 2018; Zou et al., 2010; Hameed, 2007; Kartam, 2001). The absence of reaction to innovation, on the other hand, has failed to bring any secure development destinations where a bigger offer of development work being performed by HR had prompted increased the amount of site mishaps (Yuan et al., 2018; Zou et al., 2010; Ebrat and Ghodsi, 2011). In Pakistan, around 6 to 7% work is straightforwardly appended with the development business (ADB-WB, 2005). Casual appraisals have recognized a couple of significant explanations behind security non-execution which include absence of improvement of development division fit as a fiddle industrialization (Ebrat and Ghodsi, 2011; Kartam, 2001), absence of expert development administration rehearses which has prompted risky task locales as well as brought about development deferrals (Yuan et al., 2018; Zou et al., 2010), expense invades (Yuan et al., 2018; Zou et al., 2010), poor profit (Hameed, 2007) and poor item and procedure quality (Hameed, 2007), deficient wellbeing procurements laid by the current administrative environment which has neglected to secure wellbeing as a real industry objective (Amjad., 2007), lacking and impetus less protection systems (Amjad, 2007; Amjad 2005) which have neglected to build security as a business survival issue and unfavorable business environment which has prompted ill-disposed business connections among partners bringing about debates, clashes, cases and prosecution and henceforth occupying the concentrate far from issues like security (Farooqui et al., 2008).

Work environment security is considered a complex phenomenon and the subject of mind and wellbeing execution in the development business is considerably far more perplexing (Farooqui et al., 2008). The specialists of this industry are not only ones who experience the ill effects of a mishap (Sana, 2012), however, specifically or by implication the business, builder and general society by and large likewise endures (Sana, 2012). The monetary impacts of a mishap can be crushing, aside from human expense of misery. Mishaps at work spot happens either because of absence of information, or an absence of supervision, or an absence of intends to do the errand securely, or on the other hand, because of a slip of judgment, indiscretion, or aloofness (Sana, 2012). Studies have demonstrated that dangers can be controlled and mishaps can be anticipated through the execution of fundamental security works on prompting a sound wellbeing system (Yuan et al., 2018). Numerous development organizations as far and wide as possible are executing wellbeing and natural administration framework to decrease wounds, take out disease, and to give a safe workplace in their development locales.

Similarly, this research has been focused on accidents occurring since year 2000 A.D in the high-rise buildings and commercial projects which identify the occupational hazards in the industry along with their safety practices followed by the industry as the remedial measures taken to solve these problems.

2. Survey and Data Analysis

Consequently, a questionnaire survey was conducted comprising of multiple questions regarding major fatalities and their occurrence on construction site. Thus, this questionnaire was distributed among 75 experts out of whom 56 responded as shown in Table 1, which as a result, the rate of response is 74.67 percent. The types of project focused were mostly commercial and industrial, whereas the types of respondents were mostly Project Managers and Project Engineers. The Data was collected through ongoing/ completed construction projects in Karachi like Clifton Dolmen Mall, Ocean Tower Mall, Lucky One Mall, Opal Tower (Bahria Town), Telenor Greenfield (MSC), Crescent Bay (D.H.A Phase VIII), Aman IBA – CED, Lakhany Presidency-II, Residential Units (Shah Faisal Colony), Aisha Steel Mills, Afroze Textile Mill, Floating Jetty (Boat Basin), N.M.B Wharf (Keemari), Fixed Jetty (Keemari) and LPG Plant Installation (Karachi-Hyderabad Motorway).

Table 1. No. of Respondents and their Corresponding Experience

Experience	No. of Respondents
0 – 10 years	23
10 – 20 years	21
More than 20 years	12

The multiple fatalities were identified through questionnaire survey as shown in Table 2 which indicates their importance index/ intensity along with their number of occurrences; these mishaps have been observed on construction sites. Based on their importance index and number of occurrences, an average rating of these mishaps was calculated based on which a ranking was formed of each individual mishap occurred on construction site.

Table 2. No. of Accidents/ Mishaps Occurring on-site and their Importance Index

Accidents/ Mishaps	Importance Index	No. of Occurrences on-site	Rating	Ranking
Burning	3.59	4.0	3.7	Rank 8
Caught Between heavy Objects	3.64	3.32	3.2	Rank 12
Crush Injuries	3.27	3.36	3.8	Rank 7
Electrocution	3.32	3.73	3.6	Rank 9
Eye Injuries	4.0	4.14	4.1	Rank 4
Fall from Height	3.09	3.36	3.1	Rank 14
Fall of Heavy Substance from Height	3.09	3.41	3.5	Rank 11
Struck Against Objects	4.0	4.14	4.2	Rank 3
Structure Failure	4.95	3.80	4.5	Rank 1
Sunstroke or Dehydration	3.04	3.95	3.8	Rank 6
Transportation	4.04	4.14	3.2	Rank 13
Unsafe Site Conditions	3.73	4.09	4.0	Rank 5
Wild Animal Attack	4.0	3.95	4.4	Rank 2

Extensive Work Load	4.13	4.04	3.0	Rank 15
Others (Minor Unexpected Accidents)	1.84	1.84	3.5	Rank 10

The easy explanation of the ranking of the above shown accidents/ mishaps occurring on construction sites has been better shown through Figure 1 as shown below.

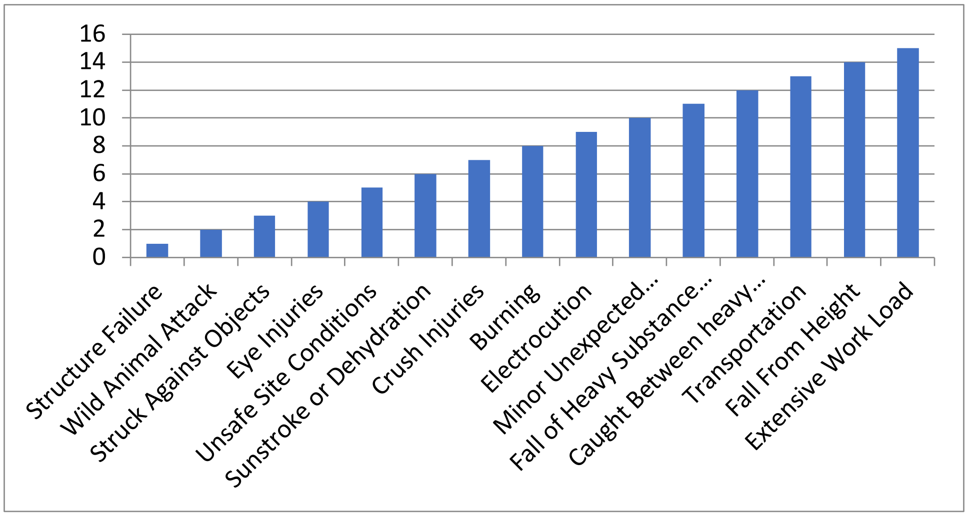

Fig 1. Ranking of Accidents Observed on Construction Site

The Figure 1 shows that the more ranking goes higher, the more chances/ intensity of the accidents occurring is considered low. For example: mostly labors fell unconscious due to extensive workload during working hours in in scorching heat, however it does not necessarily mean that the life of the labor is in danger. However, if a certain part of a structure fails or if a wild animal attacks then the life of the particular labor or laborers is in highly danger. Thus, such incidents that may occur maybe once or twice in the entire duration of the project but its extreme high intensity of danger to a labor's life make these accidents/mishaps ranked above and higher than other such incidences like electrocution and crush injuries which are observed at regular basis on construction sites.

Similarly, the Table 3 identifies the reliability of data acquired by measuring multiple central tendencies. These accidents/ mishaps were evaluated to determine the correlation between each mishap which may affect the safety of the laborers and the probability of how much it may endanger their life.

Table 3. Summary of Importance Index, No. of Occurrences and its Average Rating for the No. of Accidents/ Mishaps Occurring on Site

Accidents/ Mishaps	Importance Index	No. of Occurrences on-site
Mean	2.024	2.219
Standard Error	0.158	0.159
Median	2.14	2.45
Mode	2.5	2.64
Standard Deviation	0.612	0.618
Sample Variance	0.374	0.383
Kurtosis	2.998	5.823
Skewness	-1.513	-2.174
Range	2.29	2.48
Minimum	0.34	0.34
Maximum	2.63	2.82
Sum	30.37	33.29
Count	56	56
Multiple R	0.89	0.29

R Square	0.79	0.084
Adjusted R Square	0.78	0.013
Standard Error	0.29	0.46

The multiple fatalities which were identified through questionnaire survey were presented towards respondents in hope that whether they agree if any of the following accidents/ mishaps have occurred on their respective construction sites as shown in Table 4.

Table 4. Respondents Agreement and Disagreement on Accidents Occurring at their Respective Construction Sites

Accidents/ Mishaps	Yes	No
Burning	34	22
Caught Between heavy Objects	46	10
Crush Injuries	45	11
Electrocution	47	09
Eye Injuries	36	20
Fall from Height	46	10
Fall of Heavy Substance from Height	47	09
Struck Against Objects	34	22
Structure Failure	01	55
Sunstroke or Dehydration	31	25
Transportation	31	25
Unsafe Site Conditions	36	20
Wild Animal Attack	22	34
Extensive Work Load	31	25
Others (Minor Unexpected Accidents)	51	5

As observed from above Table 4, the Minor unexpected accidents on site can be seen on regular basis while also including the falling of heavy objects from height or crush injuries or electrocution which indicates that Labors are getting hurt regularly as fatalities can be observed from the above data. Consequently, the laborers are the walking targets to almost all types of mishaps waiting to transpire during any certain construction activity putting a minor setback in the overall progress of work.

Although, the Structure Failure is considered the most critical factor of the accidents occurring on construction site, almost all project managers and engineers shows reluctance in admitting that their projects may have faced any structural failure on their respective projects whether it concerns to a major structure like column and beams or some minor structure like shear walls of an exterior elevator.

3. Conclusions and Discussion

The results show that the lack of Interest by Project Managers and Engineers is the root cause of the occupational accidents in the Pakistan Construction Industry as their prime concern as professionals has become the sole purpose to achieve the required building as per the client's desired schedule while maintaining the finance budget. Thus, their focus towards the human factor can be observed to be quiet low, which may in result affect the overall safety and performance of the construction industry.

Thus, there is a strong need in the industry to reduce the rate of occupational accidents observed through this study, which can be achieved by multiple methods like having Laborers Insurance Policies to cover for their medical expenses with a security that the laborers can execute their work more productively with in mind that any accidents occurred on construction site shall be covered by their respective contracting firms. However, such practices can be observed are very low as the labors rights are forfeited in the fast development of the project, thus, the matter falls in the hands the regulatory government bodies and institutions to legalized and enforce such policies to be implemented at all organizational levels specially for lower work-class laborers. This can only be achieved if these controlling regulatory offices are ought to be given the power to impose punishments in case of non-compliance (Fang et al., 2003)

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Identification of Major Risk Events for Construction Industry

Syed Muhammad Yasir Ashrafi[1], Rizwan U. Farooqui[1], Rana Rabnawaz Ahmed[1], Muhammad Saqib[1]

[1]NED University of Engineering and Technology, Karachi, Pakistan
yasir.ashrafi50@gmail.com

Abstract
The construction industry is subjected to more risk than many other industries. One of the major parameters in every aspect of the project management life cycle is cost, and can be termed as one of the key variable of a project and have major impact on project success. Construction projects having many risk events that leads project to cost overruns. This study focused towards the identification and assessment of major risk events, causing overrun in construction projects of Pakistani construction industry. Study conducted with the identification of risk events by the literature review,156 risk events were identified by the literature after through questionnaire surveys and some statistical techniques, 156 risk events were shortlisted to 40 and were denoted as major risk events. Project cost overruns was also found out with the help of questionnaire surveys. Assessment of the events was done on the basis of risk score that is product of probability and impact.

Keywords
Construction Industry, Cost Overrun, Risk, Major Risk Events.

1. Introduction

Construction is a highly risk oriented industry with a low reputation for dealing with risks. Risk in the construction is unavoidable because of the complex dynamic environment (Sharma & Gupta, 2019). Risk management is a comprehensive way response on any risk starting with identification (Sarvari et al., 2019). There is a gap in identification of risk event in construction industry (Nabawy et al., 2021). In Pakistan construction industry, it is common to see a construction project not being successful in achieving its goals of completion within the estimated cost. It has been found out that every other project in this industry have overruns in terms of cost. As construction projects are unique, similarly the risks in every other project are also unique (Sarvari et al., 2019). The Risk identification can also be termed as one of the key factor of project success (Simanjuntak & Suryaningrum, 2020). Construction projects are always exposed to many risk factors, they can internal risk or external risks (Soliman, 2018). Construction industry has become one the most unsafe industry because of its dynamic and complex environment and high probability of risk involvement (Tsoukalis & Chassiakos, 2019). Construction industry has much risk but the dealing with those risks was not up to the mark. The art of encountering and mitigating these risks has not been ideal with respect to construction industry and thus provides way for large-scale failures such as uncertain project completion delays, operational and quality requirements abiding failures, and cost over runs (Hameed & Woo, 2007). Azhar et al. (2008), within Pakistan, the construction sector though not being utilized to its full capacity is still a major constituent of the country's economy and plays a major part in its sustained development. It can be seen that many contractors, however, have compiled a series of yardsticks that they apply when they have to deal with risk. These yardsticks generally rely on their experience and judgmental power. Cost limitations if not fulfilled and until otherwise, a project can't be considered completely successful (Elhag et al., 2005). In order to know the cost overruns caused by the particular risk events. This study focused on to the identification of risk events through the literature review. After the identification, 2 questionnaire surveys were performed in the construction industry and to get the consensus of construction industry experts on these events on the basis of frequency (likelihood of events) and impact (consequences of events).

2. Settings or Methods or Materials and Methods

The methodology of this study was divided into three different phases. Phase-I is about identification of the risk events and Phase-II is about the prioritization of the events and Phase-II is about the prioritization of the events and Phase-III is about the assessment of the events.

2.1 Phase-I

In Phase-I an extensive literature was studied in order to identify the risk events related to construction industry. Phase 1 started with extensive literature review that covered all aspects of projects including risk management. The research material includes different journal papers, conference papers, review papers, MS and PhD thesis. Study was more focused towards different identification of risk factors and risk management techniques Different risk events under category of Environmental, Site Location, Labor, Equipment, Owner, Design, Consultant, Contractor, Management, Financial, Political, Schedule, External, Organizational and Legal risks were identified as it can be seen in Table 1. A questionnaire survey was also conducted with local construction industry experts having minimum of 10 years' experience in order to identify risk events related to local construction industry. So with the help of literature and the survey, a total of 156 risk events were identified and on the basis of these risks Questionnaire 1.0 was made. After that, Questionnaire 1.0 was distributed among the industry experts for the identification of risk events related to the construction industry of Pakistan. The Questionnaire that was used had two parts namely. Part A "Respondent's Information" and Part B "Risk Events Detail". Part A comprises personal information of expert i.e. name, e-mail address, contact number, present position in company, work experience, years in this organization, highest qualification etc. While the part B comprises an extensive list of 156 risk events obtained through detailed literature review. The rating scale of this survey was divided into three characterizations, these are (YES), (NO) and (MAY BE). If a respondent feels it is important then he will mark the particular event as (YES). If he feels it is not important, then he mark it as (NO), and if the respondent is not sure about it then he marked it as (MAY BE). The "mode" technique was used in order to see repetitive values for each risk event and to assign that value to that particular even. The events having (YES) and (MAY BE) were considered for the next phase.

Table 45. No. of Risk Events in Phase-I

S No.	Risk Category	Numbers of Events
		Phase-I
1	Environmental	05
2	Site Location	05
3	Labor	06
4	Equipment	10
5	Owner	12
6	Design	09
7	Consultant	09
8	Contractor	15
9	Management	20
10	Financial	15
11	Political	06
12	Schedule	03
13	External	19
14	Organizational	12
15	Legal	10
TOTAL		**156**

2.2 Phase-II

In Phase-II of the study another questionnaire interview was performed assisted by Delphi technique with industry experts having minimum 15 years' experience in construction industry. The purpose of this interview was to assess the events on the basis of their risk scores. The questionnaire of this survey had two parts same as the questionnaire 1, but the number of events for this questionnaire were 78 under category which can be seen in Table 2.

The rating scale is also changed now. It is now in the form of risk matrix in which probability and impact values. The values for probability are in between 1 to 3 and for impact it is same. The individual marked the value of probability and impact against each risk events. Risk score was calculated against each risk event by multiplying the value of probability and impact. On the basis of risk score the risk events were categorized into major and minor risk events. If a risk event has got a value of 6 to 9 then it is said to be a major event and if an event has a value of less than 6 then it said to be minor events. The risk matrix can be seen in Table 3.

Table 46. No. of Risk Events in Phase-II

S No.	Risk Category	Numbers of Events
		Phase-II
1	Environmental	01
2	Site Location	03
3	Labor	04
4	Equipment	06
5	Owner	06
6	Design	05
7	Consultant	03
8	Contractor	10
9	Management	07
10	Financial	06
11	Political	03
12	Schedule	03
13	External	06
14	Organizational	08
15	Legal	07
TOTAL		**78**

Table 47. Risk Matrix

	IMPACT →		
FREQUENCY ↓	1(LOW)	2(MODERATE)	3(HIGH)
1(LOW)	(1) LOW-LOW	(2) LOW-MOD	(3) LOW-HIGH
2(MODERATE)	(2) MOD-LOW	(4) MOD-MOD	(6) MOD-HIGH
3(HIGH)	(3) HIGH-LOW	(6) HIGH-MOD	(9) HIGH-HIGH

2.3 Phase-III

Phase-III of the study is also done with the help of questionnaire survey. This questionnaire has three parts. The first part is respondent and the project details. In respondents details it is same as the previous ones but in the project details things were asked are actual cost of the project, estimated cost of the project, start date and finish date of the project and type of project. Second part that is risk event detail has changes now. There are 40 risk events in this questionnaire under suitable category that can be seen in Table 4. The rating scale for this questionnaire was also dependent of probability and impact, but the values of probability are from 1 to 5 and for the impact it from 1 to 10 which can be seen in Table 5. After the third survey, risk score was calculated against each risk event and after that. In this survey cost overrun was also asked from respondents in order to see how many projects have cost overruns by these risk events.

3. Results

3. 1 Results of Phase-I

As it was discussed in the identification part 156 risk events were identified and categorized into 15 different risk categories and from them Questionnaire 1 was made and distributed among construction industry experts this questionnaire was sent to 20 construction industry experts having minimum 10 years of experience and from 20, 15 gave response, which yields a response rate of 75 %. After the Phase-i of the study the number of events were shortlisted to 78.

3. 2 Results of Phase-II

Same strategy followed by Phase-II in which 78 events were present in Questionnaire 2 Delphi technique was also used in this Phase. The total number of experts approached were 30having minimum of 20 years' experience in construction industry and from them 25 gave response, which yields a response rate of 83.33 %. Risk score was calculated by multiplication of Probability and impact given by each respondent against each risk events which can be seen in Graphical form in Figure 1, in which it can be seen 40 risk events were scoring 6 or more than 6 and were considered as major risk events.

Table 48. No. of Risk Events in Phase-III

S No.	Risk Category	Numbers of Events Phase-III
1	Environmental	00
2	Site Location	01
3	Labor	01
4	Equipment	01
5	Owner	01
6	Design	02
7	Consultant	03
8	Contractor	07
9	Management	04
10	Financial	03
11	Political	02
12	Schedule	03
13	External	04
14	Organizational	03
15	Legal	05
TOTAL		**40**

Table 49. Risk Matrix for Phase-III

RISK MATRIX		**Potential Impact on Cost**									
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Chances of Occurrence	**1**	1	2	3	4	5	6	7	8	9	10
	2	2	4	6	8	10	12	14	16	18	20
	3	3	6	9	12	15	18	21	24	27	30
	4	4	8	12	16	20	24	28	32	36	40
	5	5	10	15	20	25	30	35	40	45	50

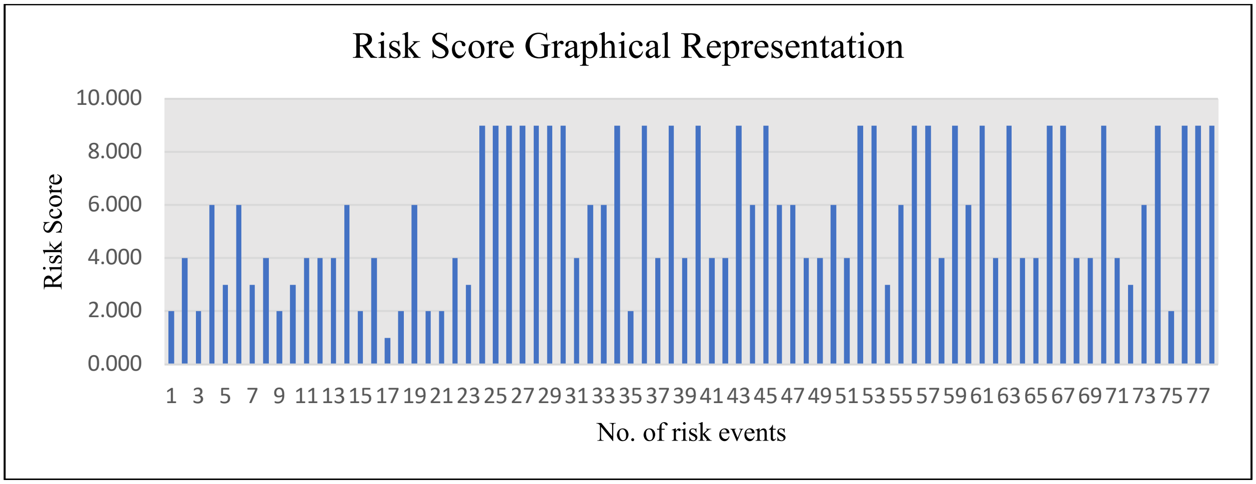

Fig 52. Risk Score in Phase-II

3. 3 Results of Phase-III

In phase-III of this study the questionnaire was sent to 150 construction industry experts and in which 101 were respond, which yields a response rate of 67.67 %. Some other things were also asked in Phase-III of the study including the experience, designations Pakistan Engineering Council (PEC) category, type of client whether public or client, type of project which include infrastructure, residential, commercial, educational and industrial. Starting with the experience. Respondents were approached to give their involvement with the organization ranging from under 5 years to over 30 years. Since for assessing the implications of risk events on project cost performance a genuine perceptive from experienced personals in local construction industry were required. Table 6 shows their percentage distribution.

Table 50. Percentage Distribution of Experience of Respondents

Experience of Respondents (Yrs.)	No. of Respondents	Percentage (%)
Less than 5	31	29.52%
5-10	24	23.76%
11-20	18	17.82%
NA	28	27.72%

3.3.1 DESIGNATION OF THE RESPONDENTS

The working background of the respondents is very influential shown by the information, got from the survey. Therefore, present positions of the respondents were required. In this survey, the targeted respondents were project-based peoples like planning engineer, chief engineer, project managers, project engineers, chief executive officer, executive engineer, owner representative and site engineer as shown in Table 7.

3.3.2 PEC CLASSIFICATION/ CATEGORY

PEC affiliation of the firm inclusion really helps in collecting sound data from the firms. There are seven different categories of firms responded in this study with their percentage distribution as shown in Table 8. However, 39.60 % respondents did not mention their PEC Category of firms.

3.3.3 TYPE OF CLIENT

To show whether the project was publicly or privately owned, the respondents were required to provide the information. Most of the projects were privately owned with percentage of 53.47 % and remaining were public projects as shown in Table 9.

3.3.4 TYPE OF PROJECTS

It was necessary to mention the type of the building project in the Questionnaire survey. The most common categories involved residential buildings, educational buildings, commercial buildings and industrial buildings as shown in Table 10.

3.3.5 CLASSIFICATION BASED ON AREA

The respondents were required to give the location of the project. the details are shown in Table 11.

Table 51. Designations of the Respondents

Present Position of Respondents	No. of Respondents	Percentage (%)
Project Manager	8	7.92
Project Engineer	17	16.83
Planning Engineer	6	5.94
Executive Engineer	6	5.94
Site Engineer	14	13.86
Chief Engineer	4	3.96
Owner Representative	6	5.94
Chief Executive Officer	6	5.94
NA	34	33.66

Table 52. PEC Classification / Category

PEC Classification / Category	No. of Experts	Percentages (%)
CA	4	3.96
C1	8	7.92
C2	5	4.95
C3	14	13.86
C4	29	28.71
CB	1	0.99
NA	40	39.60

Table 53. Type of Clients

Type of Clients	No. of Projects	Percentage (%)
Private	54	53.47
Public	47	46.53

Table 54. Type of Projects

Type of Projects	No. of Projects	Percentage (%)
Residential	34	33.66
Educational	15	14.85
Commercial	22	21.78
Industrial	6	5.94
Infrastructure	24	23.76

Table 55. Project Location

Province	No. of Projects	Percentage (%)
Sindh	46	45.54
KPK	24	23.76

Punjab	8	7.92
Balochistan	12	11.88
Islamabad	9	8.91
NA	2	1.98

3.3.6 PROJECT COST OVERRUN

The actual and estimated cost for each project was asked in order to calculate the real cost overrun occurred on these projects. In order to categorize the projects in terms of how much cost overrun actually occurred, projects were split into two ranges of overrun. One with a range of 0-25 million and another with a range of 26-50 million overruns as shown in Table 12.

Table 56. Project Cost Overrun

Project Cost Overrun (millions)	No. of Projects	Percentage (%)
0-25	80	79
26-50	21	21

Figure 2 shows the graphical representation of the cost overrun percentages which were got as the result of questionnaire 3 survey. The minimum value of cost overrun percentage was (0%) while the maximum was (66.67%).

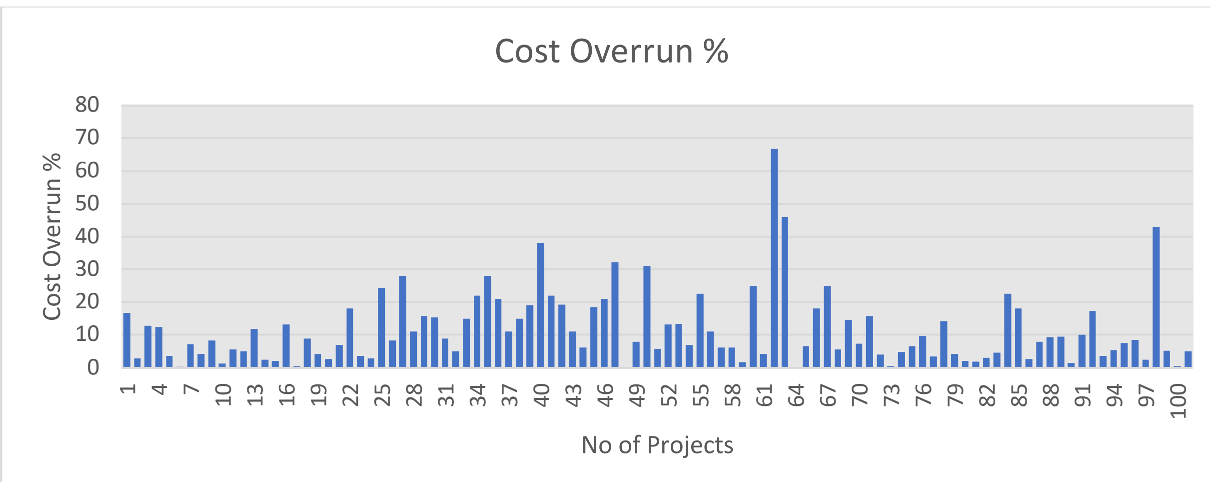

Fig 53. Cost Overrun %

Below Table 13 shows all the shortlisting of risk events in combine form. Initially the events were 156 in Phase-I, in Phase-II they were 78 and in last Phase of the study which is Phase-II they were shortlisted to 40 which were also denoted as major risk events of the construction industry.

4. Discussion

Identification of major risk events for construction has great importance because neglecting the risk events caused many failures in terms of cost time and quality. Similar studies have been conducted in the including Kartam & Kartam (2001) in which they considered 26 major risk events for the Kuwait construction industry. It was depicted by Zou et al. (2007) in which he identified 85 risk factors for the construction industry of china, out of which 10 were selected as major risk factors. Yuan et al., (2018) identified 16 risk events in for construction industry. Following these same strategies followed in this study in which it was started with the identification of risk events for construction industry after that prioritization of those events were performed with the help of questionnaire surveys meanwhile shortlisting of the risk events were also ongoing and at the end 156 risk events were shortlisted to 40 and were considered as major risk events for Pakistani construction industry.

Table 57. Combined Result of All Surveys

S No.	Risk Category	Numbers of Events	Numbers of Events	Numbers of Events
		Phase-I	**Phase-II**	**Final**
1	Environmental	05	01	00
2	Site Location	05	03	01
3	Labor	06	04	01
4	Equipment	10	06	01
5	Owner	12	06	01
6	Design	09	05	02
7	Consultant	09	03	03
8	Contractor	15	10	07
9	Management	20	07	04
10	Financial	15	06	03
11	Political	06	03	02
12	Schedule	03	03	03
13	External	19	06	04
14	Organizational	12	08	03
15	Legal	10	07	05
TOTAL		**156**	**78**	**40**

5. Conclusions

From the above survey and their results, it can be concluded that most of the risk events were belonged to management initially followed by contractor at second place, but after the final survey it can be seen that the maximum number of major risk events were belong to contractors. It can also be seen that environmental related risk events were the only category which has some risk events initially but at the end no major risk events were belong to that side.

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An Empirical Assessment of Decision Making in the Public Procurement Lifecycle

Rizwan U. Farooqui[1], Muhammad Umer[1], Muhammad Saqib[1], and Farhan Saleem[1]

[1] NED University of Engineering & Technology, Karachi, Pakistan
msaqibm@neduet.edu.pk

Abstract
Public procurement is generally an important sector of the economy and, in most countries, is controlled by the introduction of regulatory and policy mechanisms, National law in most countries regulates public procurement more or less closely in an attempt to prevent fraud, waste. The economic progress in the region, to be sustained, depends upon continuing improvements in public governance. One important hallmark of a high standard of public governance is a well-developed and efficient system of government procurement, which provides value for money. Though initially considered a clerical activity, public procurement has become one of the most important functions of the government for the following reasons. First, as the size and activities of the governments have increased in the last fifty years, the procurement outlays have also burgeoned, making them a substantial part of the annual budgets. The Bank is preparing the Sindh Public Sector reforms project. The project focuses on public financial management, procurement, and property tax. Various institutional reviews have identified that there is no data to substantiate the procurement performance of the various implementing agencies. While SPPRA is in the process of setting up the performance benchmarks and developing a monitoring and evaluation system, but currently there is no such data available. The findings are expected to aid in determining the root causes of underperformance of the procurement practices in Sindh, Pakistan.

Keywords
Public Procurement, SPPRA, Procurement Timeline, Probabilistic Analysis

1. Introduction

In recent years most of the countries of Asia have experienced noticeable economic growth, although its extent and impact on living standards have varied across the region, serious weaknesses have persisted in the area of public procurement. These include fragmented procurement procedures; the lack of professional procurement expertise etc. (Jones, 2007).

Public procurement is generally an important sector of the economy and, in most countries, is controlled by the introduction of regulatory and policy mechanisms, National law in most countries regulates public procurement more or less closely in an attempt to prevent fraud, waste, etc. (Kastanioti et.al, 2013). Laws, rules, and regulations are that are existent require overall overhauling to bring them at par with the current needs and challenges, besides the capacity of public procurement practitioners is weak (CPDI, 2011). The national budget for Public procurement expenditure is about 45-65% (Khan, 2020). The economic progress in the region, to be sustained, depends upon continuing improvements in public governance. One important hallmark of a high standard of public governance is a well-developed and efficient system of government procurement, which provides value for money. A legal procurement system that ensures transparency creates an enabling environment for competition (Benchmarking Public Procurement, 2017). Yet over the years, serious weaknesses have persisted in procurement practices in the countries in the region (Jones, 2007). According to International Governance Solutions (2014), poor procurement policies can impact developmental pace which ultimately impacts on foreign investments (International Governance Solutions, 2014).

2. Scope

The scope of the study is to identify the procurement practices existing in specific departments of the Government of Sindh (GoS), namely Irrigation, Agriculture, Works & Services, and Education. There are generally three categories of inputs that governments acquire for their smooth functioning through one of these departments. The inputs include civil works e.g. bridges, buildings, highways, etc., goods-typically equipment, material and supplies, commodities, textbooks, medical supplies, and services which cover expert advice and training, technical assistance as well as such things as building maintenance, janitorial services, security services, and computer programming, etc. Also, to prepare a set of recommendations that can help to improve the procurement practices in identified departments. The study is conducted through intense surveys and interviewing exercises through face-to-face meetings.

3. Objectives

Keeping in view the theme for the current paper writing contest organized by the prestigious Institution of Engineers Pakistan (IEP), this study is intended to find its due place within the overarching theme of, 'quantification of losses due to delayed decision making in public sector projects. The study takes an analytical look at the impact of decision-making w.r.t procurement lifecycle of various procurements at selected GoS departments. The study undertakes a probabilistic approach to simulate the impact of delayed decisions on the completion of representative steps of public procurement methodology as prescribed by Sindh Public Procurement Regulatory Authority (SPPRA). Specifically, the proposed study is undertaken with the following objectives.

i. To study procurement outlays of the last three years of selected departments including break down of procurements by goods, works and consultancies, and mode of bidding (ICBs, NCBs, etc).
ii. To analyze procurement cycle time of the sample projects w.r.t SPPRA procurement methodology.

4. Methodology

The project methodology is depicted in Figure 1.

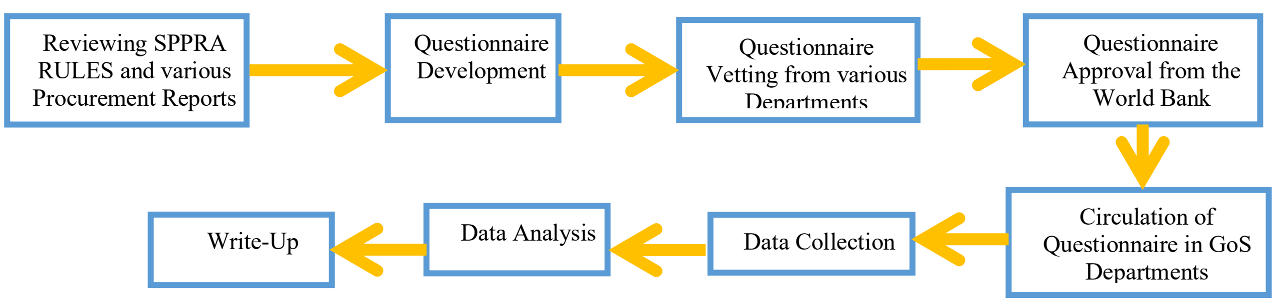

Fig 1. Study Methodology

4.1 Questionnaire Development, Pilot Survey, and Approval

A review of SPPRA Rules is done first. This is followed by a review of international studies conducted on procurement, such as those by the World Bank and ADB. Then a questionnaire is developed keeping in view the local procurement strategies. This questionnaire is then vetted by various departments/ agencies. This included experts from Sind Coal Authority, KMC, W&S Department, and SPPRA. A copy is also sent to World Bank for review and approval.

4.2 Questionnaire Disbursement in various Departments

After the approval of the questionnaire, the same is circulated in the target departments with the help of focal persons nominated by the department (Additional Secretary - Technical).

4.3 Data Collection

The data collection methodology is such that by the consent of the respective department, an adequate sample size would be selected based on the data collected by the research assistants on the questionnaire.

4.4 Data Analysis

After the data collection, data analysis will be done. The analysis would include statistical analysis as well as expert comments and conclusions.

5. Data Analysis

The data analysis is presented in the following sections and sub-sections.

5.1 Composition of Goods, Works & Services Procurements in the Selected Departments

The composition of Goods, Works, and Services is calculated based on sample projects as the data is not recorded, and archived centrally by neither of the departments, as a result, the values have highly relied on the provided sample projects and any biasness can only be attributable to non-availability of data.

After the descriptive analysis of the data, it has been learned that during the period 2010-14:

- Education Department procured Works (25%), Services (34%), and Goods (41%).
- Works & Services Department procured Works (100%).
- Irrigation Department procured Works (100%).
- Agriculture Department procured Works (33%) and Goods (67%).

Table 1, summarizes the numbers of procured contracts for works. goods and services by the identified departments for this study. It can be observed that the largest procurements of works have been carried out by the education department, it may be because of the reason that the present government regime has extensively focused on upbringing the level of education in the province, this strategic move is well endorsed by international funding agencies like the Bank, and that is why such numbers are observable.

Table 1. Summary of Goods, Works & Services Procurements in the Selected Departments

Department	Total	Works	Goods	Services
Education	92	23	38	31
Works & Services	10	10	0	0
Agriculture	12	4	8	0
Irrigation	12	12	0	0

5.2 Composition of Procurement Mechanism Adopted by the Selected Departments

The composition of ICB, NCB, and Shopping is calculated based on sample projects as the data is not recorded, and archived centrally by neither of the departments, as a result, the values have highly relied on the provided sample projects and any biasness can only be attributable to non-availability of data.

After the descriptive analysis of the data, it has been cultured that during the period 2010-14:

- *Education Department procured contracts through ICB (01%), NCB (48%), shopping (26%) and Consultancy (19%)*
- *Works & Services Department procured 100% contracts through NCB*
- *Irrigation Department procured 100% of contracts through NCB*
- *Agriculture Department procured 100% of contracts through NCB*

Table 2 consolidates the procurement mechanism for the four departments, predominantly it is seen that all of the departments under study opt for National Competitive Bidding (NCB) as their preferred mode of procurement mechanism except for the exception of very few instances. As in our sampling, only one procurement mechanism was for International Competitive Mechanism (ICB).

This observation leads to several understandings, chiefly is that the scope of work that these departments wish to execute is fully addressable and executable by our local industry, the performance specifications enlisted are fully deliverable by our local contractors, vendor, and consultancies. This in turn elaborates the adequate capacity of the local industry. Furthermore, it is usually believed that public agencies and departments are the largest employer/engager of local industry and this belief is endorsed by this finding, i.e. majorly polar procurement for NCBs.

As abridged in Table 3, the predominant use of Single-stage two envelope procedure has been found, it is usually a wise decision to allow the purchaser to evaluate the technical proposals without reference to the price, and bids of bidders who do not conform to the specified requirements can be rejected as deficient bids without the enticement of low-cost delivery. Following approval of the technical evaluation and at a date and time advised by the purchaser, the price proposals are opened in public. Using a single-stage tendering, the contractor's offer of risk transfer in the financial proposal may have little value if its assessment of costs, working method is incorrect. Also, changes introduced by the client or design team will undermine the certainty achieved in the financial proposal. Whereas two-stage tendering helps the contractor to understand the design. The use of provisional items as a substitute for a complete design can give the contractor/vendor a "second-stage" pricing opportunity. But unfortunately, this practice is found to be "absent" in the data gathered for analysis except for a few exceptions of instances from Education and Works & Services.

Table 2. Summary of Procurement Mechanism

Department	Total	ICB	NCB	Shopping	Consultancy
Education	98	1	47	25	19
Works & Services	10	0	10	0	0
Agriculture	12	0	12	0	0
Irrigation	12	0	12	0	0

As expressed in Table 3, after the analysis of the data it can be asserted that during the period 2010-14.

Table 3. Summary of Procurement Method Employed

Department	Total	Single-stage one envelope	Single-stage Two envelope	Two-stage bidding	Two-stage Two envelope
Education	197	21	175	0	1
Works & Services	5	2	0	3	0
Agriculture	3	0	3	0	0
Irrigation	12	12	0	0	0

- *Education department procured (89%) contracts through single stage-two envelope procedure and (11%) Contracts through single stage-one envelope method.*
- *Works & Services department procured (60%) contracts through two-stage bidding method and 40 % through single stage-one envelope method.*
- *Irrigation department procured (100%) contracts through single stage-one envelope.*
- *Agriculture department procured (100%) contracts through the single stage-two envelope method.*

5.3 Average Bid Response

Getting an ample response to the proposed project is considered vital to the competitive bidding procedure to commence. If a sound bid response rate is experienced for a respective project, it can be asserted that the local industry is extremely interested in acquiring the project, and in turn, the procurement agency will have strong open competition to get the best value procurement for their proposed project. The vice versa would be the case if a low bid response rate is experienced which may result in average value procurement.

At first, the bid responses of each of the sample project was calculated using the following equation, thereby allowing the project team to formulate a single indicator i.e average bid response.

$$\text{Bid Response (\%)} = \frac{\text{Number of Bids received for a particular Project}}{\text{Bid Document sold for the Project}} \qquad \text{Eq (1)}$$

The average bid response is calculated by taking an average of the bid response rate on each project as follows.

$$\text{Average Bid Response} = \frac{\sum_{i=1}^{n} \text{Individual Bid Response (\%)}_i}{n} \qquad \text{Eq (2)}$$

As portrayed in Figure 2; Works & Services and Irrigation Department were found to be enjoying on average full response to their proposed projects while Education & Agriculture were found on the slightly lower side.

5.4 Planning Process

To evaluate the extent of planning adopted in procurements at the departmental level a set of five questions were asked:

The first question pertains to the effort involved to conduct complex procurements resulting in realistic project definition, achievable completion schedules, and accurate cost estimates.

5.4.1 "Is overall planning for complex goods works and other contracts done in sufficient detail to produce realistic project definition, achievable completion schedules, and accurate cost estimates?"

The departments responded affirmatively, few highlighted tender documents as a source of sufficient detail for specification and completion schedules as well as PC-1 for estimates of costs, others simply confirmed the process of planning within.

The second question inquired about the extent of technical and financial planning causing accurate cost estimation resulting inappropriate release of funds.

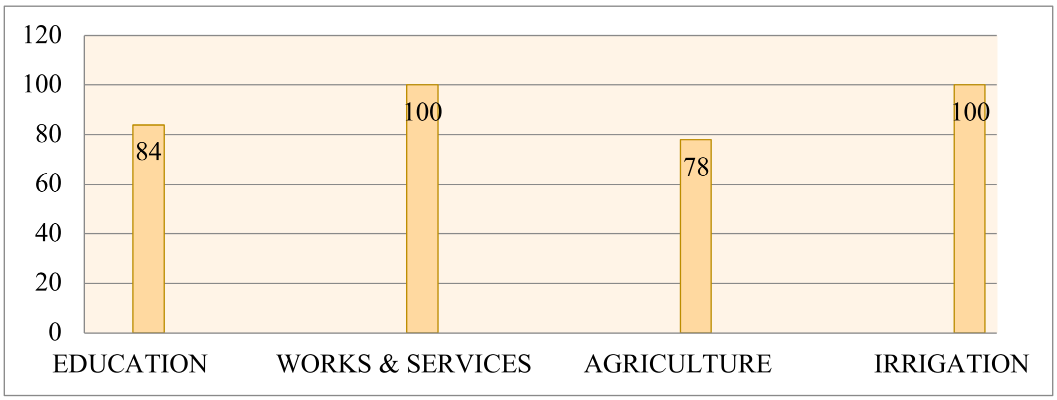

Fig 2. Average Bid Response

5.4.2 "Is the early technical and financial planning well-coordinated so that projects are fully funded when work needs to begin, based on accurate cost estimates?"

In response to this question, the departments were of the view that as a policy to allocate funds on ADP schemes estimation is done and usually well-coordinated with the technical aspects moreover tenders for ADP schemes are released on the availability of funds. However, the departments show their grievance on the delayed as well as the partial release of quarter-wise funds from the Finance Department.

The third question required category wise response on the completion of the schedule met for Goods, Works & Services Contracts.

Most of the departments confirmed that the schedules for Goods Procurements are usually met however Works & Consultancies are usually delayed.

The fourth question probed the major cause(s) of slippage – A set of five choices were offered: (i) Budget Release Time Lines (ii) Unrealistic and overly optimistic time frame (iii) Delays in contract award (iv) Weak project management and decision making (v) Inadequate contractor capacity to meet the contracted scheduled completion date.

All the departments opted for the Budget Release Time Lines as a major cause of slippage.

The fifth Question explored the aspect of market surveys to update the price database for realistic cost estimation.

5.4.3 "Does your Department regularly conduct market surveys to update their knowledge of prevailing prices for goods and works?"

One department confirmed the exercise of market surveys regularly, however, most of the departments negated due to inadequate manpower to conduct such surveys.

5.5 Analysis of Project Procurement Timeline

In this section analysis of various milestones in the Project Procurement Cycle (For example date of advertisement, number of bidders buying bid docs, number of bidders submitting bids, date of bid opening, date of award, etc.) is presented.

The following discussion presents the analysis of the procurement timeline for the short-term assignment on Review of Procurement Practices and Timelines in Specified Departments in Sindh. The analysis is performed in three phases. The brief description outlining the purpose of each phase along with the interpretation of tabulations is as follows:

This analysis has been performed to establish a rational Time Indicator for Procurement Cycle Time that is representative for all types of projects (Goods/Works/Services) and is derived on common grounds from the W&S Department, Education Department, Irrigation Department, and Agriculture Department.

As per SPPRA guidelines, the following are the major milestones in the procurement timeline along with the type of analysis selected: deterministic versus probabilistic. For processes with low variation, the deterministic approach is suitable, whereas, for processes that contain large variation and uncertainties, the probabilistic approach is more justifiable. Owing to the varying nature of processes in each of the milestones of the procurement timeline, the timelines for a particular milestone are coming out with a high degree of variation thus necessitating probabilistic treatment to have an assessment of the variation.

Table 4. Milestone v/s Selected Analysis

S. No.	Milestone	Selected Analysis
1	NIT to Closing of Bids	Probabilistic
2	Closing of Bids to Opening of Bids	Probabilistic
3	Technical Evaluation & Financial valuation (BER)	Probabilistic
4	BER to Contract Signing	Probabilistic

As per SPPRA guidelines, Table 5 shows the major milestones in procurement timelines along with the type of analysis consideration: deterministic versus probabilistic. Table 5 also summarizes the procurement steps in the cycle and their connection with the study milestones. Cross-reference is also made to the pertinent SPPRA clause along with the type of analysis (probabilistic VS deterministic) performed for a respective milestone. For processes with low variation, the deterministic approach is suitable, whereas, for processes that contain large variation and uncertainties, the probabilistic approach is more justifiable. Owing to the varying nature of processes in each of the milestones of the procurement timeline, the timelines for a particular milestone are coming out with a high degree of variation thus necessitating probabilistic treatment to have an assessment of the variation.

5.6 Description for Indicators used in Probabilistic Analysis

Since the data is non-normal, the probabilistic analysis requires normalization of data before analysis. Table 6 summarizes the indicators used in the probabilistic analysis.

5.6.1 NIT to Closing of Bids

Table 7 summarizes the probabilistic analysis of the milestone "NIT to Closing of Bids".

Supplementing the probabilistic analysis in Table 7, there had been 12 instances when the milestone under consideration took as much as 48, 38, 36, 34 days to complete.

5.6.2 Closing of Bids to Opening of Bids

Table 8 summarizes the probabilistic analysis of the milestone "Closing of Bids to Opening of Bids".

Table 5. Basis for Development of Time Indicator for Procurement Cycle Time

Procurement Steps	Days	Remarks	Study Milestones
NIT to Closing of Bids	Probabilistic	SPPRA Clause 18.2	Days b/w NIT till Closing of Bids

Closing of Bids to Opening of Bids	Treatment	SPPRA Clause 41.3	Days b/w Closing & Opening of Bids + Days b/w Technical & Financial Opening
Technical Evaluation & Financial Evaluation (BER)		For NCB (Bid Validity) SPPRA Clause 38.1	Days b/w Bid Opening to Evaluation
BER to Contract Signing		SPPRA Clause 45	Days b/w Evaluation & Contract Signing

Table 6. Description for Indicators used in Probabilistic Analysis

Log_{10} (Mean)	**Log_{10} (SD)**	**Milestone days (x)**	**Log_{10} (x)**	**Probability (%)**
Base 10 log of the mean days to achieve the milestone	Base 10 log of the standard deviation of the days to achieve the milestone	The test value for a specific confidence level	Base 10 log of (Milestone days)	The confidence level to achieve the specific milestone days

Table 7. NIT to Closing of Bids

Log_{10} (Mean)	**Log_{10} (SD)**	**Milestone days (x)**	**Log_{10} (x)**	**Probability (%)**
1.23182	0.310314	5	0.69897	4.2978
		10	1	22.7517
		15	1.176091	42.8738
		20	1.30103	58.8244
		25	1.39794	70.3788
		30	1.477121	78.538
		35	1.544068	84.2848
		40	1.60206	88.3587
		45	1.653213	91.2761
		50	1.69897	93.389
		55	1.740363	94.9372
		60	1.778151	96.0845
		65	1.812913	96.9438
		70	1.845098	97.594
		75	1.875061	98.0908
		80	1.90309	98.4737
		85	1.929419	98.7713
		90	1.954243	99.0045

Supplementing the probabilistic analysis of Table 8, there had been 07 instances when the milestone under consideration took as much as 180, 143, 79, 58, 57 days to complete.

5.6.3 Technical Evaluation & Financial Evaluation (BER)

Table 9 summarizes the probabilistic analysis of the milestone "Technical Evaluation & Financial Evaluation (BER)".

Table 8. Closing of Bids to Opening of Bids

Log_{10} (Mean)	**Log_{10} (SD)**	**Milestone days (x)**	**Log_{10} (x)**	**Probability (%)**
0.398724	0.629708	1	0	26.3305
		2	0.30103	43.8355
		3	0.477121	54.9539
		4	0.60206	62.6616

		5	0.69897	68.3248
		7	0.845098	76.0794
		10	1	83.0173
		15	1.176091	89.1489
		17	1.230449	90.6718
		28	1.447158	95.2039
		35	1.544068	96.5533
		40	1.60206	97.1994
		50	1.69897	98.0531

Table 9. Technical Evaluation & Financial Evaluation (BER)

Log_{10} (Mean)	Log_{10} (SD)	Milestone days (x)	Log_{10} (x)	Probability (%)
1.019345	0.544631	1	0	3.0629
		3	0.477121	15.9726
		4	0.60206	22.17844
		5	0.69897	27.8184
		7	0.845098	37.45081
		10	1	48.5832
		11	1.041393	51.6145
		15	1.176091	61.3250
		21	1.322219	71.0931
		31	1.491362	80.6939
		53	1.724276	90.2223
		83	1.919078	95.0733
		90	1.954243	95.6971
		138	2.139879	98.0177

Supplementing the above probabilistic analysis, there had been 06 instances when the milestone under consideration took as much as 288, 240, 211, 175, 164 days to complete. The same is visible by the x (BER days) corresponding to 95% and more probability.

5.6.4 BER to Contract Signing

Table 10 summarizes the probabilistic analysis of the milestone "BER to Contract Signing".

Table 10. BER to Contract Signing

Log_{10} (Mean)	Log_{10} (SD)	Milestone days (x)	Log_{10} (x)	Probability (%)
0.29759	0.052609	1	0	27.8748
		2	0.30103	50.2705
		3	0.477121	63.8279
		4	0.60206	72.5788
		5	0.69897	78.5568
		6	0.778151	82.8233
		7	0.845098	85.9742
		8	0.90309	88.3657
		9	0.954243	90.2217
		14	1.146128	95.2788
		22	1.342423	98.0273

Supplementing the above probabilistic analysis, there had been few instances when the milestone under consideration took as much as 36, 32, 34, and 37 days.

6. Conclusions

The prime conclusions of the study can be presented as:

- The reform of public procurement in the country may still be considered a work-in-progress.
- Non-existence of procurement cells in the identified departments leading to the inability to serve as a single-window for all procurements of the department.
- Absence of electronic data system for archiving and retrieval of information regarding the overall procurements, the procurement cycle time of the undertaken projects by the department.
- Shortcomings in the HR capacity concerning knowledge of procurement rules as well as implementation timelines.
- The lack of awareness to compile any data about procurement outlays, budget release timelines, and procurement timelines and seek self-improvement.
- Bureaucratic hurdles and bottlenecks.
- If all sampled projects are considered for a specific department (under the scope of this study, the top three troublesome milestones (in the order of descending frequency) in procurement timeline are "BER to Contract Signing" closely followed by "Closing of Bids" and "NIT to Closing of Bids".
- If all individual procurement types (goods, works, services, etc) are consolidated from each of the selected departments (under the scope of this study) the top three troublesome milestones (in the order of descending frequency) in the procurement timeline are "BER to Contract Signing" closely followed by "Closing of Bids" and "NIT to Closing of Bids" and "Technical Evaluation & Financial Evaluation (BER)". This conclusion is based on the strategy that.
- At 80% confidence level, the procurement cycle is supposed to be completed in 82 calendar days. While at 90 percent confidence level, the procurement timeline would be 124 calendar days.

7. Recommendations

The recommendations are derived as a collection of formal and informal learnings from the study, reinforced by strong statistical backing.

If the massive task of improvement has to be carried out, concerted efforts have to be made by the government, academia, and international donor agencies such as The World Bank. Addressing the challenge to ensure that the procedures laid down in the procurement reforms are translated into actual practices and are neither ignored nor side-stepped should be the key aim of all stakeholders. Therefore, a partially integrated set of improvement measures is proposed as follows:

- Concerted efforts are to be made to establish a procurement cell in the public sector departments to function as a single node for all procurements for the department.
- A national plan for training and certification of relevant personnel at all levels should be developed and implemented.
- It would be appropriate to arrange some form of formal and/or informal education and training on various aspects such as procurement management, contract management, claim management, best value procurement, etc.
- It is also necessary to specify to the prospective tenderer the criteria by which submissions are evaluated These may include the weights to be given to price and quality in a tender proposal, preferential margins to be applied, or any other conditions that will favor or exclude certain types of the tenderer.
- Well harmonized financing should be evolved for a smooth transition between procurement milestones and the execution of projects.
- There is a need to inculcate adequate level knowledge about procurement methods and systems. To some extent, NED UET has taken a lead and has started the journey to develop a self-sustainable industry. This had been mainly achieved by launching new graduate and postgraduate programs in Construction Engineering and Construction Management respectively at NED UET.

- Informal education and training could take the form of career development programs organized by academic institutions with the support of professional organizations like the Pakistan Engineering Council and Institute of Engineers Pakistan (IEP). With the support of SPPRA, PEC, IEP, and similar organizations, seminars, training workshops, and interactive symposiums can be arranged on procurements practices and management, with a focus on international best practices to uplift the local industry.
- The procurements methods, means, and mechanisms being used by various authorities in a respective department should be harmonized.
- Competent authorities in Pakistan can take inspiration from Singapore as an example. Over the many years, it has developed one of the most comprehensive e-procurement systems known as GeBiz. Through this portal, all intended procurements are advertised, with general specification requirements, and the necessary procedural, evaluative, and other information; that prospective tenderers and applicants are required for registration. It also discloses bids received with prices offered, and the results of the selection process. Details of registration and pre-tender qualification are found on the GeBiz web-site. Tenderers submit their bids through the GeBiz portal too.

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ID 141

Optimizing Commuter Travel Times on Traffic Signals Using Phasing Techniques – A Pathway for Cost-Effective Intelligent Transportation System

Farhan Jamil[1], Malik Kamran Shakir[2], Rizwan U. Farooqui[1]

[1] NED University of Engineering and Technology, Karachi, Pakistan
[2] National University of Science and Technology NUST, Islamabad, Pakistan
farhanjamil@cloud.neduet.edu.pk

Abstract

In recent times, population growth has contributed to increased motorization and urbanization in Pakistan which hinders traffic mobility. As a consequence, the country is faced with urban sprawl that leads to almost daily recurrent gridlocks on roads. Due to the changing landscape of the Central business district and suburban development, accessibility to workplaces is decreasing and people see cars and other automobiles as a necessary addition to their life. Burgeoning twin cities like Rawalpindi and Islamabad incur economic costs due to traffic congestion observed during peak hours, as people move to their workplaces, schools, colleges, business centers, recreational places, etc. through the main thoroughfare i.e. Peshawar Road, Rawalpindi highway. The traffic congestion has inflated the twin cities and is exacerbated due to a lack of proper transportation planning and design needs resulting in an imbalance between the demand and capacity of road networks. These traffic delays lead to road damages and environmental degradation and end up costing road users fuel costs in terms of lost time. Furthermore, the public well-being is impacted by air and noise pollution having health implications. The paper attempts to address and mitigate traffic delays and congestion issues on Peshawar Road, Rawalpindi by using pre-timed split and protected phasing with signal coordination, offset, and bandwidth techniques in the software Synchro Studio. The preliminary data for this research was collected through an extensive literature review, traffic counts, and the geometrical features of the Peshawar road highway. The current traffic condition analyzed, is based on pre-timed split phasing without signal coordination. Subsequently, improved design alternatives are considered for an efficient movement of vehicles which are based on pre-timed split and protected phasing with signal coordination. These simulations are modeled in Synchro to optimize road user travel time. The benefits of each phasing scheme are compared to conclude that protected phasing with signal coordination reduces the travel time and total delays of the vehicles traversing the corridor by up to 52.8 % and 56% respectively when compared with the prevailing situation.

Keywords

Travel time, Delays, Signal Coordination, Pre-timed Split, Protected Phasing, Delay costs, Traffic Signals

Introduction

The transportation network plays a vital role in the development of any country. All sectors of a country's economy are affected through economic linkages made possible through the transportation network. A transportation network ensures safe travel within time, promotes business activities, and cuts down traveling costs while providing access to markets for services and goods. A reliable transport network provides rapid access to the workforce, thus, generating employment opportunities. The economy with better road networks is positioned more advantageously as compared to an economy with poor networks. Currently, the Pakistani government is confronted with the identification and solution of transportation problems. Traffic congestion in urban transportation, poor planning of road network, lack of governance, and corruption have worsened the present transportation problems in major cities of the country. In Pakistan, transportation problems are traditionally managed by constructing bigger roads which is not the solution.

The area of study is situated along the GT Road N5 connecting Peshawar to Lahore and Islamabad. The road runs roughly parallel to the M1- motorway between Rawalpindi and Peshawar. N5 highway provides access to the

Afghan border via the Khyber Pass too, with headlong connections to Central Asia and Kabul via Salang Pass. Peshawar Road Rawalpindi (PRR Highway) serves the areas like West ridge, Askari, Commercial hub, Saddar, Chaklala, Airport, etc. Due to the location of General Headquarters (GHQ), Peshawar Road carries special movements of the Pakistan Army that includes heavily armed trucks. Intersections are the bottlenecks of urban transportation networks (Ghanbarikarekani, 2018), and delay time at intersections is about 20%− 50% of total travel time. There has been a considerable amount of research that endorses intersection signal optimization as the key to reducing and managing traffic congestion (Shen, 2018). The risks posed by congestion give the impetus to explore new techniques of signal coordination on PPR Highway to minimize congestion, and delays thereby reducing the journey time.

There are a variety of high and low-cost interventions that could be incorporated to mitigate the predicaments of traffic congestion. Cost-effective approaches involve improving signal timing and phasing while other alternatives that involve spending some capital are adding lanes along roadways or even grade separation (Hadidi, 2022). The focus of the research is to devise economical alternatives by different phasing techniques in tandem with signal coordination of the green time is essential for efficient movement of vehicles through signalized intersections without stopping. In an uninterrupted flow, the timing is synchronized for traffic movements and the progression speed is managed. The result of signal coordination is the reduction in traffic delays, travel time, energy, and fuel consumption.

This is achieved by the following key objectives of this research

- To analyze current traffic demand on PRR Highway by manual calculations and mobile recordings.
- To mitigate traffic congestion on PRR Highway by pre-timed split phasing and protected phasing design approaches.

It is envisioned that the analysis of the present scenario and design of current traffic demand during peak conditions may help design the alternatives following the optimization of road user travel time with energy conservation and environment protection. Suitable recommendations for further research will be recommended to assess signal coordination using modern tools and techniques that will be adaptable to road users.

2. Methodology

The methodology of the research project is summarized in the figure below.

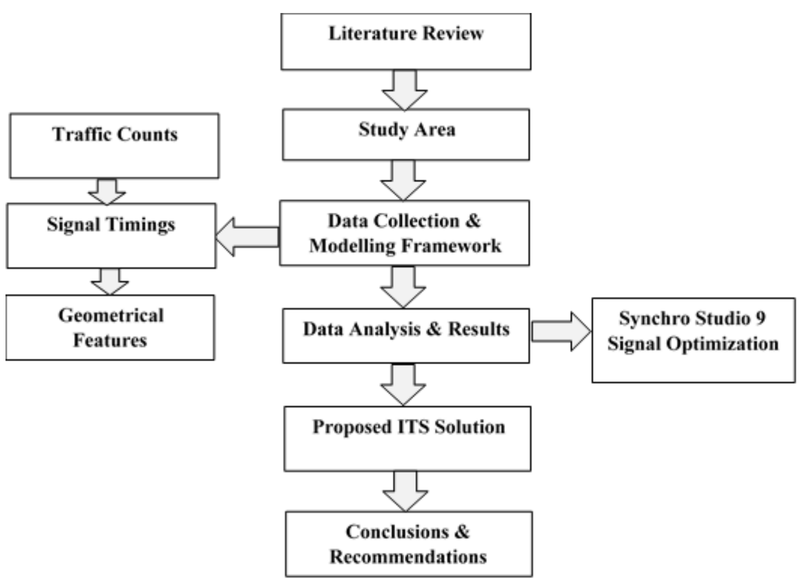

Fig 1. Research Methodology

3. Study Area

The area considered for our research is the urban arterial (Peshawar Road, N5) of Rawalpindi consisting of the following intersections are selected:

3.1 Signal 1: General Post Office GPO

This is a 4-legged signalized urban intersection located on PPR Highway. There are two major roads with Westbound WB going towards Saddar and Eastbound EB running towards the GHQ. The minor roads are Southbound SB going towards RA Bazar/Kashmir Road and Northbound NB runs towards Saddar/Kashmir Road.

3.2 Signal 2: General Head Quarters GHQ

This is a 3-legged signalized urban intersection located on PPR Highway. There are two major roads with WB going in the direction of GPO and EB towards Pearl Continental Hotel. The only minor road is NB and goes in the direction of Murree Road.

3.3 Signal 3: Pearl Continental Hotel PC

This is a 4-legged signalized urban intersection located on PPR Highway. There are two major roads with WB going towards GHQ and EB running towards Kacheri. The minor roads are SB and NB going towards Sarwar Road.

3.4 Signal 4: Kacheri Chowk

This 4-legged signalized intersection is located on Mall road Rawalpindi. It has two major roads with WB going in the direction of PC and EB going towards Airport Road. While the two minor roads, NB is going towards Rashid Minhas Road and SB running towards Ayub Park Road.

Fig 2. The Entire Corridors of PRR Highway

4. Data Collection and Modelling Framework

The basic aim of our study was to enhance traffic signal timing and coordination for each intersection on PPR Highway for the prevailing and expected conditions of the traffic at the intersections that are to be analyzed. The procedure involves collecting traffic counts for the different movements of traffic. i.e. through and turning movements at the intersections by count method and videos recorded. The traffic volumes were further validated by using the JAMAR counter. Furthermore, geometrical features of the intersection were recorded including the number of lanes, their widths, and median width. To represent a true depiction of real traffic, vehicular classification is done by converting these traffic counts into Passenger Car Equivalents and using them as an input for volumes in Synchro (Ali, 2015). The values used for Passenger Car Equivalents (PCE) are shown in Table 1.

Table 11. Vehicle Class & its PCE factor (Ali, 2015)

Vehicle Type	PCE Factor
Bike	0.4
Motor Car	1
Van/Pickup	1.5
Bus	2
Heavy	2.3

Subsequently, peak hour volumes and peak hour factor was determined for every individual intersection from the recorded traffic counts. The days and timings considered in Synchro 9, imitate an actual situation where the periods selected during the specified weekday and weekend as shown in Table 2. The selected timeframes represent critical intervals involving peak hours.

Table 2. Traffic counts considered for the following time and days of the week

Day	Morning Peak Hour	Evening Peak Hours
Thursday (Working Day)	7:30 – 10:30	16:00 – 19:00
Sunday (Weekend)	-	16:00 – 19:00

Before conducting research, an initial survey of field travel, travel distance, and cycle lengths between signals were measured. Generally, signals are automated. However, during peak timings and special movements of armed forces, these are controlled manually by traffic wardens and the Pakistan Army personnel. To have an optimum level of signal coordination in major streets and highways, the recommended distance by the Manual on Uniform Traffic Control Devices (MUTCD, 2000) between signals should fall within 800 meters for major streets and highways. The distance between the intersections of the corridor was calculated which is less than the specified standards of signal coordination. Furthermore, cardinal directions i.e. North-South (NS) to minor roads and East-West (EW) to major roads were assigned. Mirroring of directions (NB into SB and left into right and vice versa) according to American traffic signal standards for synchro analysis and design is done to represent Pakistan's road network typology.

Table 3. Travel distance between the nodes

Travel Nodes	Travel Distance (m)
GPO to GHQ	455
GHQ to PC	505
PC to Kacheri	870

4.1 Optimization Process

The SYNCHRO optimization procedure materializes after testing all the possible cycle lengths for observed intersections. SYNCHRO then determines the shortest cycle length that is suitable for critical percentile traffic for each phase. It is necessary to clear critical percentile traffic, if the splits for each phase are not able to do that, it will try a higher cycle time until the critical percentile is cleared (Siddiqui, 2015). After setting up the cycle time for each phase, SYNCHRO selects the cycle time with Measures of Effectiveness (MoEs). Finally, SYNCHRO optimized offsets and the phase sequence. Delay is the key measure of effectiveness. Stopped delay is used to quantify the coordinated actuated traffic signal system. MOEs, field measured travel times, and stopping delays collected before (non-coordinated) and after (coordinated) are compared. Changes in the MOEs measured in the field and calculated by SYNCHRO are compared and the adaptive best alternative split features are implemented. Synchro is signal-timing and optimization software package that uses the Intersection Capacity Utilization (ICU) 2003 method and supports the Highway Capacity Manual (HCM,2010) and (HCM, 2000) methodology.

5. Data Analysis and Results

Traffic signal optimization is achieved by considering different phasing techniques i.e. split phasing and protected phasing. The current traffic was analyzed using pre-timed split phasing without signal coordination followed by pre-timed split and protected phasing by signal coordination incorporating bandwidth and offset techniques. Among the different traffic signals, there are pre-timed or actuated modes or sometimes a combination of the two. Despite advancements in the field of traffic planning and operations, many major cities still rely on pre-timed signal settings. (Parr, 2011). This is because real-time traffic controllers require sensors and processors to function which induces a high cost of installation and maintenance (Patel, 2015). The Pre-timed control signal has a fixed cycle time and green time. The signal program processes periodically and can be controlled on-site and easily updated if needed. The split phasing considers an assignment of right-of-way to all movements at a particular approach which is followed by all of the movements of the opposing approach. In contrast, to split phasing, the protected phasing has a signal phase, where only through traffic has green or right-turning traffic has green (Udomslip, 2017).

The data recorded and processed to give peak hour volumes, peak hour factor is further used along with existing cycle length and green time to determine existing overall delay, the capacity of each movement, and for the whole signal along with Level of Service (LOS) and Intersection capacity utilization (ICU) with the help of software SYNCHRO. A comparative analysis of the results produced by Synchro studio 9 gives a holistic view of the traffic conditions of split phasing before improvement and the design split and protected situations for the morning, evening, and weekend after improvement. The results presented in Table 4 signify the importance of using the design alternatives with signal coordination through the corridor which yields reduced cycle lengths in comparison to split phasing without signal coordination.

Table 4. Analysis and design conditions

Stages	Phasing	Cycle Length (sec)	Coordination
Before Improvement	Split (four-phase)	107- 172	No
Design 1 (Pre-timed Split)	Split (four-phase))	125	Yes
Design 2 (Protected Phasing)	Split (four-phase))	125	Yes

The three alternatives of signal phasing are represented in Figure 3, the first stage is one without any signal coordination where we can see the travel delay by each vehicle, the total delay, and lastly, the total travel time throughout the corridor of PRR Highway is considerably higher and is the impetus to the design alternatives modeled. It has been observed that the most time-efficient phase design is protected phasing with signal coordination during all periods and days of the study.

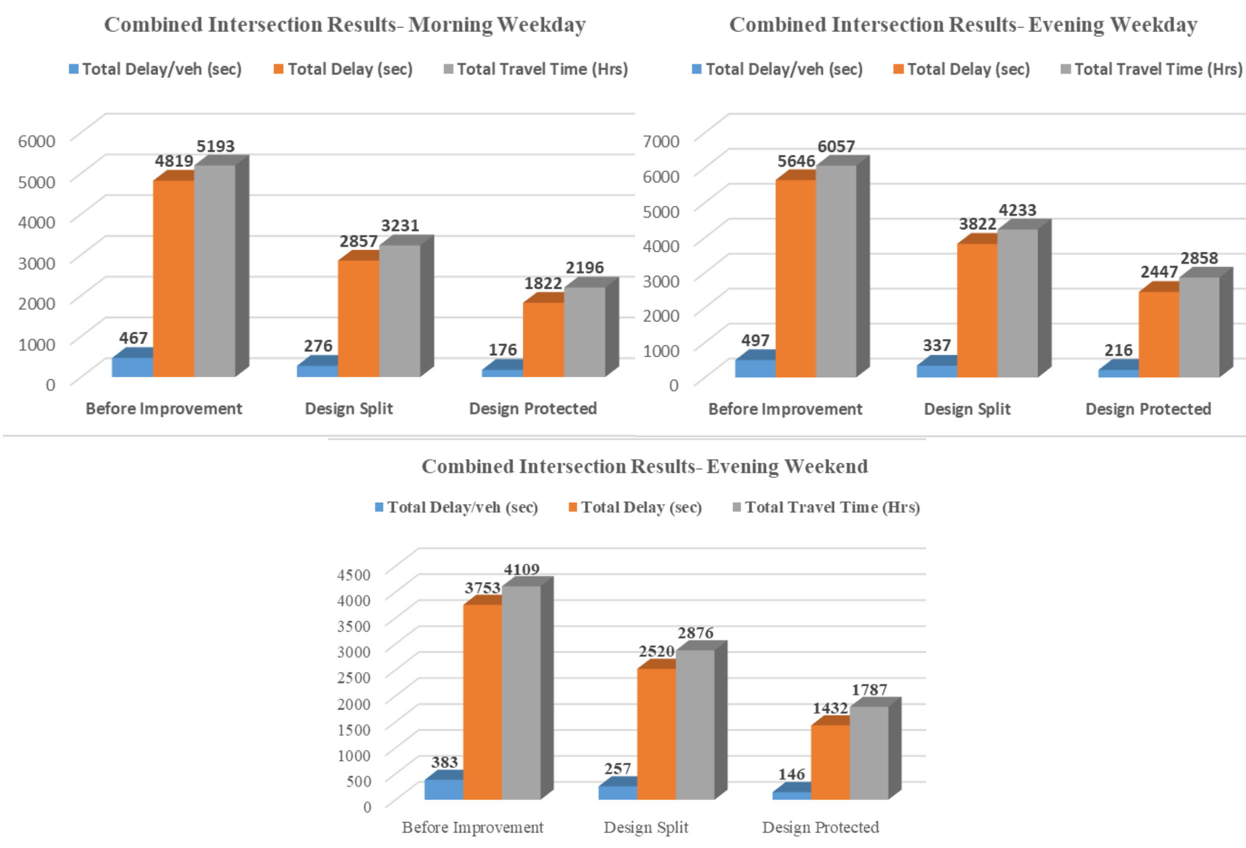

Fig 3. Intersection combined results of total delay/veh (sec), total delay (sec), total travel time (hrs), (a) morning peak hours of weekday, (b) evening peak hours of weekday, and (c) evening peak hours of weekend.

5.1 Cost Benefit Analysis

The cost-benefit analysis of the proposed interventions and their implications on the tangible metrics of a sustainable transportation system such as time and cost as a result of the phasing techniques are depicted in Table 6. Assuming a free-flow speed for different segments considered for the analysis, the unit travel time costs are derived for the year 2019 by using the CPI index for the years 2014 & 2015. The unit travel time cost for cars is taken as 295 PKR rupees. For travel time savings the following equation from (HCM, 2010) is used.

$$\text{Saving Delay Cost} = (\text{Occupancy of Vehicle}) \times (\text{AADT} \times \text{Travel Time Saved}) \times (\text{Unit Travel Time Cost}) \quad (1)$$

Where,
AADT = 1700 veh/hr

By leveraging the benefits of these phasing techniques. From the analysis, it is concluded that the reduction in travel time as a result of design interventions leads to saving time per vehicle which in turn contributes to saving of costs incurred by delays. Using the unit travel time cost already derived above, the total monetary benefit was calculated which is PKR 223.3 and PKR 167.535 Million per year for the different directions of traffic. Conclusively Table 6, clearly depicts that the design-protected alternative for signals is more feasible as the travel time cost is reduced. Since travel time cost is directly related to savings, this alternative will help in the reduction of the cost of road users which has a direct influence on the economy of the country.

Table 6. Travel time savings

Direction	Travel Time (sec/veh)			Saving Time (hr/veh)		Saving Delay Cost/year (Rs. Millions)	
-	Before Improvement	Design split	Design Protected	Design split	Design Protected	Design split	Design Protected
East	510	405	330	0.0291	0.05	153.3	223.38
West	465	390	330	0.0208	0.0375	109.5	167.535

6. Proposed ITS Solution

An Intelligent Transport System (ITS) module is proposed that is capable of adjusting to real-time traffic conditions with pre-timed protected phasing and loop detectors which circumvents to actuate cycle length for this traffic corridor. The working principle of the ITS module is explained below for different conditions and illustrated in Figure 4.

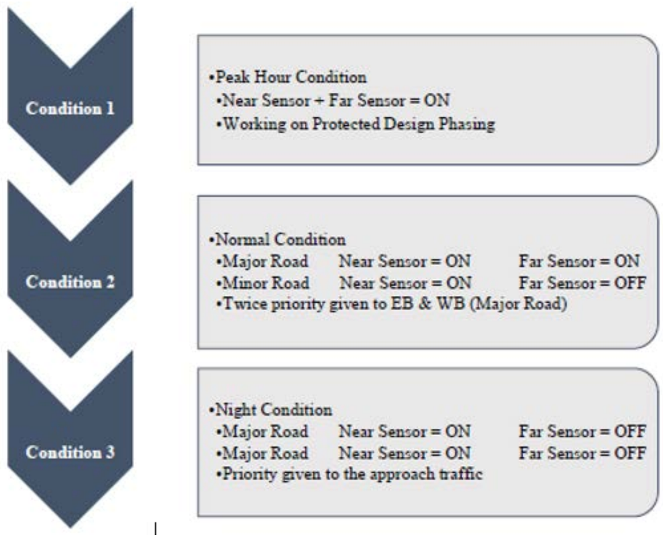

Fig 4. ITS Module Conditions

The first condition is the peak hour condition which means more traffic at intersections and due to heavy traffic, long queues will be formed, at both Near & Far sensors. They will detect traffic that will activate Protected phasing at the intersection. Condition 2 is the normal condition where when on a major road a large number of traffic is observed, which will be detected by near & far sensors. On the other hand, minor roads would have less traffic so the only near sensor will detect the traffic. Due to the above condition, ITS will give twice priority to main road traffic i.e.

- through traffic on the main road will get green.
- right protected traffic on the main road will get green.
- again, through traffic on the main road will get green.
- again, the right protected traffic on the main road will get green.
- through traffic on the minor road will get green.
- right protect traffic on the minor road will get green.

The third condition assumes night conditions where traffic is less so only near sensors will detect traffic and upon the detection of traffic on any approaching intersection, it will get green (because of the absence of traffic on other approaching), in addition to that protected phase will work normally.

7. Conclusion

Due to increased motorization, poor implementation and enforcement of traffic laws, growing population, and urban sprawl, the worst kind of traffic flow were observed at PRR Highway situated along the GT Road N5 connecting Peshawar to Lahore and Islamabad. A review of this congestion suggested the need for new techniques of signal coordination on Peshawar Road to mitigate congestion, reduce traffic delay, and enhance safety and mobility. Existing traffic demand was evaluated using manual traffic counts and recordings. From these counts, it was observed that the road users were facing continuous delays due to the presence of signals on Peshawar road. This study provided indications of good practices that could be followed in the evaluation of alternatives transportation systems from a decision-making perspective. The current scenario indicated that severe congestion occurs due to pre-timed split signals which resulted in more consumption of fuel, and vehicles produced more and more emissions which are deteriorating the environment. Moreover, the level of service is adversely impacted as a result of these traffic delays. The noise disturbances from vehicles and unnecessary honking aggravate people's misery leading to frustration and psychological disorders. It can be seen from the results that the optimization of signal timings using protected signal phasing helped in the reduction of road user travel time by 52.8%, which is directly linked to the reduction of total delays by 56% when compared with the current scenario. This helped in the mitigation of congestion caused by signals on Peshawar Road. The environment would also be protected by the reduction of pollutants caused by slow-moving vehicles with a 1.93 times reduction in vehicular traffic as compared to the current scenario. Design protected signals were also more economically efficient as compared to improving congestion by any geometrical interventions like underpasses or grade separation. Considering all the possible solutions and analyzing the results, it was concluded that the intervention of using protected phasing with signal coordination was the best possible option for this corridor as it provided the minimum delays, reduced fuel consumption, and ensures efficient flow with minimum travel time.

8. Recommendations

The potential of an Integrated ITS with a fully actuated traffic signal with different cycle lengths on both major & minor roads needs to be explored for a transportation system equipped to cater to real-time changes in traffic streams. Furthermore, the geometrical changes with a combination of channelization and diversion of traffic by providing alternative routes are suggested to optimize traffic mobility.

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ID 142

Identifying Building Information Modeling Potentials for Construction Dispute Avoidance and Resolutions

Waqas Raza[1], Rizwan U. Farooqui[1], Muhammad Saqib[1] and Rana Rabnawaz Ahmed[1]

[1] NED University of Engineering and Technology, Karachi, Pakistan
waqasraza12ce01@yahoo.com

Abstract
The time and cost invested in dispute avoidance and resolution are massive. Therefore, various studies on effective construction dispute avoidance and resolution have been conducted in the past. However, still many disputes related to time and quality of work have not been fixed to its true potential e.g., using adequate technologies. Building Information Modeling (BIM) assists project stakeholders to improve dispute avoidance and resolution in the planning, design, and construction stages. Therefore, identification of potential opportunities of BIM for efficient dispute avoidance and resolution in the construction industry and challenges faced for the adaptation of BIM for dispute avoidance and resolution are discussed in this paper which is related to design review, drawing generation, 3D Co-ordination, extraction of quantity take-off, record modeling, 4D or Phase Planning, and 5D or Site Operation Planning, etc. This paper mainly adopts a review-based methodology to identify the potential of BIM in this dimension of Dispute Avoidance and Resolution. It is learned from the review that the BIM-based approaches can support construction dispute avoidance and resolution. BIM models in a combination with some cloud-based services like primavera unifier can open a new way to deal with dispute avoidance and resolution.

Keywords
Building Information Modeling, Dispute Resolution, Dispute Avoidance, Technology.

1. Introduction
Due to the extensive number of activities involved in the projects of the construction industry claims, conflicts and disputes occur one after the other. Various studies have been conducted to highlight the causes of claims, conflicts, and disputes but still, these causes are the major causes because these causes are not avoided and resolved and adversely affect the relationship among the parties involved and also cause the loss of money and time. This is to the report published by the Hong Kong International Arbitration Center (HKIAC), which discovered that in the year 2000 the number of disputes increased 3 times in the previous decade. Hence, the ability to resolve disputes cannot be overemphasized. It should be part of the tool kit for experts, especially those in decision-making capability or management grades (Cheung et al., 2002).

Although various research studies have been conducted to resolve and improve the construction dispute resolution and minimization still various limitations in this field need attention to minimize and resolve construction disputes such as design change (Cakmak and Cakmak 2014), failure to understand the implication of instruction (Farooqui et al., 2012) delays (Sambasvan and Soon 2007), etc., are the reasons to increase the volume of construction disputes. Therefore, for effective dispute management and minimization, these issues must be answered. BIM models help in detecting causes of dispute and in evaluating these cases during dispute resolution processes. BIM made the claiming process easy by visualizing the activities and variations in these activities. Therefore, BIM can be used for claim preparation and verifying claims which are complex in nature and can also be used for claim presentation. The information required for claim preparation in BIM is accurate and can be easily available (Koc and Skaik 2014). BIM is a fully integrated and interoperable and centralized information database that carries realistic intelligent physical and performance data from all the participants throughout the lifecycle of the project.

Building information modeling (BIM) improves coordination among stakeholders through integrated building design which helps in avoiding design problems and changes (Cheng and Das 2014) and reduces the construction disputes occurrence. BIM-based properties like clash detection and design review in design validation reduce the number of design errors and rework which ultimately reduces the construction disputes. BIM uses that have positive impacts on construction dispute management and avoidance are identified through extensive literature review, which are (1) design review, (2) Drawing Generation (3) 3D coordination, (4) quantity take-off, (5) Record modeling, (6) phase planning (4D), and (7) site utilization planning (5D), etc.

2. Objectives

The objectives of the paper are as follows;

i. To highlight the potential opportunities of BIM for dispute avoidance and resolution in the construction industry.
ii. To highlight challenges for the adaptation of BIM in dispute avoidance and resolution.

3. Key Issues of Construction Disputes

Construction dispute occurs when the claims and disputes are not resolved timely and completely. Disputes are caused by the project team members due to many reasons but the ones are (a) failure due to inability to perform work duties effectively and in a well-timed manner, (b) failure to express themselves clearly, or (c) incompetence to realize the consequence of instructions (Farooqui et al.2012).

Although previously many research studies have been carried out for the construction dispute minimization and resolution, there are still many limitations that remained to be resolved. Several studies have been conducted to identify the causes of dispute but most of the researchers are failed to differentiate causes from the factors of dispute. Ilter (2012) differentiates both causes and factors of disputes and classified disputes into three categories (1) Extension of time (delay), (2) payments, and (3) Quality of work. This literature-based research centers on exploring the potential opportunities of BIM to resolve the delay and quality-related limitations in dispute resolution and minimization because limitations related to payments are almost the same as the limitations related to the extension of time (delay).

3.1 Extension of Time

Delay is considered the most important cause of the dispute in the construction industry. Construction delay is a universal evident reality not only in Pakistan but also faced by all the countries all over the globe. According to Assaf and Al-Hejji (2006). Extension of time-related limitations along with their groups is listed in Table 1.

Table 1. Extension of Time related Causes of Disputes

S. No	Phase	Extension of time-related Limitations	Limitation Group	References
DR01	Planning Design	contractor's inadequate planning and scheduling	09	(Sambasvan and Soon 2007)
DR02	Construction	contractor's poor site administration	09	(Khoshgoftar et al.2010)
DR03	Construction	mistakes during the construction stage	09	(Kumaraswamy and Chan 1998)
DR04	Planning Design Construction	Slow decision making	07	Chan and Kumaraswamy 1997)
DR05	Design Construction	too many change orders from owners	06	(Sweis et al.2008)
DR06	Construction	site condition	01	(Sambasvan and Soon 2007)
DR07	Design	Slow preparation and approval of drawings	02	(Faridi and El-Sayegh 2006)
DR08	Planning Construction	Poor estimation practices	09	(Al-Barrak1993)
DR09	Design	Poor design	01	(Al-Momani2000)
DR10	Construction	Labor supply	09	(Sambasvan and Soon 2007)

DR11	Construction	Shortage in material	09	(Sambasvan and Soon 2007)

3.2 Quality of Works

Meeting and exceeding the standards and specifications, constructing the projects in compliance with the construction drawings and design details, and the project meeting the local bylaws and codes set by the client is termed as the quality of work (Netscher 2015). Construction defects are one of the most common causes of dispute in the construction industry which puzzle the construction industry for years (Mades 2016). The quality of work-related causes of disputes is listed in Table 2.

3.3 Factors of Causes of Disputes

The extension of time-related and quality-related limitations in construction dispute resolution and minimization are categorized into nine groups. Out of nine groups here, only six groups discussed here are unclear contractual terms, adversarial approaches in handling conflicts, and unfamiliarity with local conditions that cannot be resolved and avoided through BIM utilization. The nine classified groups are as follows: (1) Variations (Muhammad et al.,2015), (2) Late instructions by the employer (3) Inadequate/incomplete specifications (Cakmak and Cakmak 2014), (4) Unclear contractual terms, (5) Adversarial approach in handling conflicts, (6) Unclear scope definition (Cakmak and Cakmak 2014), (7) poor communication (Cakmak and Cakmak 2014), (8) Unfamiliarity with local conditions (Al-Momani 2000) and (9) Technical adequacy of the contractor (Cakmak and Cakmak 2014).

Table 2. Quality of Work-related Causes of Disputes

S. No	Phase	Quality of work-related Limitations	Limitation Group	References
QR01	Planning Construction	Scattered criteria for quality control	01	(Chen and Luo 2014)
QR02	Planning Construction	Difficult to identify the responsibility of project participants	07	(Chen and Luo 2014)
QR03	Construction	The focus of quality control is on the final component	09	(Chen and Luo 2014)
QR04	Construction	Lack of proper contractor supervision of the work	09	(Mades 2016)
QR05	Design Construction	Design complexity	03	(Mades 2016)
QR06	Construction	Lack of control	09	(Erhorn 2015)
QR07	Construction	Failing to understand the specifications and standards	03	(Netscher 2015)
QR08	Planning	Inadequate planning	09	((Netscher 2015))

3.3.1 Variation

It is important to make the design accurately (DR09) to eliminate one of the main causes of construction disputes, which is variation in the design. BIM automatically reviews the geometry, spatial relationships, clearances, and other dimensional and object-oriented criteria and then determines whether the proposed design fulfills predefined user-generated instructions (Estman et al. 2018). Design reviews through BIM models help in understanding the design complexity (QR05). Change in site conditions (DR06) also causes variations which may ultimately result in disputes. BIM assists in developing a 3D model of the existing conditions for a site amenity on a site, or a specific area within an amenity (Pennstate 2010).

3.3.2 Late Instructions by The Employer

One of the causes of disputes in the construction industry is late instructions from the employer (Faridi and El-Sayegh 2006) during the design phase in the AEC industry which results in slow preparation and approvals (DRO7). BIM models help the owner to take quick, definitive, and well-informed decisions as compared to traditional drawings (Azhar 2011) because the accurate geometrical representation of the parts of a building in an integrated data environment is a vital benefit of BIM (Innovation 2007).

3.3.3 Inadequate/Incomplete Specifications

To avoid and resolve dispute specifications and standards must be understandable (QR07) for the participants because poor specifications is an important source of design-related dispute in the construction industry (Jahren and Dammeier 1990; Cakmak and Cakmak 2014) which results in too many changes Orders from the owner (DR05) which ultimately results in mistakes during the construction stage (DR03) and adversely affects the contractor's site planning and scheduling (DR01). Poor design (DR09) and poor planning for quality (QR08) are also results of inadequate specifications.

3.3.4 Unclear Scope Definition

well-defined and managed scope leads to delivering a quality product at an agreed cost and within stated schedules to the participants. Lack of clear understanding or describing the project and scope are the main contributing factors for unsuccessful project (Mirza et al. 2013) Usually contractor makes mistakes during the construction process (DR03) which causes disputes between the participants, which is a result of unclear scope definition (Cakmak and cakCakmak14). Through BIM Scopes of work can be easily isolated and defined (Azhar et al. 2008).

3.3.5 Poor Communication

In construction projects, Various parties are involved and these possess different skills and try to become self-sufficient. But it is proved that for a successful alliance communication is critical (Chengli et al.2001). Improper planning (QR08) (DR01), and poor design (DR09) are causing disputes in the construction industry which are results of poor communication among the participants (Gamil and Rahman 2018). It is often difficult and time-consuming to extract, interpret and communicate complex design information from drawings and documents. Advance visualization skills like 4D planning have the remarkable potential to increase the ability to communicate and interpretation of team members (Dawood and Sikka 2008). BIM is a powerful schedule tool for phasing, coordinating, and communicating planned work (Keymmell 2007).

3.3.6 Technical Adequacy of the Contractor

Accidents, inadequate planning, or miscommunication between the parties cause mistakes during the construction which impact the progress of the project (Sambasivan and Soon 2007). Lack of control (QR06), lack of contractor's planning (DR01), contractor's poor site management (DR02), and mistakes during the construction (DR03) are the causes of disputes which occur due to the technical inadequacy of the contractor.

Poor site administration, inadequate planning, and construction methods are the conflicting issues of contractor firms. Lack of a well-organizational structure and lack of proper procurement schedules are also some of the issues of contracting firms. BIM technology is a very effective solution for these issues because the 3D attributes of BIM assist contractor firms to observe the construction of building in a simulated environment which assists them to improve planning and construction methods and improvising site management. Exploration of the project phasing and construction sequence in ensuring proper consumption of timeline for completion which is assisted by the 4D feature of BIM. Automatic quantity take-offs and cost estimates in BIM enable contractor firms at the design stage. A comprehensive procurement schedule can be achieved and be able to plan their procurement according to the construction phase of the project well before its actual stage of execution if the contractor firm properly implements BIM.

4. Identification of Potential BIM Uses for Construction Dispute Minimization and Resolution

A list of BIM uses that can be used in construction dispute avoidance and resolution is identified in this study. They are existing condition, Quantity take-offs, phase planning (4D Simulation), Site Analysis, Design Authoring, Design Reviews, Drawing Generation, Code Validation, Site Utilization planning, 3D coordination (Clash Detection), Field/Manage Tracking, and Record Modeling as shown in Table 3.

BIM-based existing is a procedure in which a 3D model for existing conditions for a site, facilities on a site, or a specific area within a facility is developed by the team members. For proper material procurement, many BIM software applications have a built-in feature for Bill of Material (Sabol 2008) BIM increases the accuracy in increase to 3% and time will be saved by as much as 80%(Olson and Taylor 2017). Phase Planning (4D Simulation) assists in construction sequencing and space requirements for a building site and its management. To determine the most optimal site location for the construction project site Analysis is a prevailing tool in BIM. The translation of the building design which provides true collaboration among the stakeholders and provides better control and quality control of design, cost and schedule can be done with BIM-based Design Authoring. Design Reviews deliver their feedback to validate various design constraints which can be done in an immersive lab with a Computer-Assisted virtual environment (CAVE)which assists in a well-organized shorten design review consequently resulting in improved communication and coordination among the project stakeholders for better decision making.

BIM models can be used to ensure proper alignment and facilitate automatically which helps out project team mitigate potential project site conflicts effectively with collision control tools a significant step forward in the preparation and distribution of a coordinated design data (Hooper and Ekholm 2010) This will assist in avoiding disputes before they arise which saves the time and for dispute resolution also saves relationships of participants involved in the process of design. Drawing Generation by using BIM is the procedure of generation itself which include representation, design progress, construction, and shop drawings. By using BIM different views (plan, section, elevation, and details) can be quickly generated and automatically update drawing sets based on the changes in the model. BIM-based site utilization planning can be linked with the construction activity schedule to deliver space and sequencing prerequisites. In this process critical space and time conflicts are quickly identified and the time required for the site utilization planning is avoided. Construction system design will decrease the language barriers because it assists in designing and examining the construction of a complex building system. During the construction, commissioning, and handover process Field Manage applications such as web-based applications, cloud computing, pad, smartphones, tablets are used to manage, track, task, and report on quality, safety, documents, and connected to Building Information Modeling (BIM), this process optimizes first work and reduces revisions, with proper communications manage work effectively and with no faults. To aid 3D design coordination and future modeling for renovation BIM assists in record modeling. Record modeling covers the information associated with architectural, structural, and MEP components and can be used throughout the lifecycle of the project.

Table 3. BIM Uses and their Potential Effects in Dispute Avoidance and Resolutions

S. No	Phase	BIM Use	Potential Effect
BU01	Planning	Existing Conditions	Yes
BU 02		Cost Estimation	Yes
BU 03		Phase Planning	Yes
BU 04		Site Analysis	Yes
BU 05		Programming	No
BU 06	Design	Existing Conditions	Yes
BU 07		Design Authoring	Yes
BU 08		Design Reviews	Yes
BU 09		Drawing Generation	Yes
BU 10		Engineering Analysis	No
BU 11		Energy Analysis	No
BU 12		Lighting Analysis	No
BU 13		Sustainability Evaluation	No
BU 14		Code Validation	Yes
BU 15		Phase Planning	Yes
BU 16		Cost Estimation	Yes
BU 17	Construction	Existing Condition	Yes
BU 18		Cost Estimation	Yes
BU 19		Phase Planning	Yes
BU 20		Site Utilization Planning	Yes
BU 21		3D Coordination	Yes
BU 22		Construction System Design	Yes
BU 23		Digital Fabrication	No
BU 24		3D control and Planning	No
BU 25		Field/Manage Tracking	Yes
BU 26		Record Modeling	Yes
BU 27	Operation	Record Modeling	Yes
BU 28		Building Maintenance Schedule	No
BU 29		Build System Analysis	No
BU 30		Asset Management	No
BU 31		Space Manage and Track	No
BU 32		Disaster Planning	No

5. Challenges in Adopting and Implementing BIM in Construction Industry

Adaptation of BIM is slow, however, the industry gaining its benefits of improving constructability, fewer requests for information because of its property of visualization approaches, minimizing cost estimation time and conflicts, and improved coordination between stakeholders (Azhar 2011). BIM is not just a technology but it is also involved in developing new present approaches and methods of construction. Malaysian construction industry facing adaptation issues because of the absence of National standards and procedures and government interests which results in the resistance from people. Companies are trying to cut resistance from people by developing new business hierarchies and by introducing new roles and responsibilities to facilitate people and organizations (Bin Zakaria et al. 2013).

The full benefits of BIM use can be achieved when the BIM is in common practice in the Architect, Engineering, and Construction (AEC) industry. Issues posing difficulty for a small company to adopt indicated by respondents in the different surveys conducted for the adoption of BIM in the industry are interoperability, high cost, too large folder sizes, and use of diverse discipline model software. Top grade management is not supported and a lack of clearly assigned responsibilities for the BIM is also among the concerns which are indicated by respondents (Liu et al., 2010).

6. Conclusions and Discussion

Construction dispute resolution and minimization is a global issue. Many countries opted for different policies and approaches to avoid or resolve disputes. The chief key causes of disputes in the construction industry are variations, late instruction by the employer, ambiguous specifications, uncertain scope definition, poor communication and technical adequacy of the contractor have not been completely resolved yet. Technological advancements in the construction industry such as BIM can effectively handle these problems to minimize and resolve construction disputes throughout the project lifecycle from the planning stage to the operation phase. Therefore, the objective of this paper is focused on the identification of potential opportunities for BIM to effectively resolve and minimize construction disputes.

This paper identified 10 extension of time-related limitations and 8 qualities of work-related limitations, and 13 BIM uses that assists in dispute avoidance and resolution through an extensive literature review. The BIM uses include existing site conditions, cost estimation (Quality take-offs), Phase planning (4D simulation), Site Analysis, Design Authoring, Design Reviews, Drawing Generation, Code validation, Site Utilization planning, 3D coordination (Clash detection), construction system design (Virtual mockup), field/manage tracking and record making. Using BIM claimants and other stakeholders can minimize the documents such as bill of quantities logs, time, and cost schedule which will not only assist in better record-making but it will also help in dispute avoidance and dispute resolution process. All the documents will be stored in a single BIM model instead of keeping them individually. BIM also helps in clash detection, site utilization, and better coordination which ultimately minimize the chances of disputes. 3D coordination using clash detection feature in BIM in different models assists in removing systems conflicts earlier to construction. 3D Coordination through BIM also coordinates building project, visualize construction, make accurate as-built drawings, and reduce RFI'S as compared traditional method.

The end of this paper identified the challenges in a way of adapting and implementing of BIM in dispute resolution and minimization. The challenges include the unavailability of national standards for the adaptation of BIM. Challenges faced by the companies during the adoption of BIM are Lack of demand for BIM from the employer, a Steep learning curve to build, habits of 2D drafting practices, and Lack of availability of skilled BIM manpower knowing implementing BIM, Lack of Technical Skill, and Managing Risks through BIM.

BIM can provide better opportunities for dispute avoidance and resolution when used in combination with some other technologies such as web-based services such as primavera Unifier. And this area needs further efforts to explore the benefits of these services in a combination of BIM for dispute avoidance and resolution.

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Water and Energy Retrofitting – A Case Study of Community Building

Syed Muhammad Yasir Ashrafi[1], Rizwan U. Farooqui[1], Rana Rabnawaz Ahmed[1] and Muhammad Saqib[1]

[1] NED University of Engineering and Technology, Karachi, Pakistan
yasir.ashrafi50@gmail.com

Abstract
Efficiency and effectiveness are the decisive parameters for most of the appliances. It is the same when it comes to planning, designing, constructing, and maintaining a building. Less consumption of electricity and water are key parameters which are being focused by regulatory agencies, water authorities and a variety of stakeholders due to their increasing cost, scarcity, and losses. Green community buildings serve this purpose of making buildings efficient, effective, and environmentally friendly. This case study took NED University Mosque as case study for community buildings. This study investigates; first the latest energy efficient equipment available in the local market to save the energy consumption, followed by economic analysis and its lifecycle cost for different Light-emitting diodes (LEDs) products, based on these parameters the most efficient energy equipment was selected. Water consumption was also considered and for that, different types of button faucets and aerator were analyzed and among them the best one was selected. The application of these alternatives in NED University Mosque proved to be more effective and efficient which is reflected in this study.

Keywords
Efficient, Green Building, Community, Energy and Water

1. Introduction

Energy efficiency is considered as a key factor for green building movement due to its significant economic and environmental benefits (Dwaikat & Ali, 2018). The environment is getting affected negatively by building construction industry. Around the globe 20-40 % energy consumed by commercial and residential building (Zhao et al., 2019). As the population of the world increases and according to (Dwaikat & Ali, 2018), the population can go up to 7 billion to 9 billion by 2050 ultimately will increase the demand for water and energy. Worldwide energy consumption can be reduce by green building practices (Darko & Chan, 2016). As compared to conventional building, green building uses less resources yet providing better indoor quality (Darko et al., 2017). The impact of building on environment can be reduced by green building (Zhang et al., 2019). Both the developed and developing countries started Promoting green building (Kontokosta, 2011; Sharma & Swain, 2011; Dwaikat & Ali, 2018). Worldwide awareness about importance of sustainability in the construction industry is growing, and several other challenges such as climate change, population growth, and fast urbanization have boosted the demand for green buildings for long-term development (Goud & Rajaram, 2016). Green building, which has evolved over three decades, is a managerial and technological method for the building and construction industries to achieve resource and energy sustainability (Wang et al., 2018). There is a lot of emphasis on the need for 'green' structures all over the world, including Pakistan, that are efficient, have minimal negative impact during construction and during their existence, and have a positive impact on the climate and surrounding environment (Farooq & Yaqoob, 2019). Pakistan is among those countries which has highest demand of energy at domestic level, therefore there is an urgent of green building here (Baig, 2018). There has always been a concern of shortage of water and electricity in Pakistan, so there is a need of implementation of efficient retrofits which can enhance performance and, at the same time reduce consumption so as to save valuable resources which is a purpose served by green buildings. Following are the objectives of this study, i.e., first, to decrease the consumption of energy and water, second, to perform life cycle analysis of LED lights.

For energy and water retrofitting, NED University mosque is chosen for case study. Water and electricity consumption is aimed to be decreased. For water consumption, ablution area of mosque was selected. Water consumption can be reduced by using different alternatives i.e. button faucets and aerators. For electricity consumption, the same area was considered. The selected area was also used as a model for lumens calculation and life cycle cost analysis for a period of one year for LEDs.

2. Methodology

As shown in the below Figure 1, this study started from gathering and reviewing literature and observing and considering them for our study area i.e., NED Mosque and our targets which is to decrease consumption of energy and water. The considered options (faucets, aerators, and LEDs) are compared with respect to their availability, cost and different parameters defined below in further description. Existing conditions and appliances were studied, and their data was recorded. Options from the market were applied in the Mosque and data was recorded and compared with the options that were applied previously. Difference in consumption reflects savings in consumption. In case of LEDs, lifecycle analysis was also done which included Return on Investment and Pay Back period.

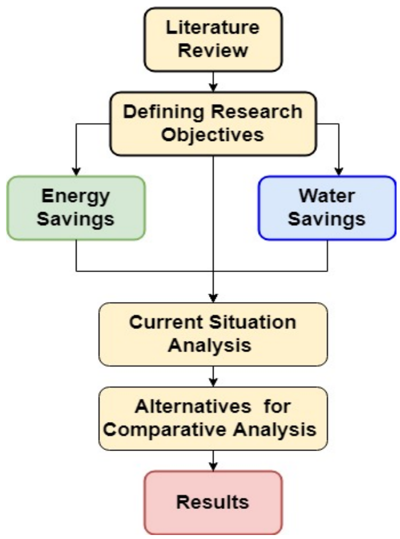


Fig 54. Methodology of Study.

3. Data Collection

3.1. Collection of Existing Data for Energy Consumption

To see the total load of the mosque, One-line diagram was used to record number of appliances and their respective consumption in terms of watts. The consumed energy (watts/hour) in existing condition was calculated. The below Figure 2 gives graphical representation of existing appliances' energy consumption based on the different areas of building.

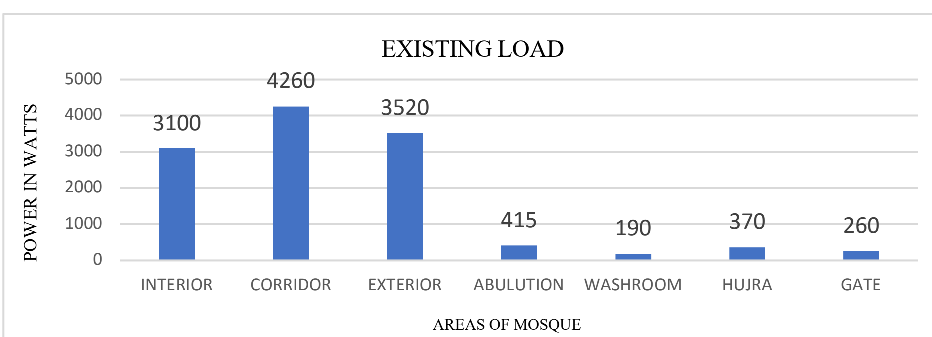


Fig 55. Existing Load of Appliances.

The optimal replacements were considered like LEDs, and they were replaced by the existing ones at a smaller scale. Scale modeling was used to calculate the overall consumption of replacements. The details of existing data are given in Table 1.

3.2. Collection of Existing Data for Water Consumption

Firstly, volume of overhead water tank (OHWT) was calculated, which was found to be 1062.1 cu-ft. The water consumption was computed before and after each prayer. Volume of water was calculated before and after each prayer for two weeks, we can find out the total usage of water per prayer or per day or per week from Figure 3.

Table 12. Loading of Appliances Inside Building

Location	# of Fans (80 Watts)	# of Tube light (40 Watts)	# of Bracket Fan (60 Watts)	# of Bulbs (25 Watts)	# of Exhaust (30 Watts)	# Of System (1000 Watts)	Total Load (Watts)
Interior	15	12	7	0	0	1000	3100
Corridor	23	38	15	0	0	0	4260
Exterior	28	32	0	0	0	0	3520
Ablution	0	6	0	7	0	0	415
Washroom	0	4	0	0	1	0	190
Hujra	1	1	2	4	1	0	370
Gate	0	4	0	4	0	0	260
Total (Load)	5360	3880	1440	375	60	1000	12115

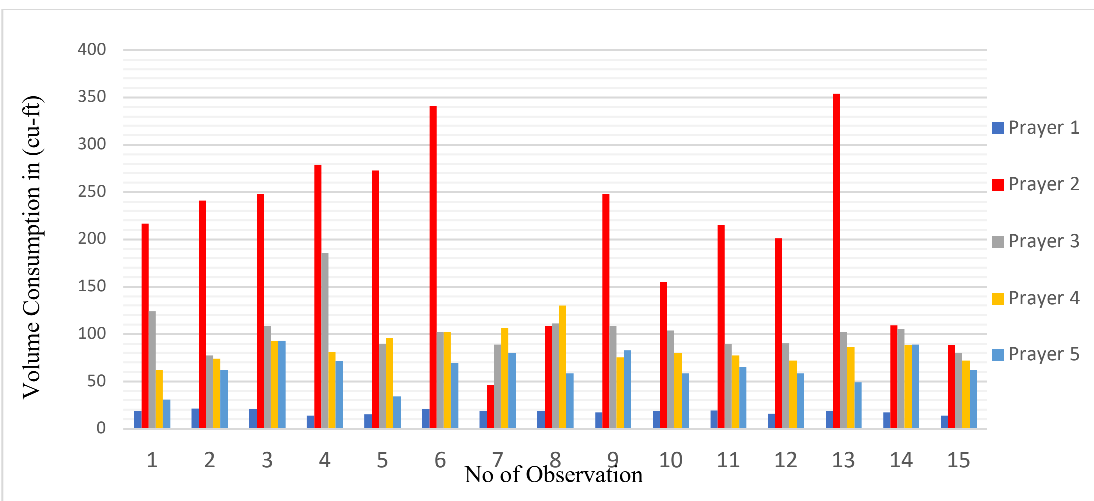


Fig 56. Volume Consumed per Day in (cft)

There are 15 observations means 15 days' observations and every day of 5 Prayers. Most of water was consumed in the noon (Zohar) prayer. After this calculation, now it is the time for the using different substitutes and makes comparison of them with existing conditions. After collecting the existing data, the study focused on a particular area where different strategies can be applied to attain the objectives.

3.3. Area Consideration

The ablution area of Mosque was selected because it had the maximum use of tube lights with respect to time. These use of tube lights and bulbs when gets replaced by LEDs gave a good model for the whole Mosque for further replacement and for lessening of electricity consumption throughout the Mosque. Same area is selected for water as most of the water in the mosque is used in ablution area.

3.4. Criteria of Energy and Water Consumption

Parameters for energy consumption like watts consumed by lights and bulbs, and lumens produced by these lights and bulbs were used to calculate energy consumption. For lessening consumption of water, flow rates and overall volumes consumed are computed before and after applying faucets and fixtures like aerators were considered as parameters to calculate the difference in consumption. They were aimed to be curtailed for making the system efficient.

3.5. Energy Consideration

Market surveys were also done in this regard to check availability, cost and operating quality and warranty of the efficient equipment within its lifetime. Best alternative for replacement of lights and bulbs was considered. Lumens produced by LED lights and their influence area with reflectance factors in accordance with lumens, their consumption, different brands offering warranted and unwarranted products like Phillips, were tested and the best choice considering the above-mentioned parameters was made. It is the process of using measurement to determine the actual savings created within an individual facility by an energy management program. The main purpose of this is to determine actual energy savings (E(saving)) due to the implementation of retrofit measures. Energy savings can be determined by equation below:

$$\boldsymbol{E(saving) = E(pre - retrofit) - E(post - retrofit)} \qquad \textbf{eq (1)}$$

Where, E_{saving} is the energy saving; $E_{pre\text{-}retro}$ is the energy use measured (or estimated) for a defined period in the pre-retrofit period; $E_{post\text{-}retro}$ is the energy use measured (or estimated) for a defined period in the post-retrofit period. Through survey, best replacements were considered with respect to availability, durability, expenses, watts, and lumens (brightness unit). These replacements or products includes, Phillips, Arkin, Dia-Shida, Alpha LED, LED-T8 respectively.

4. Analysis of Products

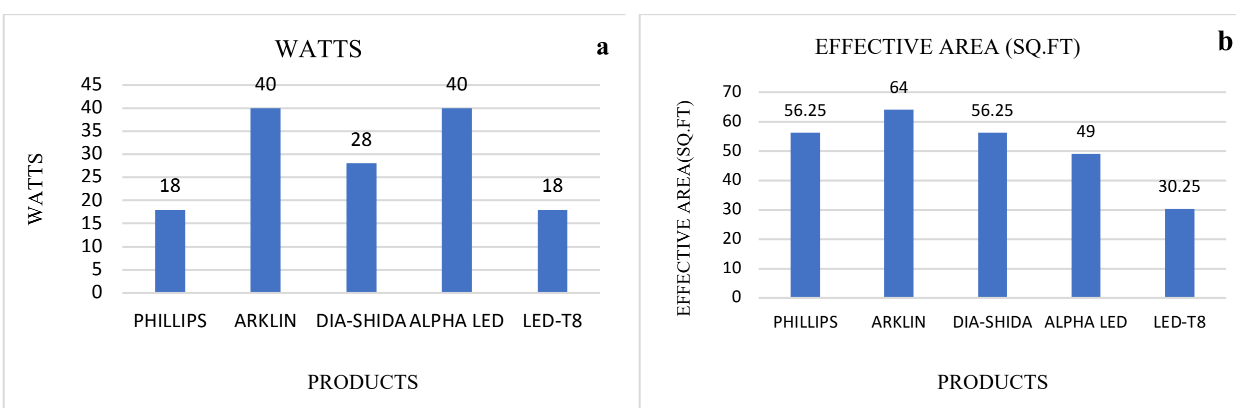
First step involves analysis and comparison of all selected energy saving products based on their watts, lifetime, brightness with respect to their effective area, as well as their price. This analysis will provide primary examination of each product. All alternatives are compared with each other for the better picture of products.

4.1. Watt Perspective Comparison

Comparison of all best efficiency products is initiated based on their watts' utilization. Product having minimum watt utilization will automatically save cost of electricity if other factors are constant and find out watt consumption of each product as shown in Figure 4(a). Figure 4(a) explains that the maximum consumption of watts is 40 which is consumed by Arkin and the minimum consumption is 18 watts consumed by Philips, if other factors including conditions of the product remain unchanged. Watts consumed by Philips LED were minimum in all.

4.2. Comparison on Basis of Effective Area

Effective area means an area where light intensity is high. If the effective area of product is high, it will provide least requirement of lights in that place. It is necessary find out effective area of each product separately and then compared all products as shown in Figure 4(b).



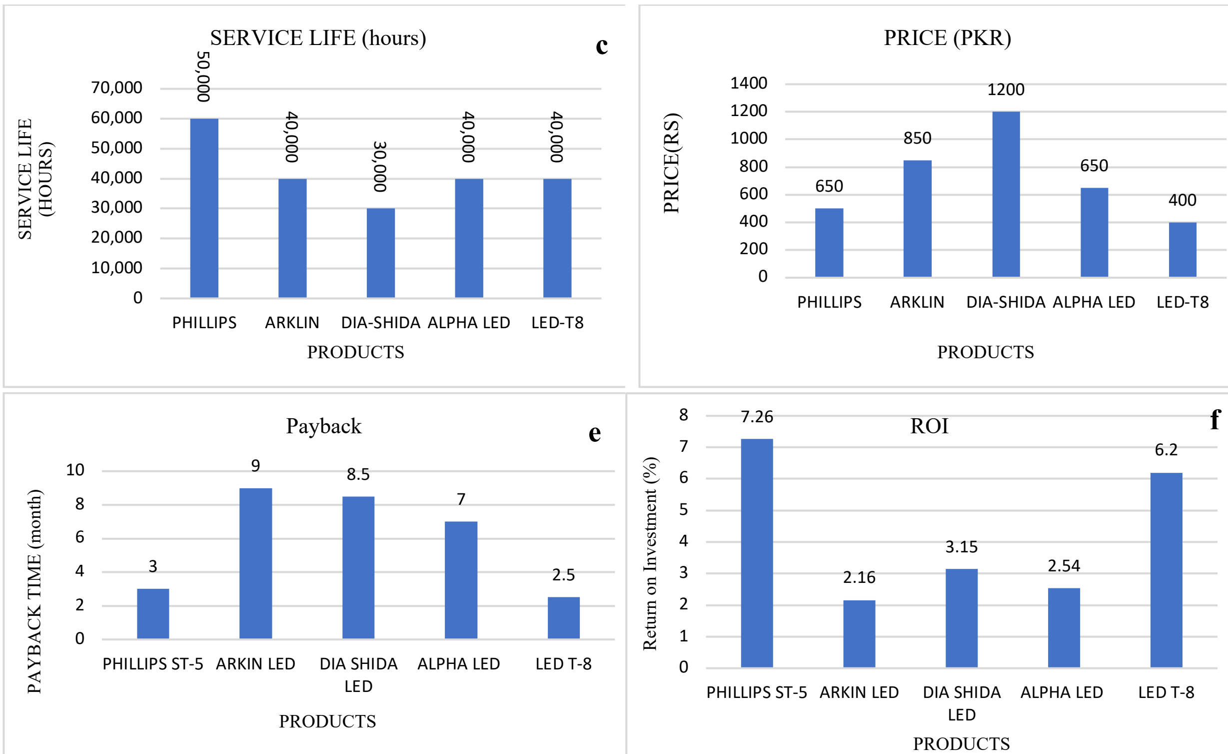


Fig. 57. (a) Watts Comparison of Products, (b) Coverage area of products, (c) Service life comparison of products, (d) Price of each product in PKR, (e) Payback period for each product, and (f) Return on investment for each product

4.3. Service Life Comparison

Comparison based on service life of all the efficient products was calculated for energy savings. Long service life of the product saves the repairing cost for long period of time. It is necessary to find out service life of each product and then compared as shown in Figure 4 (c). Figure shows that the service life of the Philips LED is much more as compared to all other energy devices. So, Philips LED provides least repairing cost because of their durability.

4.4. Price Comparison between the LEDS

During market survey the priority is to consider low pricing because it was necessary to find out effective product but with low market rate. Therefore, the comparison of price of each product as shown in Figure 4 (d). Existing Condition of ablution area was overly devised, lumens were 3300 lumens per each tube light. Light level recommendation in handbook were rendered with 2600 lumens which is tantamount to the Phillips T-5 series tube light and sufficient for brightness in ablution area. By considering all norms, tenets, regulations, and technical aspect, the team was able to devise light design for ablution area and by considering economical aspects, the team come up with the solution that Phillips is the best substitute for the existing condition in the mosque. Phillips LED is performing well in the current scenario, but it isn't finalized until the comparison of Life Cycle Cost analysis is done among the comparative products.

5. Life Cycle Cost Analysis (LCCA)

Life cycle cost analysis (LCCA) is a tool to determine the most cost-effective option among different competing alternatives to purchase, own, operate, maintain and, finally, dispose an object or process, when each is equally appropriate to be implemented on technical grounds. It was done between comparative products with considering their initial cost, maintenance, and service life for 20 years because Philips LED has life span of 20 years. The cost of other parameters including Ballast, starter and Frame was also included. The payback period and return on Investments (ROI) was calculated for a period of one year. The payback period was done in such a way that if the existing tube lights were replaced by the available LED products, then how much time would it take to recover the investment. The least payback period is in Phillips LED. From the Figure 4 (f), it can also be seen that ROI is highest in Phillips LED, so it can be said that Phillips LED is the best among other available products.

6. Water Considerations

Market survey was done for finding out the alternatives for existing faucets (bib cocks). The alternatives were button faucets and aerators. Simple devices that mix water and air can reduce both water flow rates and splashing while increasing areas of coverage and wetting efficiency. For example, faucet aerators can save water use by up to 50% during hand-washing. After doing the market survey two products were selected according to the availability in market, suitability and cost. 1st is Button and the other is Aerator.

6.1. Button Faucet Option

Button faucet is the special type of faucets which can reduces the usage of water very surprisingly. It has a button on its one end whenever a person wants to use water from this faucet he has to push or touch the button and the person whom using water has to push continuously whenever he stops to touch the button the flow of water will be stopped and meanwhile water is saving because in normal faucet this thing is not attainable. The below Figure 5 shows the market available button faucet.

Fig 5. Available Button Faucet

6.2. Aerator Options

Aerator is another substitution for the saving of water. An aerator is often found at the tip of modern indoor water faucets. It can be simply screwed onto the faucet head, creating a no-splashing stream and often delivering a mixture of water and air. During the market survey there were various kinds of aerators available with different openings and different sizes. The below Figure 6 shows, three different types of aerators which were available in market.

Fig 6. Three Types of Aerators

6.3. Comparison between Faucets and Aerators

The main purpose of this is to determine water savings due to the implementation of retrofit measures. Water savings (W(saving)) can be determined by equation below: There were two types of comparison made for mitigating the water consumption, first by flow rate, and second by taking amount of consumed water.

Figure 7 (a) shows the difference in flow rates. There were seven observations of taking flow rates and in each observation, it shows that the flow rate without aerator (normal /existing) faucet is having a high flow rate as compared to a faucet having aerator. By these results a 10-30 % of water can be saved after the introduction of faucets. Whereas the Figure 7 (b) shows the consumption of volume per WUDU by each faucet that is a normal faucet, button faucet and aerated faucet. There is total 7 observations for each faucet with the same person performing WUDU on each of them. After seeing these results, it states that there is a major difference approximately up to 60-70% difference between a normal faucet and button faucet and a 20-30% difference between a normal faucet and aerator faucet. These results show that 60-70% water can be saved after the implementation of button faucets and 20-30% water can be saved after the implementation of aerator on existing faucets.

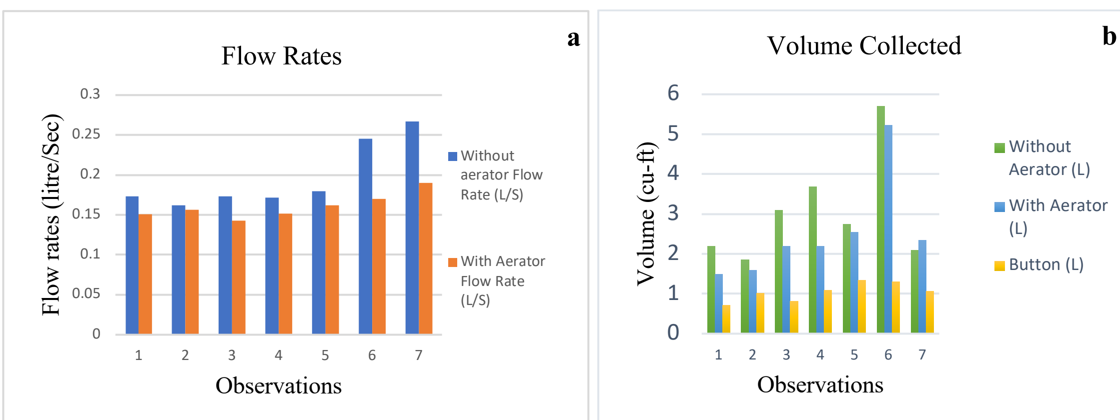


Fig 7 (a). Flowrates Graphical Representation (b) Graphical Representation of Volume Consumption

7. Conclusions

The followings are the conclusion of this case study:

For water consumption, the average volume consumed is 96.3cft per Prayer which is= 96.3 *5= 481.5cft/day. By flow rate water saving comes out to be 0.036 (liter per second). With use of aerator, saving comes out to be 0.537 (Liters).

With use of buttoned faucets, saving comes out to be (2 Liters). Button Faucet is the best alternatives as from the results i.e., 2 liter saving per person per wudu.

For electricity consumption, Phillips T-5 series would be an efficient option as a substitute by considering its lightning intensity, payback period, role in mitigating consumption, savings, and return on investment aspect
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A BIM Based Model for Energy Efficient Retrofitting of an Existing Building – A Case Study

Shahzad Ahmed[1], Rizwan U. Farooqui[1], Muhammad Saqib[1]

[1] NED University of Engineering & Technology, Karachi, Pakistan
shahzadahmed.neduet@gmail.com

Abstract
Construction sector is responsible and accounted for 40% of the energy consumption globally. As one of the largest energy consumers of the world, buildings have great potential to save energy (Liu & Ning 2019). It is also predicted that around half a million tons of CO_2 emission, each year is accredited to the energy use by the residential buildings; the use of retrofitting strategies for better energy efficiency of the existing buildings is the way forward. The improvement of the energy consumption of the already existing buildings represents a key challenge in the past but the modern technology and techniques provide a good platform to analyze what impacts any specific retrofitting strategy will have on an existing building. This research focused on to perform a detailed analysis of retrofitted strategies implemented on a 3D model of a library building (base model) of main campus of NED University. It is aimed to give a complete set of information about the 3D model development, energy analysis and life cycle cost analysis of different retrofitted energy efficient models. Retrofitted models that showed a payback period of the initial cost of the retrofitting, within six years were highly encouraged.

Keywords
Building Information Modeling (BIM), Retrofitting Strategies, Energy Analysis, LCCA, 3D Modeling

1. Introduction

It is recognized globally that there is necessity to pay more attention towards the way buildings are designed and then constructed for better or optimized energy consumption (Akande & Olagunju, 2016). In the context of retrofitting and for the purpose of sustainability the engineers and architects are eyeing for global optimization of energy consumption of already built buildings. With excessive consumption of energy, demand for saving strategies is increased. Over the last decade, a drastic increase in the energy consumption in public buildings is observed. Without compromising on functional needs, better comfort in buildings can be achieved by applying retrofitting strategies on features of diverse buildings envelope (Akande & Olagunju, 2016). Thermal, visual and acoustical, that are part of comfort needs can reduce energy consumption. Some major measures applied in the retrofitting technique of the building envelope for reduction in energy consumption include air tightness, wall insulations, windows glazing type and solar shading (Akande & Olagunju, 2016). LEDs lighting equipment are nearly 70% more energy efficient than any other system (Hermoso-Orzáez et. al, 2017). Application of these simple retrofitting strategies can result in thermal load improvements and cost reduction for buildings (Habibi et. al., 2020)

The construction sector was found responsible for 40% to 50% of the final energy consumption in the countries taking part in the research conducted by El-Darwish & Gomaa (El-Darwish & Gomaa 2017). In the European Union (EU) energy related needs for new buildings are on rise. The betterment in energy performance of the existing building play a vital challenge (El-Darwish & Gomaa 2017). Overcoming this challenge needs to identify cost optimum retrofit techniques and strategies to gain maximum reduction in energy consumption and emission of greenhouse gasses through and within building restoration. The rising number of building retrofit extending the needs of modern building standards is a pointer for the convenience and possibility of energy efficient technologies. Buildings efficiency capabilities and cost curves of building envelope assesses new buildings (El-Darwish & Gomaa 2017). In the scenario of building renovation, there is often object specific extra cost for incorporating energy related retrofit measures into existing buildings, and that give rise to an increased cost range and to doubts related to rusting costs of the building retrofit.

Green retrofits are an upgradation for an existing building either partially or completely for improvement of energy and environment performance, optimized water use, improved quality and comfort of the spaces in terms of natural or artificial light, quality of air and noise. It can be simply equal to as putting new HVAC system or installing solar panels on roof. For sustainability, the greening of existing buildings is one of the leading approaches at relatively low cost and high utilization rates. Even though there are a variety of retrofitting techniques and technologies easily available but ways to identify the most cost effective retrofit measures for projects is still a main technological challenge (Ungureanu et. al., 2013). Various attempts, around the world, have been made in developed countries like UK, USA and Australia towards improving the energy efficiency of existing buildings. Such attempts include methods such as provision of policy guidance, technical and financial support to apply energy efficient measured. Similarly, considerable number of works by many authors have been conducted to find energy efficiency through varied avenues directed to improve performance in energy use of existing buildings (Ungureanu et. al., 2013). Global environment concerns and modern computational tools and techniques have significant impact on how the buildings are designed (Montiel-Santiago et. al, 2020). This research is aimed for cost-optimized BIM models that are sustainable and energy efficient. The study facilitated in the selection of optimized sustainable building envelope alternatives and should improve the operating function of the building that would reduce the need for maintenance.

2. Objectives and Scope

Following are the objectives of the paper:

1. To develop BIM based models for energy optimization through retrofitting strategies.
2. To perform life cycle cost analysis of the retrofitted energy efficient models.

3. Methodology

The research methodology consists of the following steps:

1. Identification of retrofitting strategies through literature review.
2. Development and Energy Analysis of a 3D BIM model.
3. Development and Energy Analysis of retrofitted models.
4. Comparative energy consumption analysis of base model and retrofitted models.
5. Evaluation of Life cycle cost analysis.

Thermal comfort plays a major role in energy consumption and can be achieved by adding slight modifications to original building (base model) by the use of the selected building envelope features which include outer walls, roof, windows and doors based on their efficiency and

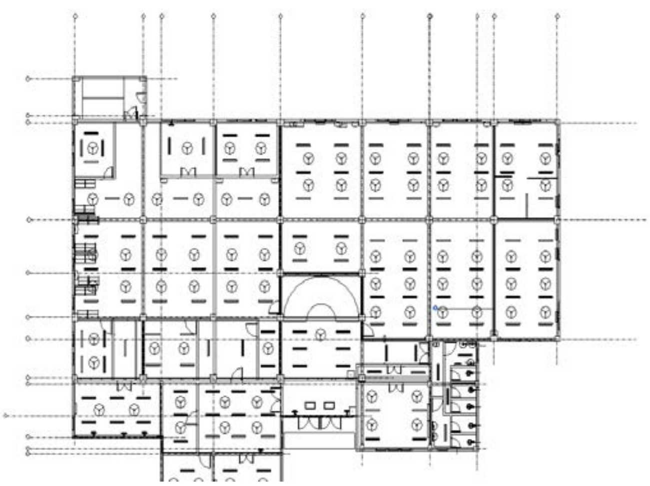

Fig. 58. Architectural Plan View of Case Project

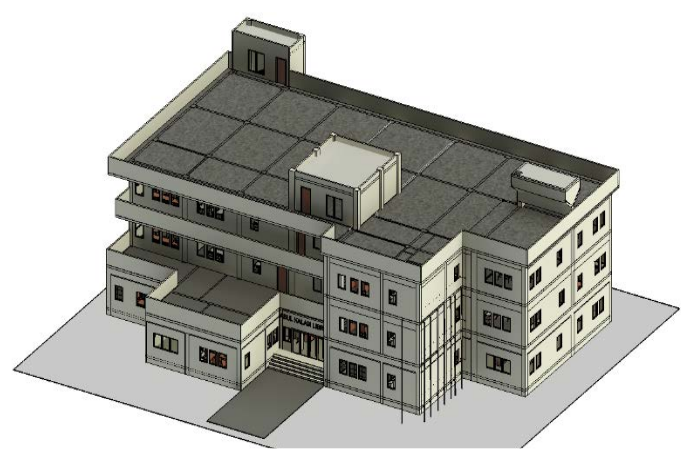

Fig. 2. 3D View of Model

feasibility for retrofit. Various retrofitted strategies were identified through literature and considering local industry practices and classified into various categories.

3.1 Development of BIM Model

Autodesk Revit was used for modeling the building of Project especially for 3D modelling due to the availability of a wide range of library of building elements, materials and other items. Figures 1 & 2 show the Architectural Plan and 3D View of Model of the case building.

4. Analysis

After the development of base model, Energy Analysis was done and the annual electrical consumption of base model was calculated. Various retrofitted strategies were applied on the base model to perform the energy analysis of the different models for optimization purpose.

A comparative analysis between the electrical consumption of the base model and the retrofitted optimized model was concluded and are shown in Table 1. Finally, the LCCA evaluation of the payback period of the initial investment was calculated.

Energy and LCCA analyses of both the base model and the retrofitted models were conducted and the computed results were compared. The annual energy consumption of the base model was calculated to be 151 MWh. The energy consumption of the retrofitted models was compared to the base model as shown in Table 1. The same table showed the individual retrofitting strategies with a drastic change in annual electrical consumption.

Table 1. Energy Consumption of Individual Retrofitted Models

Retrofitted Strategies	Building Components	Energy Consumption (MWh)
Base Model (Library Model)	-	151
EPS 2” Foam	Interior Walls	131
Lasani Acrylic Wood Board	Interior Walls	133
EPS 1.5” Foam	Interior Walls	133
EPS 1” Foam	Interior Walls	137
Insulating Panels	Interior Walls	142
Thermopore Blue	Exterior Walls	121
Isothane Insulation	Exterior Walls	127
Weather Shield Paint	Exterior Walls	146
XPS 1 Inch Board	Interior/Exterior Walls	137
XPS 2 Inch Board	Interior/Exterior Walls	131
XPS 1.5 Inch Board	Interior/Exterior Walls	134
LED Bulb	Electrical	124
LED Tube Lights	Electrical	134
Insutile	Roof, Floor	142
Gravel Roof	Roof	146

After simulating individual models of different strategies, some combined strategies were tested for more improved energy consumption and indoor thermal comfort. Efficient combinations of retrofitting strategies were taken into consideration with respect to least implementation costs, operating and maintenance costs and efficient energy consumptions.

Since LED Tube lights had the least implementation cost, other retrofitting strategies were implemented with combination to LED Tube lights. Figure 3 showed a concise representation of annual electrical consumption with respect to combine retrofitted strategies implemented on a based model.

4.1 Life Cycle Cost Analysis (LCCA)

Life Cycle Cost Analysis for the electrical consumption of the base model was done. Later, for electrical consumption of the retrofitted models was done when different strategies were implemented.

The case project fell under the category c-3(b) of K-Electric's tariff revised in 2020. The tariff schedule has different kWh rates for peak and off-peak hours. The case project is generally operated on weekdays between 8:30 AM to 5:00 PM. This schedule fell under the peak hours as revised by K-Electric. Hence rates of Rs. 21.60 kWh were considered. Figure 4 shows the K-Electric tariff for category C and it represents the cost with respect to building type.

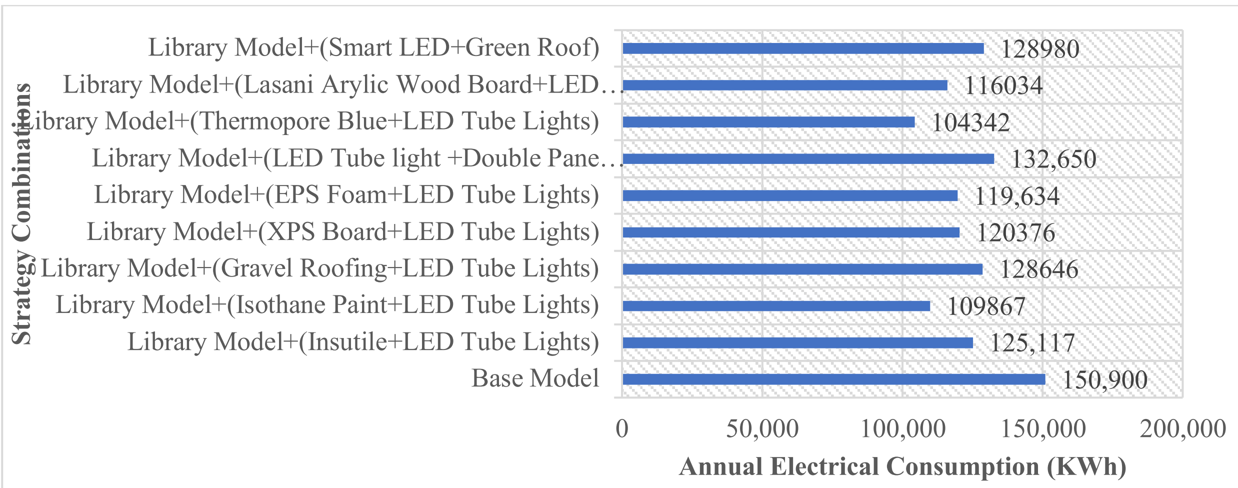

Fig 3. Annual Electrical Consumption of Combined Retrofitted Energy Models

C - Single Point Supply for purchase in Bulk by a Licensee and Mixed load consumers not falling in any other consumer class

S. No	Tariff Category / Particulars	Uniform Tariff		
		Fixed Charges Rs/kW/M	Variable Charges Rs/kWh	
C-1	For supply at 400/230 volts			
a)	Sanctioned load less than 5 kW	-	18.68	
b)	Sanctioned load 5 kW and upto 500 kW	400	18.18	
C-2 (a)	For supply at 11,33 kV upto and including 5000 kW	380	17.98	
C-3 (a)	For supply at 132 and above, upto and including 5000 kW	360	17.88	
	Time Of Use		Peak	Off-Peak
C-1 (c)	For supply at 400/230 volts 5 kW and upto 500 kW	400	21.60	15.00
C-2 (b)	For supply at 11,33 kV upto and including 5000 kW	380	21.60	14.80
C-3 (b)	For supply at 132 and above, upto and including 5000 kW	360	21.60	14.70

Fig 4. K-Electric Tariff for Different Buildings and Timings

Life Cycle Cost Analysis (LCCA) of the base project and retrofitted models were calculated. The escalation and discount rates for LCCA was taken from Statista's inflation rate estimates for Pakistan. The payback period of any strategy was calculated by superimposing the LCCA graph of the strategy over the LCCA graph of the base model.

Figure 5 shows how the two graphs are superimposed and the interaction of the graphs shows the payback period of the initial investment. As indicated LED Tube lights showed payback period of two years and it reduced the total annual consumption from 151 kWh to 134 kWh.

Since LED Tube Lights had a life of 6 years, the strategy needed to be implemented twice in the span of 15 years costing 2 hundred and 50 thousand rupees each time. Due to less investment, the return period was achieved early at about 1 year.

Similarly, payback periods of different individual retrofitted strategies were calculated in Table 5 which shows the concise representation of it.

Table 2. Electrical Consumption of Individual Retrofitted Models

Retrofitted Strategies	Building Components	Energy Consumption (MWh)	Life Cycle Cost (PKR in Millions)	Savings (PKR in Millions)	Payback Period (Years)
Base Model (Library Model)	-	151	33	-	-
EPS 2" Foam	Interior Walls	131	32	1	8
Lasani Acrylic Wood Board	Interior Walls	133	29	4	9
EPS 1.5" Foam	Interior Walls	133	31	2	6
EPS 1" Foam	Interior Walls	137	31	2	5
Insulating Panels	Interior Walls	142	30	3	9
Thermopore Blue	Exterior Walls	121	30	3	6
Isothane Insulation	Exterior Walls	127	29	4	4
Weather Shield Paint	Exterior Walls	146	31	2	7
XPS 1 Inch Board	Interior/Exterior Walls	137	31	2	5
XPS 2 Inch Board	Interior/Exterior Walls	131	32	1	8
XPS 1.5 Inch Board	Interior/Exterior Walls	134	31	2	6
LED Bulb	Electrical	124	28	5	1
LED Tube Lights	Electrical	134	30	3	1
Insutile	Roof, Floor	142	34	-1	-
Gravel Roof	Roof	146	32	1	4

LCCA of combine retrofitted strategies were performed to do a comparative analysis if the combination were more effective in terms of energy reduction and payback time compared to the individual retrofitted strategies. Since LED Tube Lights were the most effective in terms of energy reduction and implementation cost, LCCA was performed on the combinations made only with LED Tube Lights. The initial investment was the sum of the initial investment of LED tube lights and the other strategy used in combination. Since LED tube lights had a life span of 6 years, only the cost of LED tube lights was reapplied in year 5 and 11 respectively.

Table 3. Electrical Consumption of Combined Retrofitted Models

Retrofitted Strategies	Building Components	Energy Consumption (MWh)	Life Cycle Cost (PKR in Millions)	Savings (PKR in Millions)	Payback Period (Years)
Base Model (Library Model)	-	151	33	-	-
LED Tube Lights + Lasani Acrylic Wood Board	Interior Walls	133	29	4	9
LED Tube Lights + EPS 1.5" Foam	Interior Walls	120	28	5	2
LED Tube Lights + EPS 1" Foam	Interior Walls	120	28	5	2

LED Tube Lights + Thermopore Blue	Exterior Walls	104	27	6	4
LED Tube Lights + Isothane Insulation	Exterior Walls	110	27	6	9
LED Tube Lights + XPS 1 Inch Board	Interior/Exterior Walls	120	28	5	3
LED Tube Lights + XPS 2 Inch Board	Interior/Exterior Walls	111	28	4	4
LED Tube Lights + XPS 1.5 Inch Board	Interior/Exterior Walls	116	29	4	4
LED Tube Lights + Insutile	Roof, Floor	125	31	2	9
LED Tube Lights + Gravel Roof	Roof	129	29	4	6

6. Conclusions

The 3D model of Library building of main campus of NED University was developed which was later used for energy analysis of individual and combined energy retrofitting purposes. The energy results of simulated building analysis and actual energy consumption of the existing building were similar which shows the accuracy of the model generated. After applying the retrofitting strategies, a clear reduction in the energy consumption was seen. The following table summarizes the efficient individual retrofitting strategies in terms of energy consumption.

Table 4. Efficient individual retrofitting strategies

Building Envelop	Individual Strategies & Annual Energy Consumption
For Interior Walls	EPS 2” Foam (Annual Energy Consumption = 131 MWh)
For Exterior Walls	Thermopore Blue (Annual Energy Consumption = 121 MWh)
For Electrical Appliances	LED Bulb (Annual Energy Consumption = 124 MWh)
For Roof	Insutile (Annual Energy Consumption = 142 MWh)

The top three strategies which were effective as combine retrofitted strategies are as follows;

(i) Thermopore Blue & LED Tube Lights (Annual Energy Consumption = 104 MWh)
(ii) LED Tube light & Isothane Insulation & LED Tube Lights = 110 MWh)
(iii) Lasani Arylic Wood Board & LED Tube Lights (Annual Energy Consumption = 116 MWh)

Based the energy reduction and the implementation cost, the payback time of retrofitting strategies showed that the combine retrofit models of LED lights with interior walls were proven to be an energy efficient and cost effective retrofit.

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Knowledge Management Framework for Integrated Project Delivery

Rana Khallaf[1] and Chimay Anumba[2]
[1]Assistant Professor, Structural Engineering and Construction Management Department, Faculty of Engineering and Technology, Future University in Egypt
rana.khallaf@fue.edu.eg

[2]Professor and Dean, College of Design, Construction, and Planning, University of Florida
anumba@ufl.edu

Abstract
Knowledge has become pertinent in this digital age, especially with the advent of Industry 4.0. Various forms of knowledge are continuously collected for use in the construction industry to overcome its fragmentation and many inefficiencies. Integrated Project Delivery (IPD) has been promoted as a delivery method because it relies on the involvement of all stakeholders during the project stages to successfully deliver a project with the highest value to the owner and lowest waste. This necessitates that all information must be shared with the stakeholders in a timely manner for swift and informed decision-making. Therefore, this paper proposes a framework for Knowledge Management (KM) in IPD projects using the Internet-of-Things (IoT). Firstly, the knowledge components in an IPD are discussed and classified into KM pillars. The framework is then delineated and discussed, which consists of four stages: data acquisition, data integration, knowledge management, and visualization. This framework is beneficial to IPD participants because it promotes the collection and storage of tacit and explicit forms of knowledge to create an inclusive repository. It also promotes real-time sharing of information for value-based decision-making.

Keywords
Knowledge Management, Integrated Project Delivery, Internet-of-Things.

1. Introduction

Integrated Project Delivery (IPD) has gained momentum over the years as a suitable delivery method for construction projects. It is a collaborative delivery method that aims to increase value to the owner, reduce waste, and maximize efficiency. Although IPD has many merits, it still faces similar challenges to other construction project delivery mechanisms. These relate to the fact that the construction industry is fragmented and project-based, which hinder the collection and dissemination of knowledge (Forcada et al. 2013). While IPD provides an appropriate platform for the disparate disciplines involved in a construction project to work collaboratively in the delivery of a facility, there are still limitations in the mechanisms for knowledge management at this project organization level.

The data-rich era in which construction projects currently operate is characterized by a greater volume, velocity, and variety of data, which is captured (often in real-time) using a wide range of sensors, unmanned aerial vehicles (UAVs) and other data acquisition technologies from construction sites and project repositories. This makes it imperative that project teams have appropriate mechanisms for managing data, information, and knowledge emanating from increasingly complex construction projects. This requires the implementation of a 'project organization' level knowledge management system (Anumba et al., 2005; Anumba, 2009) that comprises both technologies and techniques (Ruikar et al, 2007), and enables the 'live' capture and reuse of project knowledge (Tan et al, 2010). The availability of project knowledge would create transparency among all the participants to avoid any information asymmetry, and minimize the problems associated with lessons learned by some project participants not being communicated to all members of the project team. Hence, this paper proposes a knowledge management framework for IPD projects. This framework is intended for practitioners procuring projects through IPD and aims to provide a structured method for knowledge collection, sharing, and storage.

2. Knowledge Management

Knowledge Management (KM) is defined as identifying, creating, organizing, and disseminating information that can be used for decision-support, research, or learning (Harris et al. 1998). Other knowledge management definitions include the following:

- Knowledge management is the discipline of creating a thriving work and learning environment that fosters the continuous creation, aggregation, use, and re-use of both organizational and personal knowledge in the pursuit of new business value as defined by Xerox Corporation (Source: Cross (1998));
- Knowledge management is 'any process or practice of creating, acquiring, capturing, sharing, and using knowledge, wherever it resides to enhance learning and performance in organizations' (Scarbrough et al, 1999).

Within the context of this paper, Knowledge Management (KM) can be simply defined as a systematic process of capturing, transferring, and sharing knowledge to add competitive value (Drucker, 1993; Skyrme and Amidon, 1997) and to improve performance (Robinson et al, 2001; Robinson et al, 2004). It aims to synthesize and refine data from multiple sources to create a repository of knowledge. According to Uden and He (2017), the most important asset an organization has is knowledge.

The construction industry is plagued by the inefficient management of information in its projects (Xiet et al. 2019) and some of this can be attributed to the fragmentation of the industry in terms of processes, participants, tools, etc. As such, construction knowledge needs to be captured, structured and managed for maximum utilization. Knowledge management can be divided into four main components: organizational culture, knowledge acquisition and dissemination, policies and strategies, and training and mentoring of employees (Bozbura 2007). These areas are not always utilized in all construction projects.

Knowledge can either be tacit or explicit, and the combination of both forms is needed to understand the entire picture (Khallaf et al. 2018). Explicit data includes contract documents, drawings, or specifications, while tacit data includes know-how, experience, and competence. Much of the training and experience of construction professionals is based on a balance between codified (explicit) knowledge and tacit knowledge (Anumba and Pulsifer, 2010). Specialized expert knowledge and problem-solving know-how are the real products of knowledge-intensive industries (Egbu and Robinson, 2005) such as construction. Zhang et al. (2013) found that tacit knowledge sharing among the IPD team leads to flexibility and better connections among the participants. It is also important for IPDs because of its cooperative nature and the need to create new methods to reach the target cost. A structured KM framework is needed to combine all forms of knowledge for ease of use. Effective knowledge management can lead to various benefits including streamlined processes, accelerated knowledge creation, and increased profitability.

Knowledge Management Systems (KMS) are tools that help manage the knowledge available. They typically consist of a set of tools, made up of technologies (IT Tools) and techniques (non-IT tools). Both technologies and techniques are equally important to support different KM processes (Anumba et al, 2005). KM technologies rely on an IT infrastructure and can be in various forms that include databases, repositories, online platforms, or context-specific retrieval systems (Uden and He 2017). KM techniques do not depend on IT and include brainstorming, communities of practice (CoPs), face-to-face interactions, post-project reviews, recruitment, mentoring, apprenticeship and training (Ruikar et al, 2007). Thus, a KMS is composed of both physical and digital assets, and a set of techniques which can facilitate knowledge transfer between project stakeholders. It can also provide real-time visibility and traceability for the stakeholders involved. The following section will introduce IPD and the flow of knowledge throughout the projects.

3. Integrated Project Delivery

The Integrated Project Delivery (IPD) method relies on the joint participation of all stakeholders for the successful delivery of a project. These stakeholders include the owner, designer, contractor, and subcontractors. Among the challenges that face IPD adoption are integration of information and lack of knowledge management systems (Roy et al. 2018). A major source of delay in projects is from locating and transferring data (Fischer et al. 2014). In the traditional project delivery approach, project data is usually scattered among the participants and is not openly shared. However, in the IPD approach, since all participants are expected to work together, project information must be shared to avoid any delays or information asymmetry between participants. This involves a large volume of information that can pertain to resources, operations, or labor. This information is then converted to knowledge (by the addition of contextual information), which can aid in reducing waste and increasing the amount of value-added work throughout the project.

For an IPD to be successful, open communication and knowledge sharing between parties must occur. To foster collaboration, many tools and techniques have been developed and used for construction projects. These include the Last Planner System (LPS), Building Information Modeling (BIM), Internet-of-Things, and many more. Previous research have mainly focused on using LPS and BIM for IPD projects. Reda and Khallaf (2019) proposed a framework for LPS adoption in Egypt. Fischer et al. (2014) proposed a framework based on integration of the product, process, and organization. Ilozor and Kelly (2012) studied the interactions between BIM and IPD and their combined effect on the design and construction processes. Ma et al. (2017) proposed a collaboration platform for IPD participants to motivate the use of this method by reducing the need for constant physical presence. However, there are unexplored technologies that can support IPDs such as the Internet-of-Things (IoT). According to Hickethier et al. (2013), information is not equally distributed among all participants and that some participants will have more information than others. Although increasing the information available to everyone is aimed at increasing the efficiency, it can also backfire from information overload. This reinforces the need for a unified framework to collect and share knowledge among participants across all disciplines/teams to increase project success. Robinson et al. (2010) explored the issue of governance and knowledge management in public-private partnership (PPP) projects and made several important observations and recommendations that would translate well to the IPD environment. This paper builds on some of these by proposing a framework for knowledge management in IPD projects that leverages the emerging IoT technology. The next section introduces IoT and the tools available for construction projects.

4. Internet-of-Things (IoT)

4.1 IoT in Construction

The Internet-of-Things can be defined as interoperable objects, whether physical or virtual, that are connected together. These connected 'things' enable the collection, storage, and distribution of data over a network. Sensors are used to enable the transmission of real-time data through wireless networks. This real-time data can be shared among the project stakeholders such as the owner, contractor, and vendors for quick decision-making (Uden and He 2017). Real-time monitoring of physical assets such as buildings or infrastructure systems can also be performed. IoT has been used for monitoring different things such as smart libraries, transportation, smart cities, energy, industrial automation, and tower crane safety monitoring (Bai et al. 2012; Gul and Bano 2019; Xie et al. 2019). They have also been used to monitor the physical environment (or facilities) in buildings for the lighting, security, firefighting, air, ventilation, room temperature, and energy (Xie et al. 2019). This can help in understanding the current conditions and patterns, and in proposing modifications for the future. It can also minimize the need for physically checking the assets or performing unnecessary scheduled maintenance.

Tools for IoT

According to Ben-Daya et al. (2017), the collecting and processing of data, especially in a timely manner, has been an issue. This can be solved by utilizing new technologies like IoT. The Gartner Institute estimates that the number of interconnected devices will reach 20 billion in 2020 (Gartner Inc, 2017). These devices include sensors, Global Positioning Systems (GPS), Radio Frequency Identifiers (RFIDs), actuators, and mobile phones. RFIDs enable automatic object identification and location and can be used for product identification, data acquisition, and tracking. RFID tags can be placed on the procured materials to label them and ensure quick retrieval and installation. For example, placing these tags on window panels can help in determining where to install each one, thus increasing productivity and reducing costs (Li 2018). They can be used to sense the location of an object, building component, equipment, or even personnel. This can help in determining the crew's productivity and the number of hours of use for equipment or its downtime. Thus, proactive or condition-based maintenance can be performed instead of prescheduled maintenances that may hinder operations if unnecessary. GPS can be used for spatial positioning while GSM/GPRS are used for wireless transmitting. Mobile phones can be used for their Bluetooth connectivity or to transmit real-time information from the site personnel to the rest of the team. Using a combination of these tools/technologies can be effective for streamlining operations in an IPD.

Many studies have found that construction can benefit from emerging technologies such as IoT and cloud computing (Anumba et al, 2020). This connectivity enables quick knowledge sharing and asset management. There are many benefits to using IoT for KM; these include: (i) collecting data from real-time sensors; (ii) generating more data from diverse outlets; (iii) enabling the automation of decisions and autonomy of applications/devices; (iv) predicting future behaviors; (v) measuring on-site progress; (vi) offering visibility for the entire supply chain; and

(vii) providing early warning for conditions that require immediate intervention. The use of IoT can then help in the creation of a knowledge-based decision system for construction projects.

5. Knowledge Management Framework for IPD

5.1 Knowledge Components

Knowledge consists of the information and data as well as the methods through which it is processed and the context for its use. An IoT framework is needed to streamline the processes in construction and reduce non-value-added work. This paper proposes a framework for knowledge management for IPD projects based on extensive literature review conducted. The framework uses the concept of the Internet-of-Things to collect, store, and analyze the data. This framework can enable the sharing of real-time information between all parties involved. It can also reduce the amount of waste occurring from non-value-added work, rework, errors in design, ordering excess material or ordering material earlier than needed. The proposed IoT framework can provide a repository of information that enables diagnostics and analytics throughout the project phases.

Figure 1 shows the knowledge components of an IPD. These knowledge components can either be from tacit or explicit sources. Another classification depends on the medium through which a component is conducted, which can be divided into physical and non-physical. Physical components include templates, plans, or drawings, while non-physical components rely on people such as huddles, workshops, and big room meetings. Another example is A3, which is a structured process of framing a problem, solutions, and action plan (on an A3 paper). Kanban boards are another project management tool used to visualize the work to be done and the flow. The QA/QC, safety, lean, and design plans are all grouped into 'Plans' (in Figure 1). Four KM pillars were identified according to Ahmed and Elhag (2017), which are people, process, technology, and information. Each knowledge component was assigned to one or more KM pillar depending on its application. For example, dashboards are created for project information to be shown using technology and the 'Big Room' refers to the physical location where all project participants meet as well as the collaborative process.

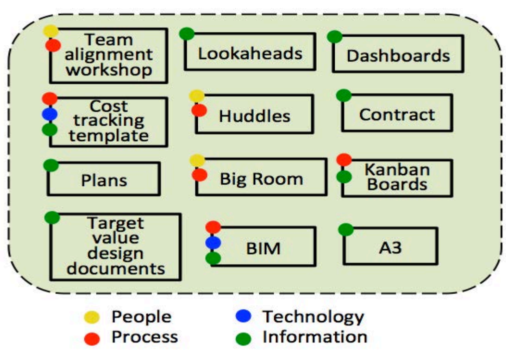

Figure 1. Knowledge Components in

5.2 Knowledge Framework

A knowledge framework is typically composed of multiple layers that structure how knowledge will be captured, managed, and disseminated. Figure 2 shows the knowledge management framework for IPD projects. The user layer shows the three contractual parties: the owner, designer, and constructor. These are the main participants, although there are sub-participants under them. For example, there are 'Cluster Groups' who are co-located and operate in cross-functional teams and can be under any of the three parties (Hickethier et al. 2013). These members are supervised by the 'Core Group', which is composed of an executive committee. The framework is composed of four layers:

1.The first layer is the data acquisition layer where the required data and technology are identified and acquired. Two types of sources are recognized: physical objects and non-physical sources. The non-physical sources are the meetings, team alignment workshops, and user expertise. During these events, the users discuss project information and convert it to knowledge through the use of A3 and Kanban boards to visualize the information. The information obtained includes both vertical and horizontal information. The technologies used in this layer include sensors and RFID tags and inter-equipment connection can also be enabled. The two physical sources suggested are:

a. Sensors: can be used to collect data on the physical environment such as temperature, which may affect inventory.
b. RFID tags: can be used on equipment (to determine the location, utilization, and downtime), on materials (to determine the location, available inventory, and rate of use), and on personnel (to determine their location and productivity). This information can be used to find the production rate for each activity and the productivity of crew. This can then be used to predict estimates for future activities and suggest modifications to lookaheads based on previous/current situation.

The data from these physical objects can be used for space management and planning. It can also be used to track the procurement loop from delivery to installation, hence overlooking the entire cycle. Data on equipment and worker location and their movement across the site can be captured. This can be linked to progress made on an activity, which can also be linked to visual data captured using unmanned aerial vehicles. This would enable streamlining the acquisition and sharing of data among parties to an IPD, which would improve the project delivery process.

2. The second layer is for data integration and storage through a wireless network. This layer collects the transmitted information and stores it to be sent to the computing layer for processing. Data such as activity progress, material levels available, and equipment usage are stored here.

3. The third layer is the knowledge management layer that is responsible for the processing of data. Analytic tasks such as diagnosis, assessment, or prediction can be done using artificial intelligence. For example, machine learning can be used to determine patterns related to work package durations and reasons behind delays in activities. Data can also be stored in the cloud to allow for remote access. A cloud-based intelligent monitoring and control system can then be adopted for the projects.

4. The fourth layer is the visualization layer. Here, the data is translated to readable text and displayed visually using tools such as dashboards, BIM, and Virtual Reality (VR) or Augmented Reality (AR). These tools can be used during the design or construction phase. During the design phase, BIM can be used not only to visualize the project, but also to monitor the cost, schedule (from Last Planner), and sustainability issues for a holistic view of the project. Virtual/Augmented Reality are a step higher than the 3D view from BIM and can offer a full immersive experience for the participants. Using VR, a virtual model can be constructed, which can aid in visualizing the product at an early stage and making changes to it. Both VR and AR can be used for safety training before/during construction. They can also be used to show details of the final facility/building to make decisions on it instead of having to construct a real-life mockup. Additionally, they can be used to evaluate alternatives and choose between them. During construction, a dashboard can be created to view project control data or real-time work package data. It can be used to track progress, expended resources, and to keep track of the budget. After construction, BIM can be used to create as-built drawings for facility management during the operation and maintenance phase post project delivery.

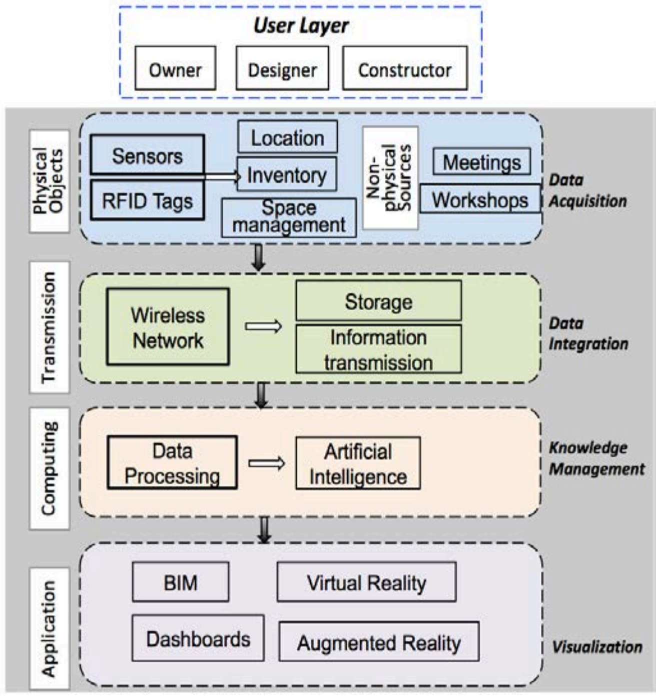

Figure 2. Knowledge Management Framework for IPD

Although there may be variations to the contractual methods in an IPD, the most common one is the single multi-party contract between the owner, builder, and constructor. Additionally, one commonality between all IPDs is the partnership and relation between all contracting parties regardless of the contract type. This partnership allows them to work together for a fixed contract amount whilst sharing risk and reward as well as responsibility.

The knowledge components (from Figure 1) can be shared among the participants through the user layer thus converting the data from tacit (through meetings or huddles) to explicit. The knowledge obtained from the users (tacit) and physical objects (explicit) is combined to create the full knowledge repository. The proposed framework can allow remote access to project participants so that it is not necessary for them to be physically located on-site at all times. It also serves the integration of four KM pillars in a project, which are people, process, technology, and information. It can support the just-in-time ideology for procurement to reduce inventory and can aid in real-time cost planning and quantity measurements. Additionally, it supports the dynamic nature of IPD and the quest for continuous improvement and innovation. This will also ensure alignment of business objectives and strategies between the various parties from the beginning of the project. All this data can be stored in a searchable lessons-learned repository after the successful completion of the project to be used for future projects.

6. Conclusions

The use of IoT for KM has many potential benefits. It can enable the collection and analysis of large datasets and informed decision-making based on multiple data sources. It can also enable predictive and prescriptive analytics. This is especially beneficial to IPD because of the unique nature of projects that require the presence of all participants throughout the project phases. IPD is seen as a solution for many of the problems that face the construction industry; however, it needs a structured framework to foster efficient and effective collaboration and knowledge management. The proposed framework aims to connect all participants, achieve effective knowledge transfer, foster collaboration, and foster human-machine interactions that can lead to automated/semi-automated procedures in the future. Smart technologies can also be used in the construction phase and added to the framework, such as autonomous equipment. Finally, this framework takes into consideration four main KM pillars, which are people, process, technology, and information. Further research can be conducted on each of these factors to identify their specific components and their effect on the knowledge management process in IPD projects.

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A GIS Evaluation for Accessibility to Wash Facilities in Mantapala Refugee Settlement

Kalle Musalilwa Silwimba[1], Erastus Mishengo Mwanaumo [2, 3], Penjani Nyimbili[2], Wellington Didibhuku Thwala[3]

[1] University of Lusaka, Lusaka 10101, Zambia
[23] University of Zambia, Lusaka 10101, Zambia
[3] University of South Africa, Pretoria, South Africa

Abstract

The paper sets to address the challenges of planning, implementing and monitoring of Water Sanitation and Hygiene (WASH) interventions in Mantapala Refugee Settlement (MRS) through combination of the paper-based method and geographical information systems (GIS). This method was used to assess the accessibility of WASH services by monitoring the interaction with other infrastructure such as the distance between water points and households. To incorporate spatial, qualitative and quantitative concepts, the research adopted the socio-spatial grounded theory and a non-experimental design specifically a cross-sectional study. The study identified 51 water points which translated to providing 31.88 litres per person per day (l/p/d) of clean water, with 75.69% of households covering less than 200 meters to fetch water. 21.88% of the households had decent latrines, 70.71% had permanent substructures and 7.41% had no latrines. 62 households walked less than 50 meters to the constructed refuse bays out of 3,574 households. The study concluded that organizations should consider employing this approach because decisions can be made with adequate information, leading to the optimization of scarce resources. Additional features such as contours made it possible to identify and avoid constructing dump sites/landfills along the flood-prone areas as well as a basis for designing drainage networks and solid waste management plans.

Keywords

Geographical Information system (GIS), Mantapala Refugee Settlement (MRS), United Nations High Commissioner for Refugees (UNHCR), Water Sanitation and Hygiene (WASH)

1. Introduction

Mantapala Refugee Settlement (MRS) was established at the end of 2017, as a response to the high number of asylum seekers from the neighbouring Democratic Republic of Congo (DRC), who crossed over to Zambia with the hope of finding a haven (UNHCR, 2019). The settlement is located approximately 30 kilometres from Nchelenge central business district in Luapula Province of Zambia and has a population of 15,000 individuals, who occupy 3,574 households which span a land cover of 1,800 hectares (UNHCR, 2019). Like many other settlements and camps, Mantapala is faced with developmental challenges such as the provision of decent sanitation facilities and clean and safe drinking water for persons of concern (UNHCR, 2018; Ahmed, et al., 2021).

2. Literature Review

To curb these gaps, several humanitarian WASH partners including United Nations Children's Fund (UNICEF), Norwegian Church Aid (NCA), New Apostolic Church Relief Organization (NACRO), Zambia Red Cross Society, World Vision Zambia (WVZ) and Oxfam came on board to carry out developmental activities, using both the Central Emergency Response Fund (CERF) and their resources (UNHCR, 2018). The various WASH partners chaired by the Government of the Republic of Zambia (GRZ) and the United Nations High Commissioner for Refugees (UNHCR) formed the WASH coordination working group with the aim of utilizing the available resources in the most cost-effective manner. With the available human resource, the working group adopted the paper-based method (UNHCR, 2018). In this approach, data is collected and consolidated manually into a spreadsheet for review and sharing with other key players such as donors (Agung, 2017; Newman, et al., 2020; Mambwe, et al.. 2021). It was, however, observed that the paper-based approach was not adequate for organizations to make an informed decision because of its inability to provide a geographical linkage between the WASH services and the users as well as to infrastructure, both existing and new (Bohnet, 2015; Day, 2018). This made it difficult to trace interactions between WASH services (boreholes, toilets, washing facilities and solid waste sites) and other facilities/features within the settlement such as households, clinics, playgrounds, schools, and rivers (Achilli, 2015; Evans, 2017).

3. Methods

3.1 Research Design

To incorporate spatial, qualitative, and quantitative concepts, the research adopted a *grounded theory*, particularly the *socio-spatial grounded theory*. The research further employed a non-experimental design, specifically, a *cross-sectional study*. This is because the study took place at that time point and conclusions were made based on the observations at this moment in time. This study provided representations of WASH facilities in Mantapala Settlement by describing existing facilities and how they are used. Data was collected on the households, WASH facilities and other infrastructure in Mantapala Settlement both through mapping of the settlement and questionnaires.

3.2 Data collection (Mapping WASH facilities)

Location coordinates for each desired feature were collected (i.e. water points, dumpsites, institutional and household latrines and all existing infrastructure such as schools, houses, roads, clinics etc.) using a handheld GPS receiver device and then loaded into QGIS software to generate the map for the entire settlement. It covered the entire population of 3,574 households (approximately 15,000 persons of concern) within the Mantapala settlement.

3.3 Data collection (sample households for the survey)

This study adopted a *stratified random sampling approach.* This method was preferred because the population of interest was segmented into 19 blocks each with a different number of households (HHs).

This was done in the following steps by:

1. Calculating a representative sample size (n) given by:

   $n = \frac{N}{1+N(e)^2}$ (Yamane T. 1973).

   Where:

   $n =$ Signifies the sample size, $N =$signifies the population under study, $e =$signifies the margin error

   This method was preferred because there was a finite population.

   In this case we had,

   N=3,574 HHs,

   e=5%,

   n=3,574/1+3,574(5%)², where n=360, being the sample size

2. Obtaining the proportion of the number of households in each block to the total number of households.

   For example, block 8 had 99 HHs.

   Its proportion of the number of HHs is 99/3,574 = 0.028

3. Then, the corresponding proportion for each block in the preceding calculation was then multiplied with the total sample size calculated in step 1 to obtain the representative sample size for each block.
   For example, block 8 with proportion of 0.028 will have, n=360 x 0.028 = 10 HHs.

4. After which the households to be sampled were then randomly selected. Example: All HHs in block 8 were assigned a number, after which ten (10) of all the representative HH numbers were selected via a random number generator in excel and these were selected to be part of the sample.

3.4 Questionnaire

The study used closed-ended questions to collect data from the selected households using a questionnaire. This questionnaire aimed at collecting data relating to water sanitation and hygiene (WASH) at the household level. It captured information on sources of household water for daily use. It further captured information on the level of awareness in terms of public health risk, how household waste is generally disposed and information on the usage of household latrines i.e. to capture the population practising open defecation.

4. Results and Discussion

4.1 Water supply and coverage

The settlement has a total of 51 water points of which three are mechanized and 48 are equipped with 'Indian Mark II' water pumps. The population against the number of boreholes puts the water coverage at 31.88 litres per person per day (l/p/d), which is well above the sphere standard of 20 litres per person per day (l/p/d). Besides the crude 31.88 l/p/d water coverage, 75.7% of residents cover less than 200 meters while 24.3% need to walk more than 200 meters to access clean and safe water. This is summarized in Table 1.

In comparison to the paper-based method, which was demonstrated in this research using questionnaires, it can be observed that the use of GIS is more accurate in the water coverage of 31.88 l/p/d as opposed to the 25 l/p/d which was analyzed from the questionnaire responses. The ability of a GIS to link geolocation to the facilities allowed for the planning of where the additional 10 water points could be positioned to reduce the coverage distance between water points and facilities within the sphere standards distance of less than or equal to 200 meters (=<200 meters) as shown in Figure 1. With such information, the resource is well utilized, and the risk of duplication is minimized.

Table 13. Summary of water point distribution in Mantapala Refugee Settlement (MRS)

Block	Total Number of Households	Number of households not accessing water within a 200-meter distance	% not accessing water within a 200-meter distance
Block 19	74	73	98.65
Block 18	121	102	84.30
Block 17	314	92	29.30
Block 16	259	80	30.89
Block 15	225	20	8.89
Block 14	250	70	28.00
Block 13	160	0	0.00
Block 12	175	0	0.00
Block 11	167	141	84.43
Block 10	200	12	6.00
Block 09	166	11	6.63
Block 08	99	28	28.28
Block 07	174	14	8.00
Block 06	206	0	0.00
Block 05	196	110	56.00
Block 04	211	44	20.85
Block 03	180	33	18.33
Block 02	239	39	16.32
Block 01	158	0	0
Total	**3,574**	**869**	
Average population covering more than 200 meters to fetch water			**24.31%**

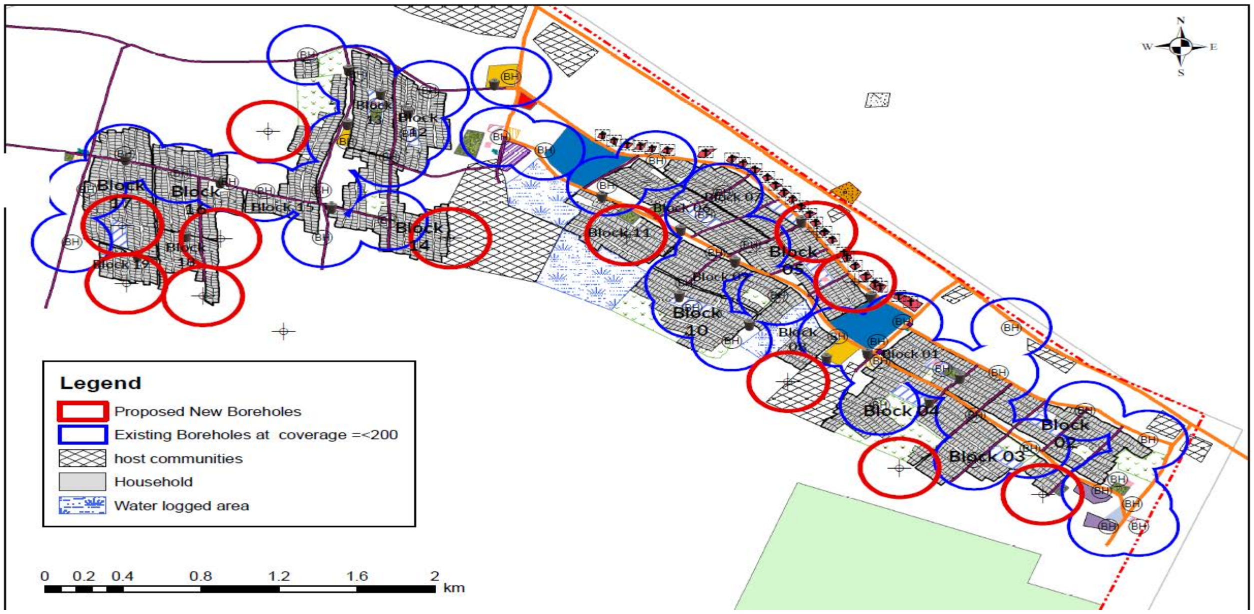

Fig. 1. Proposed new and existing boreholes

Household latrine coverage and hygiene promotion

From the mapping in Figure 2 and Table 2, it can be seen that 21.9% (782) of the households have decent latrines – permanent sub and superstructures, 70.7% have only permanent substructures with temporal superstructures while 7.4% (265) have no decent latrines.

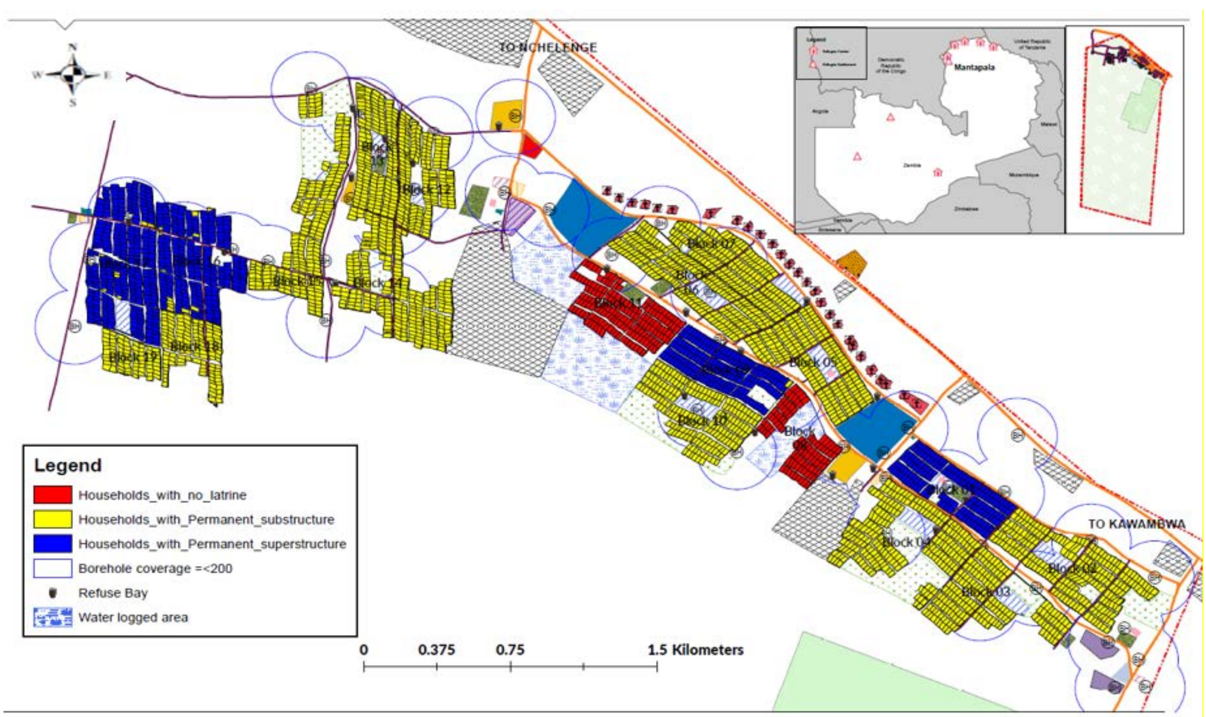

Fig. 2. Status of household latrines

A decent latrine is one that provides privacy,is structurally stable and that does not contaminate the environment or pose a risk to the user. According to UNHCR/Sphere standards, 85% of households should have access to decent shelter. In this regard, stakeholders should consider focusing resources to complete the 70.7% and 7.4 % of households who have temporary and no latrines, respectively.

Table 14. Summary of the type of latrines in the settlement

Type of Toilet	Number of Households	Blocks
Permanent super and substructure	782	17, 09 and 01
Permanent superstructure and temporal substructure	2,527	02,03,04,05,10,12,13,14,15,16,18,19
No latrine	265	09 and 11
Total Households	**3,574**	

4.3 Solid waste management

In this study the waste referred to is domestic waste, particularly at the household level and in public places, such as marketplaces and schools.

Results on solid waste management presented in Figure 3, indicated that only 62 out of 3,574 households had access to refuse bays within 50 meters of their houses.

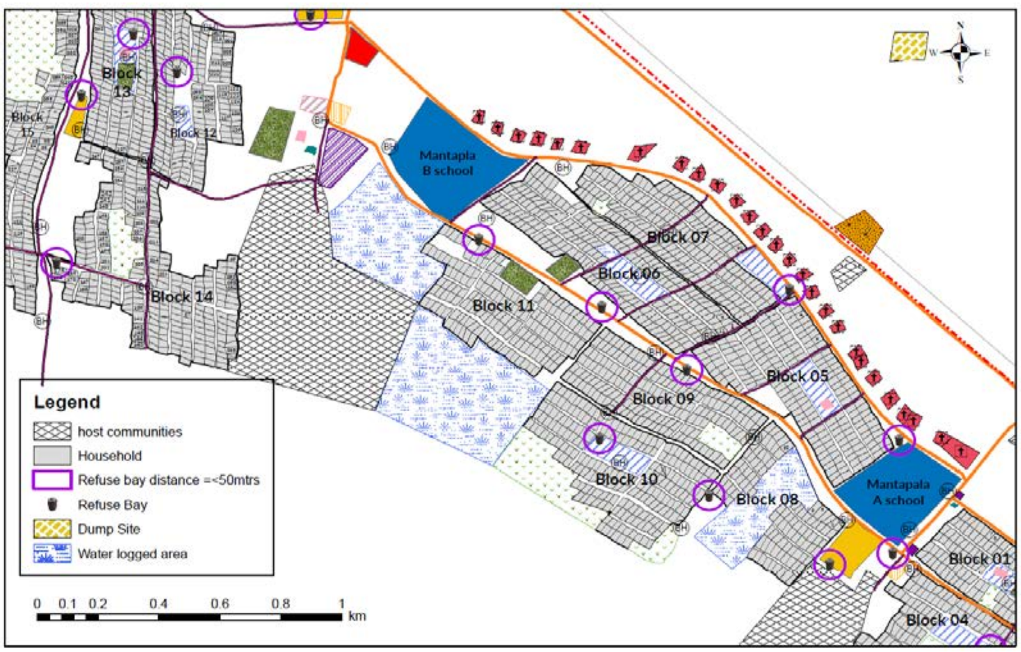

Fig. 3. Distribution, coverage of refuse bays and location of dumpsite.

In Figure 4, contours were applied to show the drainage path of the area and hence plan on how to position the required services. It was therefore suggested in this research that it would be cost-effective to relocate the dumpsite and select an alternative location since its current location is very close to the drainage path and poses a high risk of flooding and water contamination.

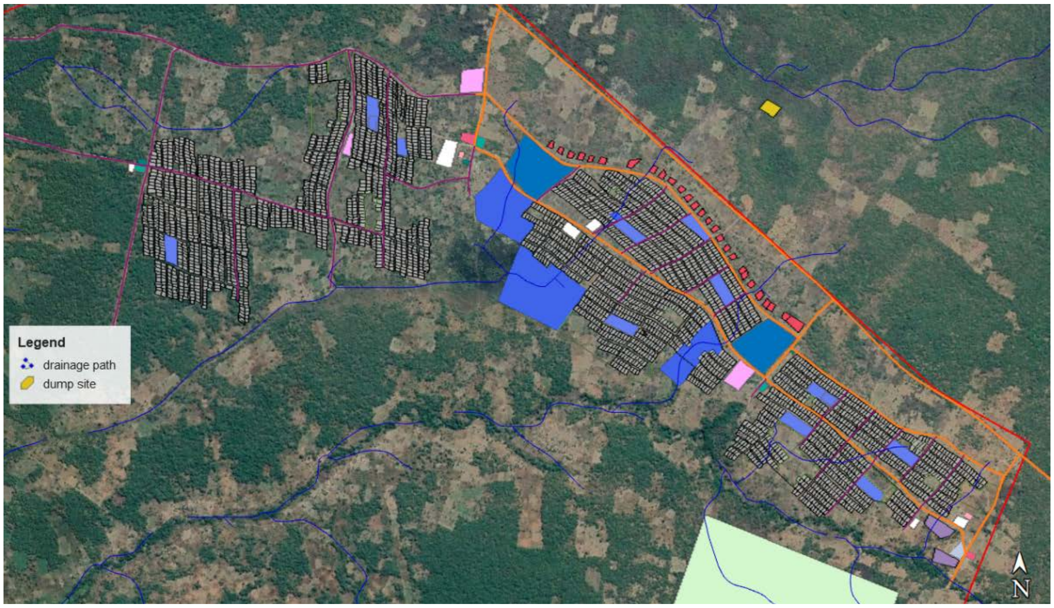

Fig. 4. Drainage path/contours and location of the dumpsite

5. Conclusion

This research aimed at demonstrating how GIS can be used to assess the accessibility of water, sanitation, and hygiene facilities in Mantapala Refugee Settlement of Nchelenge district. The findings demonstrate that GIS is a vital tool in the planning, implementation and monitoring of WASH programs conducted by various stakeholders. Displaying information using maps gives a more visual and conceivable picture of the study area, thereby understanding the spatial entity distribution in the settlement. This has made it possible to have a more accurate way of comparing WASH situation in the settlement, such as the distance from farthest structure to water point, number of persons accessing each water point, distance between latrines and water points, against sphere and UNHCR standards. This then becomes a basis of decision making. Contours enabled the identification of areas that are flood-prone and would assist in placing various infrastructure such as drainages, roads, boreholes, and shelter. From this study, it can be concluded that Mantapala Settlement is well covered in terms of the water supply as most of the population accesses water within the recommended distance, however the immediate focus should be put on the construction of household latrines to ensure that all households and drainage network are covered. This is necessary in order to reduce the risk of flooding and ground contamination.

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