Joint CIB WO99 & TG59 International Web-Conference 2020

Good Health, Wellbeing & Decent Work

W099
Safety Health & Wellbeing in Construction
Coordinators: Professor Billy Hare & Dr Fred Sherratt

TG59
People in Construction
Coordinator: Professor Fidelis A. Emuze

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Introduction

These proceedings are published under the umbrella of the CIB, the purpose of which is to provide a global network for international exchange and cooperation in building and construction research and innovation. The CIB is the International Council for Research and Innovation in Building and Construction, and comprises a world-wide network of over 5000 experts from about 500 member organisations active in the research community, in industry or in education. They cooperate and exchange information in over 50 CIB Commissions covering all fields in building and construction related research and innovation. These include Working Group 099 (Construction Safety, Health and Wellbeing) and Technical Group 59 (People in Construction).

Objectives and Scopes of W099 (Construction Safety, Health and Wellbeing):

The Commission is committed to the advancement of safety health and wellbeing of construction workers. The tools necessary to accomplish this end include designing, preplanning, training, management commitment and the development of a safety culture.

A country's involvement with construction safety, health and wellbeing is influenced by factors like: varying labour forces, shifting economies, insurance rates, legal ramifications and technological development.

Objectives and Scopes of TG59 (People in Construction):

The Task Group focuses on "boots on the ground" managers, professionals and workers.

The Task Group aims to involve representatives of employers, workers and governments, and researchers in both developed and developing countries, and aims to foster dialogue and collaboration.

Main research activities of the Task Group focus on various items related to people in construction, including: competencies, aging workers, gender issues, disability, work and labour conditions, H&S, work/life conditions and socio-economic issues, stress, respect for people, skills supply and employment relationships.

These proceedings are from the W099 and TG59 joint conference, held on the 10th September 2020. This one-day conference was due to be held at Glasgow Caledonian University, Glasgow Campus, but became an on-line event due to restrictions on conference attendance due to the COVID-19 pandemic. The GCU Built Environment & Asset Management (BEAM) Centre hosted the conference, which is the third of its type held in the UK and the first in Scotland. Since 1996, this is the 28th meeting focused on at least one of the CIB groups' topics.

The conference provided an international forum for researchers and practitioners to put forward their research and ideas on how to improve safety, health, wellbeing, and the life of people in construction. The theme of this year´s conference was "Good health, wellbeing, and decent work", aligned with the UN Sustainable Development Goals 3 (good health and wellbeing) & 8 (decent work and economic growth).

Conference Statistics

Prior to the global lockdown, the conference received 99 abstracts. Post lockdown, 39 scientific research papers were submitted and after a strict peer-review process, 32 were accepted for publication. These papers had 81 authors from 15 countries, demonstrating the global research community that contributes to the groups' important research areas:

Country	No. of Authors
Australia	8
Brazil	4
China	6
Croatia	3
Ghana	1
Greece	1
Ireland	1
Oman	1
Portugal	2
S. Africa	21
Saudi Arabia	1
Singapore	4
Slovakia	1
UK	24
USA	3
TOTAL	**81**

Papers were divided into six themes:

- Healthy Bodies
- Healthy Minds
- Digital Solutions
- Policy & Performance
- Design & Technical Skills
- Leadership & Engagement

An on-line vote at the end of the conference placed 'Digital Solutions' as the most favourite theme from the day.

Paper Awards

There were awards for best papers in two categories: The Jimmie Hinze Best Paper; and Best Student Paper:

Jimmie Hinze Best Paper Award 2020: Mindfulness-based Stress Reduction Workshop: Reducing Stress of Construction Professional (Mei Yung Leung & Khursheed Ahmed)

Best Student Paper Award 2020: Impacting Construction Health and Safety Performance Using Virtual Reality - A Scoping Study Review (Mark Swallow & Sam Zulu)

Commendations were also given for first and second runner-up papers:

> **1st Runner Up (Silver)**: Tuning into Heat: Acclimatisation on Construction Site and Horizontal Integration in Major Project Management (Andrea Y. Jia, Dean Gilbert, Nicholas Tymvios, Yang Miang Goh, Michael Behm, Steve Rowlinson)
>
> **2nd Runner Up (Bronze)**: Impact of construction work environment on quality of life of ageing workforce (Alex Torku, Turker Bayrak, Stephen Ogunlana, Albert Ping Chuen Chan, Amos Darko and De-Graft Owusu-Manu)

We congratulate all those recognised here!

Although this year's conference was curtailed due to the global pandemic, it will run again in 2021, in Glasgow as originally planned, with lessons learned from these events, which includes a 'blended' format to accommodate on-line and face-to-face delegates.

We look forward to seeing you all there!

Professor Billy Hare

Glasgow Caledonian University, United Kingdom

Joint Co-Ordinator W099

TG59 People in Construction: Now and Tomorrow

The CIB task group on construction people (PiC) called TG59 held its first meeting on June 17th 2005 in Helsinki, Finland. The task group puts 'people' at the forefront of construction research. At inception, TG59 was a brainchild of the CIB through the active involvement of Dr Wim Bakens and the International Labour Organisation (ILO) through Dr Edmundo Werna. Although the task group was muted in 2004, it was only formally established in 2005 with Dr Jill Wells as the group's first coordinator. Dr Jill Wells, former construction specialist the ILO, served as the coordinator from 2005 to 2006. The objectives of the group in her tenure were twofold:

> Bring together two kinds of researchers: those whose primary objective is to improve the industry's performance and see the focus on people as a way of achieving this; and those whose primary interest is in the lives of the people who work in the industry.
>
> Create a dialogue between these two groups of researchers, from both developed and developing countries, to foster collaboration

The objectives mentioned above were expedited at the macro and micro levels of research focus. The macro-level involves a look into the labour market and its dynamics in addition to national and cross border migration. At the micro-level, the group's focus was on the reality of work on construction sites and views of the workers, the links between skills and productivity, future skill requirements, including professional and managerial skills, and the meaning of 'HRM' in construction. Ms Robyn Gordon took over from Dr Well in 2006. She focused on skills shortages, health, safety and welfare, change in attitude concerning productivity, leadership and resources, education, training and development, automation and technology and knowledge management. In 2007, joint international coordinators were appointed for the task group. The joint coordinators served for nine years (2007 – 2016). As joint coordinators, Prof Theo Haupt and Prof John Smallwood, expanded the research focus of TG59 while hosting conferences to attract emerging scholars to the group.

In 2016, Prof Fidelis Emuze took over the coordinator baton for TG59, emphasising people in the frontline of construction work. Thus, the research focus included respect for people, gender issues, older workers, workforce engagement, diversity, and wellbeing. The overarching idea is that people that binds the construction process together are the most valuable resource in the sector, and as such, their interests are essential research considerations. So, an intentional focus on 'boots on the ground' and frontline managers, professionals, and workers as the PiC came into being in the task group. Given that construction remains labour-intensive where people's contributions significantly impact performance, improving people's wellbeing is paramount. The task group that was recently upgraded to a CIB Working Commission (CIB W123) will build upon the work and antecedent of TG59. The work of W123 will involve scholars and practitioner identifying as employers, contractors, regulators, and all categories of people in construction operations (craft, technical, professional and managerial workers), in both developed and developing countries. W123 will foster dialogue and collaboration among PIC by expediting a range of forward-looking objectives, which include:

1. To create a network of interested and involved members in research into work (employment), people, and social issues in construction.

2. To bring into the network, scholars from outside the construction disciplines who are working on people issues.
3. To provide a forum for the exchange of ideas on social and people issues in construction.
4. To provide a forum for the exchange of ideas on people issues concerning Sustainable Development Goals (3 Health and Well-being, 4 Quality Education, 5 Gender Equality, 8 Decent Work & Economic Growth, 9 Industry, Innovation & Infrastructure, 10 Reduced Inequalities, 11 Sustainable Cities and Communities) in construction.
5. To provide a forum for the exchange of ideas on people issues concerning cyber technologies for fourth Industrial revolution (4IR) (Artificial Intelligence [AI], Quantum Computing, Internet of Things [IoTs], Big Data, Blockchain, Cloud) in construction.
6. To provide a forum for exchanging ideas on people issues concerning physical technologies for 4IR (3-D printing, Robotics, New Materials) in construction.
7. To provide a forum for exchanging ideas on people issues concerning health disruptions in the form of pandemics and epidemics (inequalities, job securities, revised safe work procedures [SWPs]) in construction.
8. To provide a forum for the exchange of ideas on people issues concerning ethical reasoning in construction.
9. To identify critical issues for future research and possible sources of funding.
10. To disseminate research findings to a broader group of scholars and practitioners working in the field.

Professor Fidelis Emuze

Central University of Technology, Free State, South Africa

Co-Ordinator TG59 (now W123)

Making History: the evolution of joint CIB W099 and TG59/W123 Conferences

W099 'Safety, Health and Well-Being in Construction', and TG59 'People in Construction' (now W123) first joint ventured for an annual conference in Cape Town, South Africa, June 2017, followed by Salvador, Brazil, August 2018, and virtually (Glasgow), September 2020. During the Triennial CIB World Building Congress, June, 2019, W099 and TG59 staged separate sessions. The 2021 virtual (Glasgow), conference in September promises to be a further joint venture success.

The joint venturing has its origins in the scope of the respective commissions, resultant synergy, and dual allegiance of a number of members of the respective commissions.

In terms of scope, given that W123 focuses on people in construction issues, many are directly related to H&S, such as H&S itself, labour conditions, stress, work conditions, and work life conditions. Other W123 issues are indirectly related to H&S, such as ageing workers, and gender. Furthermore, recently completed people in construction research directed towards developing a W123 research roadmap, resulted in respondents identifying 53 issues relative to the top five people in construction issues, top five research priorities, and top five research gaps in their countries. Based upon the mean response, the top four issues were mental health, workforce well-being, workforce engagement, and H&S, which are all W099 issues, albeit in the case of workforce engagement, to a lesser extent. These findings also underscore the rationale for evolving the W099 name from 'Safety and Health in Construction' to 'Safety, Health and Well-Being in Construction'.

Professor John Smallwood

Nelson Mandela University, Port Elizabeth, South Africa

Member W099 (since 1996) and TG59/W123 (since 2007)

Fred's Rant 2020: In Praise of Slow Construction – Lessons from C19

As ever, I would like to thank colleagues for this opportunity. This session was first presented to me on the programme as a plenary, which confused me a little, but then Billy explained this was actually just a space for me to have a bit of a rant, so in the end, it's all good! The plan for this session was, as usual, for me to get a bit cross and snarky about stuff, but mainly to raise some things about our current predicament, and the ways in which we are thinking about them. I will explore this a little and also consider what we as academics could, or perhaps even should, be making of this, and even doing about it all.

In sharp contrast to pretty much everything else of late, this conference was actually very Covid19-lite! We took this view, as we were (and still are) in the pandemic. Hence our current virtual gathering, and why we are not yet in a position to see how this will all play out. There will be winners and losers, and I'm not sure anyone has the crystal ball gazing quite right yet.

For example, the technological leap made to enable everyone to work from home has had some wonderful unintended consequences here in the UK. There is currently a massive panic, Boris is urging everyone to go back to the office to work! Like right now! But why…? Well, I doubt he's all that worried about the little independent sandwich shop closing down (should we have any left that have not yet become Pret-a-Mangers!). He's worried because the now-empty massive shiny commercial city centre property portfolios that prop up a massive chunk of our economy (and the rich folks behind them of course!) are now in a bit of a pickle. Because basically, no-one wants to go back. Not the workers. And not the bosses. And there's the surprise. Workers *can* work from home! But this has also revealed a new awesome place for said bosses to maximise their profits. Get rid of your estate! You don't *need* to rent super-expensive offices! No matter what Boris may say! It is an absolutely beautiful 'leopards ate my face' moment for neoliberalism. And without the pandemic, it never would have happened.

And this brings at least a little bit of joy to this otherwise terrible situation. Mainly because I do not own any property other than the shed on my allotment!

But let's get back to PEOPLE! We have seen many reports (mainly from the big firms who also advise people about massive shiny commercial property as well, it should certainly be noted!) about *opportunity*. About the *potential* for this pandemic to catalyse change.

Just to pick a few…

Well, the UK Government is Building Back Better! This includes building greener, building faster, drawing on the New Deal rhetoric from post-war America, but without quite the same ambitions for public good. Instead we have a new Infrastructure Delivery Taskforce, named 'Project Speed' (I wish I'd made that up, but I didn't!) to deliver the government's public investment projects more strategically and efficiently. But although we have an awesome project name, it's all still a bit lite on detail and how this will actually change anything!

The UK's Construction Leadership Council (2020) have set out their 'Roadmap to Recovery' with three key stages; to restart, to reset and ultimately to reinvent. I will mention here their ideas around resetting specifically, as this raises concerns about the need to compensate for the loss of productivity due to restrictions, noting there are 'innovations' available through the Transforming Construction Programme that can improve productivity and help ensure safe working.

Whilst McKinsey and Co note nine shifts in the way construction projects are delivered, including productization and specialization, increased value-chain control, greater customercentricity and branding, as well as higher levels of investment in digitzation, R&D and equipment, sustainability and human capital. I'm doubtful some of those are actually words, but you get the general idea.

But neologistic concerns aside, I have a nagging feeling this is missing the point. I shall elaborate…

So firstly, nobody panic! Technology will save us all! But then again, that was already on the cards before all this happened. Remember, Construction 4.0? The answer to all our problems and prayers!

I'm afraid that rant has already happened. I spoke at ARCOM on Monday where Paul Chan asked us to reflect on whether we should use the pandemic to *accelerate* Construction 4.0. You can probably guess my answer. For the avoidance of doubt it was No! Not without a bit more thought at least, please! And so I won't repeat that here – but please do check out the November Special Issue of ICE MPL (shameless plug!) which pretty much sums up my position on that!

But yes, digital will save us! And from pandemic perspectives it did. Well, some of us at least…

For those able to work remotely, architects, designer's etc., this all went pretty well according to the recent report from colleagues at Loughborough University (Early Lessons for a new normal), with 'substantial benefits reported in terms of cost, productivity and flexibility' for our white collar workers, as remote meetings became the norm. There were issues around isolation and overworking too, but they're still probably preferable to the virus.

Because as Bloomberg reported back in May (data lacking since then) low-skilled construction workers in the U.K. have one of the highest rates of death from the virus. In fact, UK construction never actually stopped. Instead we had a nice letter from the government thanking us for being essential and keeping going - but this has not been without consequence.

Although, despite this horrific statistic in which construction workers get the worst of things AGAIN, things *did* change on UK sites:

Things slowed down. There was more space on site. People took better care of their Health and Wellbeing. Sites were cleaner and tidier. Folks could get more work done. Frontline trade workers were more effective and, well, happier. According to my next door neighbour Terry who's a window fitter (I know, what a robust and rigorous empirical claim!), it was loads better, and all rather nice. And better researchers than I also agree, the Loughborough team highlighting a quote from their data: "this isn't actually too bad; this is how we should have done this in the first place".

Well, now that's a damn good point, isn't it?! And remember, this didn't involve *new* digital technologies (how Skype missed that one I cannot fathom!), or innovation, or productization. It involved doing what we usually do, but better.

There was *time* to plan, *space* to work. And BFS, the productivity of those on sites went up, and those undertaking it were happier all round. The Loughborough Team felt in the longer term this approach would also lead to even more improvements in safety, quality and productivity. Projects would take a little longer, that's all. And that's not the end of the world now, is it? In fact, it's not all that much of a surprise either. As Simon Smith pointed out in CME a while ago, better working conditions and worker safety *will* negatively impact productivity. But we (the 'we' in Simon's case this being the UK government, but we as academics are also guilty of this) still tend to focus on our industry's 'economic shortcomings' rather than considering any balance with its health and safety successes to date.

But this doesn't find a happy fit with the wider rhetoric… and this is what I find most worrisome.

Potential and opportunity for many seems to be about getting back to normal, and then *beyond* normal, as soon as – I was going to say humanly possible, but I fear that is what we are missing. The need for Speed, concerns about loss of productivity, the need for more control, these don't find fit with a 'slow it down' approach. They find fit with a 'speed it up as much as we can' approach, – and this is inevitably linked to change, innovation and technology.

But I would suggest this is the point of challenge. This is the place to mark our ground. We should be mindful of the few benefits this pandemic has brought us as an industry and look to maximise on them. And it's easy! 'Slow Construction' talks to the SDGs of Decent Work, No Poverty, Good Health and Wellbeing, and Sustainable Cities and Communities – and more.

We should be *cautious* of those trying to peddle us solutions to problems we don't actually have. Problems that have now been revealed to be far more rooted in factors other than simply a lack of innovation or use of technology.

These are problems that we as academics have been exploring for decades, but we have also been quick to add our voices to those looking to 'speed up' innovation, to increase the use of digital technologies. And often without full recognition of the bigger picture. Which is of course that those outside of academe who are also seeking such change have different motives. They seek profit through productivity, patents and products for sale. But these are not necessarily also be in the best interests of construction's people. And given the reason for our gathering here today, I don't think any of us are here just for the money.

I have previously suggested that construction work could be good work for all, if we do it right. Construction work has so much to give – it's outdoors, in the fresh air, you're moving, you're stretching and flexing, you're not sitting in front of a screen performing computer-controlled craftsmanship – and hey, sitting in front of a computer hasn't done much for me lately.

I'm old enough to remember a pre-email world, my first job on a site was to work '*the* computer', and I'm not convinced that doing things faster, able to tap into vast amounts of information that we simply don't have the capacity to digest, has made things any better – I'm not sure I agree that this is something that is good for the human condition. I'm sure some of you at least have been managing emails whilst I've been talking!

So yes we *should* innovate, yes we *should* change, but in a *way* that works for people, that enhances all the good things that made workers happy in the pandemic, and that does not lose sight of the greater good that construction work provides for so many all over the world.

So what if we do things a little more slowly? If by doing so we create a much better quality product from the efforts of happier and healthier workers, well, I can get behind that!

Dr Fred Sherratt

Anglia Ruskin University, United Kingdom

Joint Co-Ordinator W099

Review Committee

The peer review for this conference was only possible because of the voluntary contributions of experts from various countries. The editors are sincerely grateful to:

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Papers

Healthy Bodies

Healthy Minds

Digital Solutions

Policy and Performance

Design and Technical Skills

Leadership and Engagement

Assessing Tendonitis Among People in Construction

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Abstract

Musculoskeletal disorders (MSDs) such as tendonitis affect the health of workers. The purpose of this reported study was to assess if contractors address tendonitis, using the central region of South Africa as a case example. The exploratory mixed methods design produced the primary data that emanated from 14 contractors active in the Free State province of South Africa. The participants were sought on-sites. The data were collected from 62 survey respondents and 26 interviewees. The results show that workers do experience hip and shoulder tendonitis, which leads to reduced work performance on construction sites. The study revealed that most contractors do not adequately handle the MSD. It was observed that regular awareness meetings and discussions about various sicknesses and disorders that might arise on construction sites are essential to mitigate MSDs. The study concluded that hip and shoulder tendonitis leads to low work performance due to body pains. The study recommends, amongst others, that there should be tendonitis awareness programmes on construction sites. The deployment of the three Es (engineering, education and enforcement) of preventive safety is also suggested.

Keywords: construction, hip and shoulder, ill health, musculoskeletal disorder, workers.

Introduction

The construction industry is a sector where workers are exposed to varying working conditions (Paap, 2006). The sector provides job opportunities for skilled and unskilled individuals (Sang et al., 2007) with potentials for harmful outcomes. Such harmful outcomes include musculoskeletal disorders (MSDs) (Boschman et al., 2012). MSDs are ergonomic injuries that affect connective tissues of the body (Reese, 2016). Such tissues include muscles, nerves, tendons, joints, and cartilage. MSDs account for a significant number of injuries on construction sites (Antwi-Afari et al., 2017). While the examples of MSD signs include decreased grip strength, decreased range of motion and loss of function, the symptoms of MSDs are not limited to numbness, tingling, pain, burning, stiffness and cramping (Reese, 2016). The harmful impact of MSDs necessitates research into causations, outcomes and mitigation strategies.

The MSD that constitute the focus of this paper is tendonitis. Tendonitis is linked to tendons that are the rough but flexible bands of tissue that connect muscle to bones (Choi et al., 2016). In the human body, there are about 4000 tendons that make it possible for people to bend their knees, shoulders and grip with their hands (Choi et al., 2016). Statistics have it that several construction workers suffer from tendonitis (Forde et al., 2005). Tendonitis is an inflammation of a tendon, meaning that muscles become swollen as they rub against bone leading to painful movement. These are disorders that affect workers after they had worked in the industry for an extended period, especially older workers. This phenomenon occurs amongst workers operating in various trades, thus resulting in a high percentage of tendonitis in construction (Antwi-Afari *et al*., 2017). If the problem is not investigated, it may mean prolonged suffering of construction workers in conjunction with poor quality of work delivered and low production of work. It is, therefore, essential to examine: Do contractors address tendonitis in South African construction?

To be able to answer the above question, an exploratory investigation was conducted in the Free State province in 2018. It is worthy of note that workers that are affected by the MSDs are mostly experienced workers who cannot operate to their best abilities because of pains. As such, there is a need for the reported research.

An Overview of MSDs and their Impact in Construction

As opposed to other sectors such as manufacturing, work in construction is more labour-intensive (Ofori, 2012; Paap, 2006; Sang et al., 2007). The difficulty of construction activities often demands workers to work beyond their natural physical postures or perform strenuous repetitive activities for an extended period (Latza et al., 2002; Tak et al., 2011). For instance, Repetitive Strain Injuries (RSI) is a disruption of muscles, tendons, bone, or nervous system made worse by repeated forceful exertions, awkward posture sustained for a long time, surface contact stresses, and vibration or cold (Rozmaryn, 2005). Over time, sustained physical demand on worker's bodies may result in health issues and bodily injuries, apart from financial losses (Nath et al., 2017; Antwi-Afari et al., 2017).

MSDs is linked to lost workdays and wages, reduced productivity, early retirement and unemployment (Aumann and Galinsky, 2009). Workers infected with an MSD may experience a limited ability to work, which may, in turn, result in lost wages, unwanted time away from work, lowered self-esteem and social disconnection (Aumann and Galinsky, 2009). An employer may experience lost productivity, loss of personnel or a rise in sickness payments and staff absenteeism due to MSDs (Antwi-Afari et al., 2017, Aumann and Galinsky, 2009, Nath et al., 2017). The physically demanding nature of construction work helps explain why MSDs are a common type of injury resulting in days away from work. However, an organization with a high MSD prevalence could benefit from a comprehensive ergonomics programme that includes engineering and administrative controls (Choi et al., 2017).

The prevalence and negative impact of MSDs is due to the complexity of duties that need to be carried out, which often require workers to exceed their natural physical limits, or do repetitive tasks for lengthy periods (Nath et al., 2017). Working overtime, for example, in awkward postures places high physical exertions on worker's bodies, which may involve activities such as heavy lifting, manual handling, body twisting and continuously working in awkward postures resulting in physical injuries, health problems and work-related MSDs (Nath et al., 2017).

Hip and shoulder tendonitis affects the health and safety of construction workers. According to Antwi-Afari *et al.* (2017: 41), hip and shoulder tendonitis is an influential occupational health difficulty encountered by manual workers. When workers are affected by tendonitis, it is difficult for their bodies to fully function as before because they are mostly in pain and struggle to work continuously for long periods without taking required breaks (Silverstein and Evanoff, 2011). In these instances, it is not only the worker who suffers but also the contractor since these actions lead to low productivity and financial loss. In the United Kingdom (UK), for example, it is the most common occupational illness, affecting 1.1 million people per year and costing society 5.7 billion pounds (Paton, 2005).

The above narrative indicates that proactive measures should be implemented to prevent tendonitis. Contractors as the employer of labour (general workers and tradespersons) should be in the frontline of the implementation of such measures. A UK example can serve illustration purpose in this context. In the UK, there are workplace General Health Checks (GHC's), which are useful methods for assessing individual health risks, increasing health awareness and initiating healthier lifestyles among workers. Contractors start GHCs, but it needs to be consistent to assure effectiveness. If GHC can be introduced and promoted in South African construction, perhaps it will make a difference. In addition, there is a need for policies and rules that would support and rehabilitate workers that are affected by tendonitis (Paton, 2005: 8).

Research Method

The research philosophy that was utilized in this study was pragmatism. The study deployed two data collection methods. Questionnaire survey and interview data collection methods were expedited concurrently in the study. Although the study is exploratory, the use of mixed methods helps to deepen the insights obtained from the data collection exercise (Creswell and Plano Clark, 2011).

The primary data were obtained from active construction companies operating in the Free State Province of South Africa. The sample consisted of 21 construction organizations identified by utilizing the CIDB's online Register of Contractors and visiting construction sites. However, only 14 of them agreed to participate in the study (both interviews and questionnaire survey). Information about company name, professionals or tradespeople name was obtained from the questionnaire that was distributed on various sites. From the 14 construction companies who participated, 26 individuals were interviewed (please see Table 1) and 62 validly completed questionnaires were returned for analysis.

The targeted sample for questionnaire survey was mainly the tradespersons and general workers as they are likely to be affected by tendonitis. The questionnaire survey achieved 40 responses from supervisors, tradespersons and general workers. The remaining questionnaires (22) were completed by professionals having site management roles. The responses from tradespersons and general workers who are likely to experience MSDs exceed that of professionals. The total number of participants in the fieldwork was 88 (26 interviewees plus 62 survey respondents) people in construction affiliated to 14 contractors.

Interviews were requested and scheduled with relevant tradespeople and professionals on construction sites, who are more likely to be affected by hip and shoulder tendonitis. In-depth interviews were conducted over a month on active construction sites for the participants' convenience. The interviewees were general workers, tradespeople, foremen and professionals. Interviews were between 15 to 30 minutes in duration and were all conducted in English Language and sometimes translated into Sesotho and isiXhosa whenever the participant could not understand questions. All interviews were conducted personally by the researchers who are knowledgeable about the phenomenon.

Before the interview, interviewees were made aware of the research questions and the expected duration of the meeting. Each interviewee was given a covering letter, which stated the underlying reasons for the study and a short questionnaire to complete, which captured additional information. After that, a semi-structured interview was conducted. The responses were handwritten on the prepared interview protocol as the interview continued. A similar process was followed in the distribution of the structured questionnaire on the same project sites. The questionnaires were hand-delivered and retrieved from each company within a month to give enough time for completion.

Table 1: Interviewees' trade and length of industry experience in construction

SN	Trade/Profession	Years of Experience
1	Plumber	1 to 5
2	Plumber	5 to 10
3	Site surveyor	1 to 5

4	Foreman	5 to 10
5	Electrician	More than 10
6	Electrician	1 to 5
7	Electrician	More than 10
8	Contract manager	5 to 10
9	Plasterer	1 to 5
10	General worker	1 to 5
11	General worker	1 to 5
12	Bricklayer	1 to 5
13	Bricklayer	More than 10
14	Steel fixer	5 to 10
15	Painter	1 to 5
16	Carpenter	More than 10
17	Site agent	1 to 5
18	Site agent	1 to 5
19	Architect	5 to 10
20	Supervisor	More than 10
21	Mechanical engineer	1 to 5
22	Civil engineer	1 to 5
23	Civil engineer	5 to 10
24	Quantity surveyor	1 to 5
25	Quantity surveyor	More than 10
26	Contract manager	5 to 10

The collected textual data were examined using Creswell and Plano Clark (2011) explanation about interview analysis and interpretation. Only significant statements from the textual data were selected for analysis. These statements were treated as being of equal value and listed accordingly. This step allowed the removal of repetitive sentences. The remaining sentences were then grouped into five themes. The interview protocol was dominated by themes addressing the research questions of the study. The themes include:

- Identification and reduction of tendonitis impact among workers;
- Contractors' disposition to addressing the effects of tendonitis among workers;
- Improvement of labour productivity through reduction of tendonitis, and
- Awareness programmes that mitigate the effects of tendonitis on workers.

This process was concluded with the development of a description of how the interviewees experience hip and shoulder tendonitis. Descriptive statistics were used for analyzing the data from the questionnaire survey. As such, in the next section, the survey data are presented with response percentages based on the type of questions asked.

The Results and Interpretations

Survey results

The survey data shows that of the 62 respondents, 43.3% have worked in the industry for between 1 and 5 years, 25.6% have worked for between 5 and 10 years, and 29% have worked for more than ten years. By implication, 35 (54.6%) survey respondents have more than five years' work experience on construction sites. Table 2 shows that the respondents have at one time or the other experienced health problems related to back pains and hip and shoulder tendonitis. However, it is notable that the majority of the survey reports fail to report such pains either to their employers or safety officers.

Although more than half of the respondents do not miss a working day because of the pains from their back, hip or shoulders, a significant number could be absent for up to 5 working days. Such absenteeism has significant cost implications in construction. Some of the respondents have limited knowledge of MSDs and tendonitis in particular, as shown in Table 2.

Table 2: Perception of MSDs among survey respondents

Option	Response	Percentage (%)
1. In your years in the industry, have you experienced any work-related health problems?		
Yes	41	66.0
No	21	34.0
2. If yes to question 1, what was it?		
Headaches	1	12.0
Back pains	17	30.0
Hip and Shoulder pains	16	29.0
None of the above	16	29.0
3. After a day's work, do you experience any hip and shoulder pains?		
Yes	48	77.0
No	14	23.0
4. If yes to question 3, where did you report it?		
Nowhere (zero reports)	29	28.0
To contractor and safety officer	8	16.0
Medical doctor/hospital	13	26.0
5. How many working days did you miss due to these earlier cited pains?		
1 to 5 days	26	45.0
5 to 10 days	0	0.0
More than ten days	1	1.0
Zero missed days	31	54.0
6. Do you know what musculoskeletal disorder (MSDs) constitute?		
Yes	25	40.0
No	37	60.0
7. Have you heard of the term tendonitis?		
Yes	20	32.0
No	42	68.0

Interview results

The results of the questionnaire survey feed into the insights provided by the interview data. The emerged textual data from the analysis are arranged in themes.

Theme 1: Hips and shoulders tendonitis among construction workers and their impact

As mentioned in the literature, hip and shoulder tendonitis is the inflammation of tendons in the hips and shoulders, causing tremendous pain, initially resulting from repetitive movements in awkward positions for long periods. The interviewees were asked of their understanding of hips and shoulders tendonitis. Based on the outcome of the interview, a construction foreman with more than five years of experience in the industry indicated that tendonitis is a joint pain based on the strain of muscles when overworked without stretching. Also, more interviewees explained that it is a pain felt on hips and shoulders due to hard work executed by the concerned person for an extended time. Others stated that hips and shoulders tendonitis is having pains in one's body, especially in the joints due to stress, work activities or incorrect body postures during work. These feedbacks show that the interviewees have a fair idea about tendonitis and its potential causes.

Even though the majority of the interviewees stated that they have never encountered hip and shoulder tendonitis, a young bricklayer voiced that he has heard one of his colleagues mentioning hip and shoulder pains. Following this incident, the diagnosed individual was given two days off work to rest and recover. The interviewees perceive that the impact of tendonitis on construction workers contribute to lower work progress, and absenteeism as they encounter health problems.

Theme 2: Contractors disposition to addressing tendonitis among workers

When construction workers are diagnosed with tendonitis, it should be reported through the appropriate channel. However, the reality is different from theory, as indicated in the survey data. Most of the interviewees perceive that in this instance, the patient should report their sickness to the health and safety representative for the contractor’s attention. Following that they should seek medical help immediately so that they can get treatment. The response of the interviewee is the ideal situation. In particular, a health and safety representative suggested that when workers encounter this disorder, they should try to do the following to assist them with the pains. These activities are massaging the injured areas, warming up of muscles before work by stretching the body and going for frequent physical check-ups.

An interviewee says that diagnosed workers are not clueless alone when such incidents occur, but also the contractors are sometimes not responsive to tendonitis issues. He stated that most of the times, contractors do not know how to advise affected workers. The remedy from employers (contractors) mostly emphasizes that workers should take a few days to rest, and after that, return to work. Notably, an experienced plumber revealed that the majority of the contractors do not appropriately handle MSDs. He shared a story where one of his colleagues had pains in the hips and was not given medical attention or even a few days off. He, furthermore, expressed that contractors are concerned mainly with productivity and not the well-being of the workers because, at times, workers are forced to continue to work under challenging conditions. Still, an interviewee who has experienced a different situation revealed that some contractors conduct morning exercise sessions involving their worker at least twice a week to ensure that workers’ muscles are maintained and flexible when they do their duties.

Theme 3: Improving labour productivity by reducing tendonitis

Labour productivity is a vital aspect of every construction project. It should ensure that the work is correctly and precisely done without defects and mistakes. A site agent with extensive industry experience concurred with the opinion of most interviewees who contend that hip and shoulder tendonitis leads to prolonged work duration and low productivity as unhealthy workers execute tasks slowly on construction sites. An interviewed plasterer says MSDs may not affect labour productivity initially. However, in the end, it negatively affects the health of people in construction to the extent that it reduces the ability to work with a knock-on effect on productivity. The interviewee opined that some workers end up losing their jobs because they are no longer productive enough. He further revealed that when those workers are diagnosed, the diagnosis is not taken into consideration until it begins to affect work progress, which influences production negatively and result in higher costs of work and lower profits at project completion.

Theme 4: Mitigating tendonitis through awareness programmes

Conducting regular awareness meetings and discussions about various sicknesses and disorders that might arise on construction sites are essential, and many of the interviewees agreed to this. The interviewed carpenter observes that

> "*if such discussions could be conducted on sites they would create awareness and therefore reduce the occurrence of disorders such as tendonitis*".

Some of the interviewees recommended that these awareness programmes and discussions should be done because they could assist in improving labour productivity while reducing the time wasted. It would encourage the workers to exercise regularly to improve their well-being, stay fit and useful in the workplace. The interviewees offered tendonitis reduction-related suggestions to employers and employees. For instance, a civil engineer suggested that

> "*employers must identify risks associated with each task and teach them the correct measures of handling and executing those tasks without hurting themselves in the process*".

Another female electrician advised that

> "*employees should avoid the overuse of any body part, such excessive repetition of movements and when working with heavy objects, keep the load centred in front and use both hands evade tearing any muscles and injuring themselves*".

Discussion

Reese (2016) noted that force, vibration, repetition, contact stress, awkward postures, cold temperatures, and static postures are ergonomic risk factors contributing to the manifestation of an MSD such as tendonitis. Of these risk factors, repetitive motions, awkward positions, vibration and forceful exertions are common among people suffering from tendonitis. These risk factors are aspects of a construction task that impose biomechanical stress on the worker. Practical experience on a project site often flags one or more of these ergonomic risk factors that could lead to health problems, which some of the survey respondents have experienced concerning back pains, apart from hip and shoulder tendonitis.

The survey data also show that the respondents have limited knowledge of MSDs and tendonitis. The knowledge gap has implications for prevention and control. The gap in knowledge has to be closed as construction workers tend to have remarkably higher risks of MSDs (Liu et al. 2020). In a Taiwanese study of 15989 participants, Liu et al. (2016) determine that in professionals and skilled workers, MSDs of the neck and shoulders were more prevalent while MSDs of the hands, wrists, and lower back were common among manual workers. More insightful is the observation that the most prevalent MSDs among male workers and professionals is that of the shoulder, which implies the possibility of shoulder tendonitis.

Effective interventions for MSDs require a systematic approach that takes into account a combination of measures. However, it is notable that the data presented earlier revealed that the contractors do not adequately handle MSDs. The perception of the interviewees is consistent with the notion that those charged with the management of MSDs do not apply the right approach (Oakman et al. 2016). Although an H&S representative suggests that massage, physical exercise and frequent medical check-up as precautionary measures, it is crucial that employers take the lead in limiting exposure while implementing controls. As advised, indeed a short dose of morning warm-up exercise could lead to increasing or maintaining joint and muscle flexibility for construction workers exposed to manual labour and strenuous working positions (Holmstrom and Ahlborg, 2005). Apart from the physical exercise, it is essential to limit exposure to the ergonomic risk factors that cause MSDs such as tendonitis. Limiting exposure is crucial because MSDs results from cumulative exposures and injuries that may be far from the risk factors (Oakman et al. 2016). Applicable controls could be administrative, engineering and work practice in nature. However, engineering controls (safety through design or use of control technologies) are preferred because they tend to be reliable, consistent, effective, measurable and free from human behaviour (Reese 2016).

Concluding Remarks

It is evident from the results that some of the interviewees and survey respondents are familiar with hip and shoulder tendonitis and its impact on their work performance. The findings affirm that hip and shoulder tendonitis reduce the working ability of workers, work performance, quality of craft (workmanship) and safety performance in construction. The data suggest that MSDs lower labour productivity as workers have to seek medical help. For example, inflammation and pains on the hips and shoulders tend to weaken workers' gripping abilities with implications for their alertness and mindfulness when executing tasks. The study found that hip and shoulder tendonitis causes low labour productivity as affected employees will take time to complete daily activities. It is, however notable that surveyed contractors do not appear to give tendonitis the attention it deserves in South African construction.

The data shows that the interviewed and surveyed people in construction have limited knowledge of MSDs in general and tendonitis in particular. While some of the participants may be able to identify tendonitis symptoms, the limited knowledge would hinder an attempt to prevent and reduce it. It is therefore argued that construction workers should have access to the knowledge of MSDs (causes and impact) to engender an effective prevention regime. The prevention regime should involve the three Es of safety. These include engineering (designing for safety), education (training workers on how to perform their job safely), and enforcement (ensuring compliance to rules to create a safe workplace) be achieved since the potential witnesses would be able to avoid any actions leading to it.

Regarding whether or not contractors sufficiently address the effects of tendonitis on workers, the study revealed on one hand that the majority of the contractors do not appropriately handle the issue. On the other hand, it can be concluded that contractors are raising awareness of among their workforce. In general, less is done by contractors to mitigate hip and shoulder tendonitis amongst workers because of inadequate awareness of the impact of MSDs. By implication, contractors have to create MSD awareness through their safety management systems. The promotion of awareness should replace instances where workers are assumed to be lazy when suffering from MSDs. Conducting regular awareness meetings and discussions about various sicknesses and disorders that might arise on construction sites are essential.

It is, however notable that reported research only focused on hip and shoulder tendonitis among construction workers. The limited scope justifies a call for a broader future study on other forms of MSDs. Future research can be directed to any of those forms such as wrist and knees tendonitis. Furthermore, the reported research is exploratory. It provided a foundation for further inquiries that will lead to theory development and hypotheses testing using a quantitative method or mixed-methods.

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Sensors based physical exertion monitoring for construction tasks: comparison between traditional physiological and heart rate variability based metrics

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Abstract

Among different industries, construction industry is well-known to be physically intensive and demanding. As such, construction workers are frequently exposed to the risk of overexertion and physical fatigue. To avoid overexertion, recent research has focused on automated exertion monitoring using multiple wearable sensors. While these efforts may lead to accurate exertion prediction on actual construction sites, using multiple sensors may not be always a practical solution. To overcome this limitation, a single heart rate sensor that could measure heart rate variability (HRV), may prove itself a viable solution. HRV is an analysis based on measurements of successive time periods between heartbeats. Previous studies in the clinical environment and sports settings have shown that HRV could be used effectively to monitor cardiovascular health and prevent overtraining or excessive workloads. However, in the construction industry, studies on the use of HRV to monitor physical exertion have been scarce. Whether HRV metrics can differentiate different exertion levels or not remains unknown. Accordingly, this study entailed a manual material handling experiment to induce physical exertion among participants which was administered by using the rate of perceived exertion scale (i.e. Borg-20 RPE scale). Meanwhile, they were also being monitored using traditional physiological (i.e. skin temperature and breathing rates) and HRV based metrics. HRV metrics included both linear (heart rate and mean beat-to-beat interval) and non-linear features (including Poincare plot metrics and approximate entropy). Statistical analysis revealed that (1) both of the traditional and many of the HRV metrics were able to differentiate among different exertion levels (i.e. low, medium, high and very high), (2) maximum correlation coefficient for RPE was achieved using skin temperature, however (3) high level and very-high level exertion level could not be distinguished using skin temperature which could be readily differentiated using HRV features. Overall this study contributes to the body of knowledge by highlighting the advantages and limitations of HRV for monitoring exertion among construction workers.

Related conference theme: W099, Technology, innovation & safety & health

KEYWORDS: fatigue, health & safety, heat stress, workers.

Introduction

Construction industry is well known to be heavily dependent of manual and arduous work (Umer et al. 2017b; c). This is attributed to the nature of construction tasks which are often extended over prolonged time duration, involve excessive forceful movements and working on outdoor worksites with harsh environmental conditions (Forde et al. 2005; Umer et al. 2017a). A quantitative study by Abdelhamid and Everett (2002) found that construction workers often surpass the recommended exertion levels on a regular basis. This overexertion may cause a number of issues such as heightened risk of work-related musculoskeletal injuries, decrease in workers' vigilance which could lead to accidents, poor quality of the work and lower morale of the workers (Chan 2011; Umer et al. 2018a; c; De Vries 2003). As such, there is an immediate necessity to monitor and mitigate physical exertion among construction workers.

The role of excessive physical exertion leading to accidents in the construction industry cannot be overemphasized. Accordingly, numerous accident models such as developed by Mitropoulos et al. (2005) and Haslam et al. (2005) have included excessive exertion as a primary contributor to accidents at worksites. Statistics from the US indicate that among all work-related injuries and illnesses, 33% are caused by excessive exertion (BLS 2016). Similarly, recent studies have highlighted that excessive exertion could lead to loss of balance which in turn could lead to fall accidents (Umer et al. 2018b; c). Likewise, an exploratory study conducted in Hong Kong found that excessive exertion leads to an increased number of accidents immediately before and after lunch on construction sites(Chiang et al. 2018).

Given the pervasiveness and its ill effects, there is a consensus among construction professionals and academicians to develop tools to monitor and mitigate excessive exertion among construction workers. Wearable sensors is currently a booming industry around the globe and new wearables coming to the market have made it possible to solve many problems that were impractical previously. Among such promising sensors, optical heart rate wrist bands could help improve occupational health and safety substantially. Contemporary optical heart rate wrist bands are capable of monitoring heart rate variability (HRV, beat-to-beat analysis of heart beats) in addition to heart rate. Previously, HRV has been used to assess cardiovascular health of the patients in the clinical domain whereas, recently, it has been used to avoid overtraining (Makivić et al. 2013) and monitor workloads (Dong 2016) among athletes. Are HRV metrics capable to differentiate between different levels of workload for construction tasks, remains an unanswered question. The author hypothesizes that HRV could also be used to monitor physical exertion among construction workers. Accordingly, using experimentation and statistical analysis, this study has investigated the usefulness of HRV metrics against traditional physiological measures to see whether they can better discriminate among different physical exertion levels than traditional measures or not. Accordingly, this could help researchers develop better technologies to monitor physical exertion among construction workers.

Literature Review

Prior to sensor technologies, questionnaires have been used to monitor physical exertion among construction workers. Mitropoulos and Memarian (2013) used NASA TLX (Task Load Index) to monitor cognitive and physical load among masonry workers. Some researchers are of the opinion that because of industry specific characteristics, distinct questionnaires should be designed for the construction industry incorporating these characteristics. Following the idea, Fatigue Assessment Scale for Construction Workers was developed by Zhang et al. (2015). While such questionnaires are certainly helpful in assessing exertion level among workers, they possess a number of drawbacks such as their inability to monitor workers in real-time and being invasive (i.e. requiring workers to responding verbally or in a written form).

Owing to these limitations, numerous researchers have explored the use of sensor technologies to monitor exertion. Some of them limited their studies to passive monitoring of physiological signals which could then be interpreted to estimate exertion levels of the workers. For example, Wong et al. (2014) compared heart rate, energy and oxygen consumption of steel reinforcement benders against fixers. Alike, Ueno et al. (2018) monitored average heart rate, water intake, sweating and urination of workers at different work shifts.

Although such quantification of physiological measures is helpful, subjective interpretation is required to estimate the exertion levels. To mitigate this issue, recently researchers have focused on machine learning models to estimate physical exertion level using physiological data. To automatically monitor exertion of construction workers, Yi et al. (2016) collected heart rate, wet-bulb globe temperature, duration of work activity and worker specific data to train an artificial neural network (ANN) to predict ratings of perceived exertion. Using heart rate, skin temperature, personal features and brain activity of workers, Aryal et al. (2017) explored different machine learning models to computerize exertion modeling and monitoring. In contrast, Sedighi Maman et al. (2017) proposed a mechanistic approach to estimate exertion of workers. Instead of relying heavily on physiological measures, they also collected acceleration and jerk data by placing sensors at different body parts. They hypothesized that with increase in fatigue and exertion, there would be changes in heart rate, acceleration and jerk data and by feeding this data to machine learning models, exertion levels among workers could be monitored. Recently, Umer et al. (2020) utilized breathing rate, heart rate, skin temperature, activity duration, standard deviation of the beat-to-beat interval, age and BMI of participants to build machine learning models to predict physical exertion. This led to prediction accuracy of up to 95%.

Despite the advantages of each of the aforementioned studies for exertion monitoring, all of them present a common problem that they require numerous and multiple types of sensors to train machine learning models. To address this issue, HRV features could present a potential solution. HRV features could be computed using a single optical sensor which is often found in smart wrist bands/ wrist watches. To explore how well HRV features could differentiate different physical exertion levels, this study entailed manual material handling experiments and collected various physiological datasets along with HRV metrics which were followed by statistical analysis for comparison purposes.

Methods

Participants

To compare HRV features against traditional physiological measures, ten participants having age between 19 and 30 years were recruited from the university student/staff population. The exclusion criteria for the participants was the presence of heart and respiratory disorders, and musculoskeletal symptoms in the past one year. Prior to participation, the experimentation along with the purpose was briefed to the participants and their consent was sought.

Experimental procedures

On arrival for the experimentation, participants were requested to put on a vest (EQ02 Life-Monitor, Equivital) to collected physiological data and HRV measures. To collect physiological data, the vest was instrumented with breathing and skin temperature sensors. Additionally, it was equipped with ECG (electrocardiography) sensor which enabled collection of a traditional physiological measure (i.e. heart rate) along with numerous HRV measures (explained in the following section). After equipping the participants with the vest, the participants were asked to perform a manual material handling of a 15-kg box as shown in Figure 1. The experiment required the participants to repetitively perform alternative cycles of following the path as shown in the figure, with and without carrying the load, for a total duration of 60-min for each participant. Alternative cycles with and without the load were prescribed to gradually develop whole body physical exertion. At the start and every five minutes, the participants were asked to rate their physical exertion using Borg-20 ratings of perceived exertion (RPE) scale (Borg 1998).

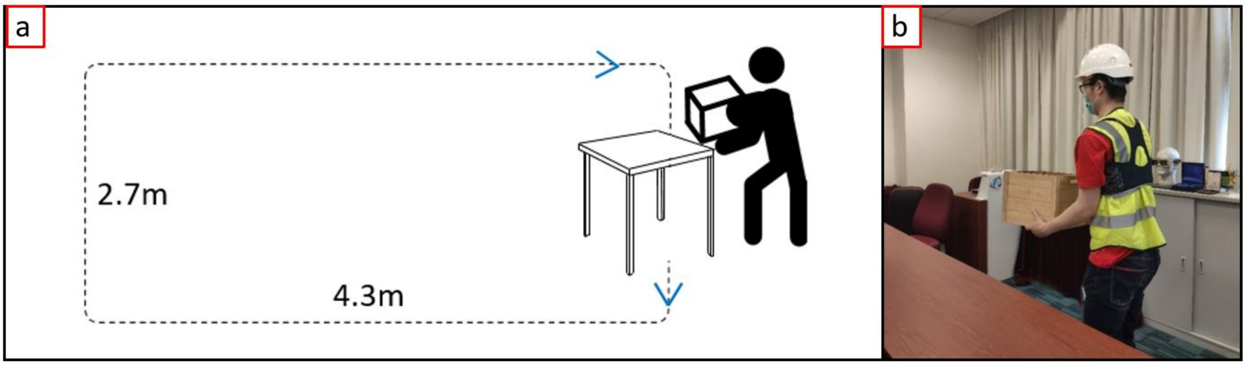

Figure 1: (a) Layout of manual material handling task (b) experimental illustration

Traditional and HRV metrics monitored

As aforementioned, traditional physiological measures to monitor physical exertion in this study included breathing rate, skin temperature and heart rate. These metrics were averaged for every 5 minutes to compare with HRV measures. The HRV measures computed included a linear metric (i.e. mean beat-to-beat interval) and the following non-linear metrics (1) Approximate entropy (ApEn); (2) Sample entropy (SampEn); (3) standard deviation of Poincare plot points perpendicular (SD1) and (4) parallel (SD2) to identity line; detrended fluctuation analysis (DFA) metrics (5) short term fluctuation slope (alpha 1, α_1) and (6) long term fluctuation slope (alpha 2, α_2). For all of these metrics, akin to traditional measures, first data was sliced into 5-min bins and then these HRV metrics were computed for the prospective analysis and comparison.

Statistical analysis

First, correlation analysis was conducted between ratings of perceived exertion (RPE) values and the corresponding values of all the metrics described in the section *Traditional and HRV metrics* using Pearson Correlation Coefficient. The metrics that exhibited significant correlation ($p<0.05$) were further analyzed using repeated measures analysis of variance (RMANOVA). Prior to conducting RMANOVA analysis, data for significant metrics was binned into four categories based on corresponding ratings of perceived exertion (RPE) values. Specifically, data corresponding to RPE scale values from 6 to 11 was categorized as low exertion. Similarly, data for corresponding RPE values from 12 to 14, 15 to 16 and 17 to 20 was classified as medium exertion, high exertion and very high exertion respectively. Metrics with significant differences in values for different categories of exertion (i.e. low, medium, high and very high) were further analyzed using paired t-tests with Bonferroni correction. Bonferroni correction was applied to control Type I errors because of multiple t-tests which otherwise could lead to statistically significant results which in reality are not significant.

Results

Correlation analysis for RPE values and corresponding traditional and HRV metrics are summarized in Table 1. Overall, skin temperature demonstrated the strongest correlation (Pearson correlation 0.889) followed by Poincare plot metric SD2 and mean beat-to-beat interval with corresponding Pearson correlation coefficient values of -0.633 and -0.613 respectively. The results also indicate that all of the three traditional physiological measures depicted statistically significant correlations. On the other hand, for HRV measures, out of seven, only three metrics showed significant correlation with RPE values. Specifically, the correlation between RPE values and approximate entropy (ApEn), sample entropy (SampEn), detrended fluctuation analysis (DFA) metrics (5) short term fluctuation slope (alpha 1, α_1) and (6) long term fluctuation slope (alpha 2, α_2) was statistically insignificant.

Table 1: Correlation analysis

	Breathing rate	Skin temperature	Mean heart rate	Mean beat-to-beat interval	ApEn	SampEn	Poincare plot, SD1	Poincare plot, SD2	DFA, alpha 1	DFA, alpha 2
Sum of Squares and	750.7	766.8	4149.4	-23351.9	9.59	3.31	-1256.2	-5599.30	-8.73	5.27
Pearson Correlation	.355*	.889*	.611*	-.613*	0.145	0.022	-.489*	-.633*	-0.075	0.087
Significance(2-tailed)	<0.001	<0.001	<0.001	<0.001	0.100	0.802	<0.001	<0.001	0.395	0.325

*. Correlation is significant at the 0.01 level (2-tailed)

Based on correlation analysis, repeated measures analysis of variance (RMANOVA) was conducted for metrics that demonstrated significant correlation (i.e. breathing rate, skin temperature, mean heart rate, mean beat-to-beat interval and Poincare plot metrics SD1 and SD2). The results are shown in Table 2. As illustrated, all selected metrics could differentiate among different physical exertion levels (i.e. low, medium, high and very high) with p-values less than 0.001 for all metrics except for Poincare metric SD1, for which the p-value was 0.001.

Table 2: RMANOVA analysis

	Breathing rate	Skin temperature	Mean heart rate	Mean beat-to-beat interval	Poincare plot, SD1	Poincare plot, SD2
RMANOVA p-value	<.001	<.001	<.001	<.001	0.001	<.001

To further explore the performance of each metric, RMANOVA for each metric was followed by pair-wise comparison for different physical exertion levels. Pair-wise comparisons involved calculating mean differences, standard errors as well as paired t-tests with Bonferroni correction. The results are tabulated in Table 3. The results highlight that all of the selected metrics were able to statistically differentiate low physical exertion against medium, high and very high physical exertion however this was not the case for medium level against high and very-high level exertion levels, and high level against very-high level exertion levels. Additionally, the results also signify that all of the metrics were not equally capable to discriminate among different fatigue levels. For e.g. breathing rate could not statistically differentiate high and very-high physical exertion from medium exertion as well as high against very-high exertion levels. The case was similar for Poincare plot metric SD1 and SD2. In contrast, three metrics (skin temperature, mean heart rate and mean beat-to-beat interval) were able to statistically discriminate all pairs except one.

Table 3: Pair-wise comparisons for the selected metrics

		Low			Medium		High
Metrics	Statistics	Medium	High	Very-high	High	Very-high	Very-high
Breathing rate	Mean difference	-8.465	-8.164	-7.215	0.301	1.25	0.95
	Std. error	1.636	1.479	1.903	1.667	1.968	1.292
	p-value	0.001	<.001	0.01	1	1	1
Skin temperature	Mean difference	-3.743	-5.291	-5.438	-1.548	-1.696	-0.147
	Std. error	0.276	0.408	0.342	0.332	0.247	0.151
	p-value	<.001	<.001	<.001	0.002	<.001	1
Mean heart rate	Mean difference	-19.718	-19.005	-37.048	0.713	-17.33	-18.043
	Std. error	5.738	3.952	4.8	3.412	4.643	3.983
	p-value	0.02	0.001	<.001	1	0.011	0.002
Mean beat-to-beat interval	Mean difference	127.378	126.62	202.478	-0.758	75.1	75.858
	Std. error	38.458	27.872	30.351	19.744	21.833	18.303
	p-value	0.026	0.002	<.001	1	0.02	0.005
Poincare plot, SD1	Mean difference	8.366	7.875	9.148	-0.491	0.782	1.273
	Std. error	3.329	2.775	2.653	1.259	1.893	1.242
	p-value	0.138	0.071	0.02	1	1	1
Poincare plot, SD2	Mean difference	42.261	37.769	47.81	-4.492	5.549	10.041
	Std. error	7.392	7.513	6.733	2.381	4.607	5.072
	p-value	<0.001	0.001	<0.001	0.465	1	0.391

Discussion

Monitoring physical exertion and fatigue has been identified as an important need of the construction industry. Accordingly, for the past many years, researchers have tried to develop tools for the purpose. With new wearables coming to the market every year, the goal of monitoring real-time physical exertion in a non-invasive way is coming nearer and nearer. This study is a part of this effort. Many wrist fitness bands and watches are nowadays equipped with optical sensors which are capable of measuring advance metrics based on analysis of beat-to-beat interval known as HRV metrics. The objective of this study was to investigate how well these HRV metrics could help in accurately differentiating different physical exertion levels.

The results indicate that not all of the traditional and HRV are equally well correlated with RPE data. Specifically, the correlation between skin temperature and RPE was the highest among all (Table 1). This result is in accordance with the studies of Aryal et al. (2017) and Umer et al. (2020) who while performing RPE modeling, found it to be the best individual metric when compared to other traditional physiological measures. The results also emphasize that despite all of the selected metrics were able to statistically differentiate between physical exertion levels as determined by RMANOVA (Table 2), some of the metrics were better at distinguishing distinct exertion levels as explained by pair-wise comparison tests (Table 3).

An interesting observation from the Table 3 is that skin temperature could not statistically differentiate between high and very-high level fatigue which could be readily distinguished by mean heart rate and mean beat-to-beat interval metrics. On the contrary, the latter two metrics (i.e. mean heart rate and mean beat-to-beat interval) could not differentiate medium physical exertion from high physical exertion but skin temperature could do that. This might suggest that no one metric is capable to single handedly statistically discriminate among all exertion levels with the best Pearson correlation coefficient. Therefore future tools for physical exertion and fatigue monitoring and modelling should use a combination of traditional and HRV metrics to enhance the accuracy.

While this study has advanced our knowledge related to use of HRV measures to distinguish different level of exertion for construction tasks, this study possesses some limitations which should be acknowledged. First, this study utilized non-construction workers as participants for the experiments. Second, the duration of the task was limited. Third, this study explored a single construction task i.e. manual material handling. Future studies should verify the results with construction workers, prolonged work duration and multiple construction activities.

Conclusion

This study contributes to the body of knowledge by statistically comparing traditional physiological measures (heart rate, breathing rate and skin temperature) and heart rate variability (HRV) features for physical exertion monitoring purposes using manual material handling experiments. The results found that skin temperature, Poincare plot metric SD2 and mean beat-to-beat interval had a higher correlation with ratings of perceived exertion than other metrics. Pair-wise analysis revealed that skin temperature, mean beat-to-beat interval and mean heart rate were better able to discriminate individual exertion levels than other metrics. Overall, the results underscore the use of a combination of both traditional and HRV metrics for physical exertion and fatigue monitoring. Accordingly, future tools should make use of both types of metrics and inform the industry and academia about the accuracy achieved using such an approach.

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A secondary analysis of risk factors contributing to the prevalence of TB in informal settlements: A study of Khayelitsha in Cape Town, South Africa

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Abstract

Purpose - Informal settlements are characterised by poor housing, inadequate infrastructure and sanitation facilities. This leads to the prevalence of diseases such as tuberculosis (TB), which is one of the causes of death globally. The main purpose of the study is to evaluate prevalence of TB informal and formal dwellers in Khayelitsha and identify risk factors that contribute to the prevalence of TB in informal settlements.

Design - A secondary research was conducted using data from Statistics South Africa in addition to existing literature on the subject in South Africa. A case study analysis was undertaken using Khayelitsha suburb in Cape Town province of South Africa.

Findings - The study found that prevalence of TB is higher among people living in informal settlements as compared to formal settlements. Further, pre-existing health conditions such as HIV, overcrowding, unemployment and lack of education were found to be some of the determinants associated with the occurrence of the disease.

Limitations – The study adopts a secondary research approach and focuses on one suburb in South Africa.

Originality – The study uses a case study to identify risk factors that could lead to the prevalence of TB in informal settlements and ways to mitigate the risks.

Practical implications – Effective strategies could be developed to reduce the spread and mitigate the effect of TB in informal settlements.

Keywords: Unemployment, HIV/AIDS, Tuberculosis, socioeconomic, overcrowding, informal settlements.

Introduction

Informal settlements are areas where groups of housing units have been constructed on land that the occupied illegally or unplanned settlements areas where housing is not in compliance with current planning and building regulations (Housing Development Agency, 2013). They are characterised by poor housing, insecure tenancy, socio-economic deprivation, inadequate infrastructure and sanitation facilities that threaten the health, safety and wellbeing of the habitants. Some common health and safety threats in informal settlements include the spread of chronic and communicable infections such as tuberculosis. These threats are further exacerbated by the social and spatial marginalisation experienced by inhabitants of informal settlements (Weimann and Oni, 2019).

Tuberculosis is a major public health concern globally (Sulis et al., 2014). Whilst TB has been noted to be among the highest 10 causes of death globally by the World health organisation, South Africa is one of the nations hit with the hardship of the disease (TBfacts, 2016). The disease is also known to be prevalent in third world countries, which are countries where there is a lack of access to clean water, lack of access to public health care, poor sewage systems and also lack of sanitation. In 2016, there was an estimated 1.3million deaths caused by TB among people who are living without HIV, which is a decrease from the 1.7million deaths in the year 2000. Furthermore, there was an extra 374000 deaths among people living with HIV (de Queiroz-Mello et al., 2018). In 2016, an approximate 10.4million people were sick with TB. Among those, 90% were adults, 65% were male, 10% were people living with HIV and of those, 74% were in Africa. In countries such as India, Indonesia, the Philippines and Pakistan, there 56% of the people who were infected with TB. An estimated prevalence of 454000 cases of active TB have been released by the data from the World Health Organisation (WHO), which means that roughly of 80% of a population of 54million develop active TB on a yearly basis (TBfacts, 2016). Asia and Africa alone constitute 86% of all cases (Zaman, 2010). Furthermore, a significant amount of South Africa's people who have been infected with the TB germ have Latent TB and not Active TB illness being an approximate 80%. People living in townships and informal settlements between the ages of 30-39 years old have been found to have the highest occurrence of Latent TB roughly 88% (TBfacts, 2016).

The disease has been linked to socioeconomic elements such as unemployment which may favour its occurrence (Przybylski, et al., 2014; Pelissari and Diaz-Quijano, 2017). Among the socioeconomic elements involved, poverty also plays a role in the occurrence of the illness. Living and working conditions which are crowded and terribly ventilated, as well as other risk factors such as HIV, smoking and the abuse of alcohol, and low level of health knowledge. Further, according to the WHO (2020), the control of TB has been a challenge globally given the incidence of the COVID-19 pandemic and consequent reduction in TB detection could lead to a 13% increase in TB deaths. It is therefore pertinent to identify these factors in order to continuously inform and develop effectual strategies to control the spread of the disease.

Previous studies have dealt with various aspects of TB prevalence, and control strategies. Dye and Floyd (2006) identified the costs and benefits of global TB control, with some cost-effective strategies, which ultimately increase average economic productivity of workers. Zama (2010) studies the factors contributing to the development of multi-drug resistance to TB, including non-adherence to therapy, lack of direct observed treatment, limited or interrupted drug supplies, poor quality of drugs, widespread availability of anti-TB drugs without prescription, poor medical management, and poorly-managed national control programmes. Another study by Sulis et al. (2014) investigated the challenges of controlling the spread of TB and identified vulnerable groups that were most at risk of contracting the disease. These challenges include multidrug-resistance and the limited advances in the search for new drugs, diagnostics, and vaccines. More recent studies established that pre-existing conditions may influence the spread and prevalence of TB and increase predisposition to other viruses such as COVID-19 (Boffa et al., 2020). Loveday et al. (2019) suggested that the profile of people dying from TB changed over the years, with the proportion of males dying from TB increasing from 55% to 62% and a corresponding decrease in the female proportion. It however appears that the informality of dwellings and community as the most susceptible people has been studies to a limited extent. This is concerning since TB is more prevalent in informal settlements in South Africa (Ncayiyana, 2016). This is the premise of the current study. The current study explores the prevalence of TB in formal and informal settlements in a suburb in Cape Town province of South Africa. The current study therefore identifies the risk factors linked with TB prevalence.

Overview of Literature

TB Control efforts globally

Efforts have been made to reduce the prevalence of TB globally. Some of these include the launch of the Global Plan to Stop TB (2001-2005),, establishment of the Global Trust Fund for international mobilisation of funding to strengthen national programmes to control TB (Sulis et al. 2014), and setting international targets for TB control, embraced by the United Nations Millennium Development Goals (MDGs), to detect and successfully treat active cases, thereby reducing incidence rates, prevalence and deaths (Dye and Floyd, 2006). Further, the new post-2015 Global TB Strategy approved by the 67th World Health Assembly (WHA) in May 2014, aimed at "ending the global TB epidemic" by 2035 (Sulis et al., 2014). The new strategy emphasises that action on social and economic, "upstream" determinants of TB must be addressed and these can be achieved through; strong coalition with the civil society and communities; government stewardship and accountability; protecting and promoting human rights, ethics and equity; and adaptation of the strategy and targets at country level with global collaboration. Although TB rates have declined and treatment rates have increased considerably in recent years, with these efforts, there is still a cause for concern especially in low-income countries that lack adequate infrastructure and finance to combat the disease (Migliori, 2018). Moreover, meeting set targets for TB control requires a set of interventions that are not only cost-effective but also affordable and capable of having an effect on a large scale (Dye and Floyd, 2006).

TB prevalence in South Africa

In the past two decades, efforts have also been made to reform TB control in South Africa. These include such interventions as the internationally recommended DOTS strategy, whose essential elements, implemented in 1996 after TB was declared a national emergency, include bacteriological confirmation of disease, standardized first-line treatment regimens that are exclusively based on fixed-dose combination formulations and an electronic recording and reporting system (Weyer, 2007). In 2003, the strategy was expanded to cover the nine provinces and 183 health districts, with management of patients intensified through a network of referral centres. However, TB incidence and fatality rates is still a concern in South Africa (TBfacts, 2020). Although the number of fatalities due to TB steadily declined over two decades from 76,881 in 2006 to 29,399 (6% of total mortality) in 2016, TB has consistently been the leading cause of death in SA (Loveday et al., 2019). Reducing TB deaths to meet the End TB Strategy mortality target of a 95% reduction in TB mortality (from 2015) by 2035 is within our reach, but will require ongoing focus and effort.

Factors contributing to the prevalence of TB in South Africa

Although TB control has been fully integrated into primary health-care services and decentralized to district level, delivery is hampered by competing health priorities, slow district reform and deficient management capacity, especially at the level of implementation (Loveday et al, 2019). Further, defaulting on treatment (up to 25% of patients) and failure of treatment (around 10%) reduce the overall effectiveness of intervention programme to less than 50% (Weyer, 2007). Other barriers, which are similar to other developing countries are exploding HIV epidemic, deteriorating socioeconomic conditions among already vulnerable populations and constraints on human resources in the health-service sector. (Loveday et al., 2019). Further, unemployment rates of up to 40%, as well as the resultant migration and massive growth in informal urban settlements, lead to failures in supervision of TB treatment and follow-up. The study by Loveday et al. (2019) posited that certain groups are more at risk of contracting TB and these include pregnant women and people living with HIV/Aids.

Housing standards

The standard of housing in informal settlements was shown in a study in Beirut which investigated the prevalence of acute illnesses in informal settlements (Habib et al, as cited in Petersen, 2011). Statistics South Africa has defined formal housing as a structure which has been built with accordance to accepted building plans for example a house on a separate stand, a flat, or an apartment, townhouse , a room in back yard, rooms or flatlet elsewhere. Whereas, informal housing or traditional housing has been defined as a makeshift structure that has not been built in accordance with accepted building plans for example shacks or shanties informal settlements or backyards (Statistics South Africa, 2016). Poor housing could compromise primary human necessities such as water, public health care, safe food preparation and storage and also helping in the fast spread of food borne illnesses (Brown, as cited in Govender et al., 2011).

Services and infrastructure such as lack of water, sewage systems and electricity were pointed out in the study as some of the problems that have had a hand in the breakout of diseases (Habib et al, as cited in Petersen,2011). Conditions such as high humidity, pest infected houses, lack of heating during the cold seasons and lack of electricity were found to be harmful to the health of many people in informal housing and low cost housing. Furthermore, breathing problems, poor mental well-being in children, household burns and accidents have been linked with crowded and cramped environments (Habib et al, as cited in Petersen, 2011).TB is easily transmittable in damp and crowded conditions, which are common among township (Cramm et al). The housing conditions such as overcrowding are considered to be risk factors for the contraction of the disease as the above studied literature agree with the statement. Furthermore humid conditions as stated by(Habib et al, as cited in Petersen, 2011) do play a role in the contraction of the disease which also supports the findings from the study done by Cramm et al) that damp conditions contribute to the occurrence of TB.

HIV infections

Bearing in mind that Africa has the highest HIV/AIDS infection rates, the number of TB infections is said to be increasing because of the close relationship between HIV/AIDS and TB in Sub-Saharan Africa. With Sub-Saharan Africa having the top estimated percentage of which 71, 9% of the people in urban areas have been categorised as people living informal settlements, Sub-Saharan Africa and Asia account for 75% of urban poverty globally (David et al, as cited in Petersen , 2011). He also notes that while there is a data restriction on HIV/AIDS and TB that compares people living in informal and formal settlements. The reasons for the people living in informal settlements having high occurrence rates of diseases are that they are quiet and not expressing their views. For these reasons, TB prevention and control becomes a serious problem in informal settlements (David et al, as cited in Petersen, 2011). Furthermore, with regards to the link between TB and informal settlements, low to low middle income nations make up roughly 90% of the deaths linked to TB (Petersen, 2011)

Socioeconomic factors

The complicated concept of socioeconomic deprivation means lack of social and economic primary needs which includes a combination of elements such as lack of schooling, low income, overcrowding and unemployment (Lönnroth et al, as cited in Duarte et al, 2017). Numerous studies have found a link between the total value of goods produced and services provided in a country in 12 months and the occurrence of TB. Housing factors and the state which people live are liable for a significant part of the health inequalities and the greater risk of TB contraction. Lack of social and economic needs causes poor state of living, overcrowding and malnutrition which increases the contact cases of TB and further increases the risk of undesirable treatment outcomes (Murray et al, as cited in Duarte, 2017). The articles studied come to an agreement that the prevalence of TB is in communities where there is a low level of income and prevailing socioeconomic issues such as overcrowding, lack of education and unemployment contribute to the occurrence of the disease in informal settlements (Petersen, 2011).

Research Methods

The study adopted a secondary research approach. A case study analysis was undertaken using secondary data on Khayelitsha Township in Cape Town, South Africa (Reddy and Agrawal, 2012). An integrative literature review and hand-searching of secondary data to examine previous work on the subject were undertaken (Johnston, 2014). Secondary information, which was freely available in the public domain were used and effort was made to select data sources to improve the quality and quantity of information that was collected (Reddy and Agrawal, 2012).

Various data sources were consulted for the study. The integrative review was conducted to identify targeted literature on the risk factors and their influence on TB prevalence. Hand-searching was also used to amass data on Khayelitsha from pre-determined reliable sources (Vassar et al., 2016). These sources included the WHO published literature and web articles, Statistics South Africa, Department of Health, South Africa, Census 2011 and other published relevant documents. A case study analysis was conducted. The secondary data collection included an investigation of the disease and risk aspects connected to TB, current readings based on wider and international studies were found to be helpful in this respect. There were not many case studies found about South Africa (Petersen, 2011). Census data from 2011 was taken from the website of the City of Cape which indicates the demographic profile, economic profile, dwelling profile and household service profile in Khayelitsha. The Global Tuberculosis report 2018 from the World health Organisation and South Africa was the country profile which was looked at. The study area chosen for this research was Khayelitsha. The township is located on the Cape Flats and situated 30km south-east of Cape Town in the Western Cape Province. According to the Census, the population of Khayelitsha was 391 749, with households amounting to 118 809 in 2011.

The collected data was entered into an Excel spreadsheet and arranged into a table according to variables and the type of house (Petersen, 2011). Housing data on formal housing and informal housing were separated from each other. A descriptive analysis was conducted and the findings are presented in the next section.

Findings on Factors Contributing to TB Prevalence in Informal Dwellings

Occurrence of TB in households

Statistics South Africa has described a household as a group of persons who live together, and provide themselves jointly with food or other essentials for living, or a single person who lives alone (Statistics South Africa, 2018). Table 1 indicates the prevalence of Tuberculosis in the different types of dwelling. It was found that the prevalence of TB is higher in informal housing with 57.14%. This finding suggests that the prevalence of TB is higher in informal housing and people living in informal housing run a higher risk of contracting TB than those in formal dwellings.

Table 1: The occurrence of TB in the households

The occurrence of Tuberculosis

Type of Dwelling	Number of cases	Total number of houses	Percentage
Formal housing	4	10	40%
Informal housing	8	14	57.14%

Average household area occupied per person

The average number of people per housing type was obtained from Census 2011. As can be seen from Table 2, people living in informal housing have a less share of the house area as compared to occupants of formal housing. This may lead to overcrowding as there is less space to share which is a risk factor for Tuberculosis. This lack of space may lead to overcrowding in a house which is also a risk factor for the contraction of Tuberculosis.

Table 2: The average (house) area, per person among people occupying formal and informal housing.

Area per person		
Average Dwelling size(m^2)	30	25.6
Average number of people per housing type	3.30	3.30
Average share of house area, per person	9.09	7.76

Economic profile

Unemployment is also another risk factor for Tuberculosis. The unemployment rate in Khayelitsha is quiet high at 38.02%. This means that the prevalence of TB may be high due to unemployment being high. Socioeconomic deprivation has been defined as the lack of social and economic primary needs such as education and unemployment to name a few. Unemployment is also risk factor associated with the incidence of TB. Furthermore low income communities have been seen as places where the prevalence is high and the GDP has also been linked with the occurrence of TB which has been supported by other studies. The study is in line with other studies.

Table 3: Economic profile (Source: Census 2011)

Khayelitsha Labour Force Indicators	Black African	Coloured	Asian	White	Other	Total
Population aged 15 to 64 years	27,0798	1,590	201	237	2,160	27,4986
Labour Force	176,280	927	126	147	1,755	17,9235
Employed	108,735	639	102	105	1,512	11,1093
Unemployed	67,545	288	24	42	243	6,8142
Non Economically Active	94,518	663	75	90	405	95,751
Discouraged Work-seekers	11,061	90	9	3	36	11,199
Other not economically active	83,457	573	66	87	369	84,552
Rates %						
Unemployment rate	38.32%	31.07%	19.05%	28.57%	13.85%	38.02%
Labour absorption rate	40.15%	40.19%	50.75%	44.30%	70.00%	40.40%
Labour Force participation rate	65.10%	58.30%	62.69%	62.03%	81.25%	65.18%

Profile/category of dwelling

The table below shows the number of people living in formal and informal housing and also other categories of dwellings. It has also been categorised according to race, with the number of black African people topping the list because Khayelitsha is a township dominated by black Africans, and this may contribute to the prevalence of TB. The prevalence of TB may be associated with race and geographic location, among other things (WHO, 2018).

Table 4: Dwelling profile (Source: Census 2011)

Khayelitsha	Black African		Coloured		Asian		White		Other		Total	
Type of Dwelling	Num	%	Num	%	Num	%	Num	%	Num	%	Num	%
Formal Dwelling	52,186	44.5%	339	69.6%	34	54.8%	62	60.2%	369	46.1%	52,990	44.6%
Informal dwelling / shack in backyard	9,463	8.1%	47	9.7%	6	9.7%	4	639%	211	26.3%	9,731	8.2%
Informal dwelling / shack NOT in backyard	54,679	46.6%	95	19.5%	22	35.5%	36	35.0%	198	24.7%	55,030	46.3%
Other	1,028	0.9%	6	1.2%	0	0.0%	1	1.0%	23	2.9%	1,058	0.9%
Total	111,356	100.0%	487	100.0%	62	100.0%	103	100.0%	801	100.0%	118,809	100.0%

Educational profile

Education is another risk element linked with Tuberculosis. Education is important as it helps one to be able to understand and comprehend things. Most uneducated people live in informal settlements because they are often unskilled and it may be hard to find employment due to lack of schooling, and this perpetuates the high level of poverty (Pelissari and Diaz-Quijano, 2017).

Table 5: Educational profile (Source: Census 2011)

Khayelitsha	Black African		Coloured		Asian		White		Other		Total	
Adult Education (for all aged 20+)	Num	%	Num	%	Num	%	Num	%	Num	%	Num	%
No schooling	6,066	2.5%	45	3.2%	21	12.3%	18	8.5%	327	16.1%	6,477	2.6%

Some primary	23,613	9.8%	219	15.4%	12	7.0%	9	4.2%	156	7.7%	24,009	9.8%
Completed primary	10,662	4.4%	126	8.8%	9	5.3%	6	2.8%	75	3.7%	10,878	4.4%
Some secondary	114,675	47.4%	651	45.7%	63	36.8%	84	39.4%	768	37.8%	116,241	47.3.%
Grade 12	74,442	30.8%	327	22.9%	57	33.3%	51	23.9%	585	28.8%	75,462	30.7%
Higher	11,886	4.9%	51	3.6%	9	5.3%	45	21.1%	81	4.0%	12,072	4.9%
Other	411	0.2%	6	0.4%	0	0.0%	0	0.0%	39	1.9%	456	0.2%
Total	241,755	100.0%	1425	100.0%	171	100.05	213	100.0%	2,031	100.0%	245,595	100.0%

Discussion

The study found that socio-economic factors as well as pre-existing health conditions contribute to the prevalence and spread of TB in informal settlements. The findings showed that the type of dwelling could contribute to the spread of TB as a result of overcrowding. Informal settlement improvement efforts should therefore focus on reducing crowding. This is in line with studies which showed that those who live in shacks (not in backyards) are most commonly affected by an acute respiratory infection (Claassens, et al., 2014).

The size of dwelling was also found to be a contributing factor. This view was shared by Ncayiyana et al. (2016), who opined that ventilation can help in reducing the prevalence of TB in crowded households. The current study supports literature, which stated that overcrowding is a risk factor (Pelissari and Diaz-Quijano, 2017; Kalonji et al., 2016). However, according to Pelissari and Diaz-Quijano, 2017), household crowding may be as a result of socio-economic factors such as low income and level of education.

Unemployment is a major risk factor for TB prevalence as most unemployed people in South Africa are informal settlers (Hunter and Posel, 2012). These findings are in line with extant literature which revealed that individual and household characteristics including employment and socio-economic conditions, as well as lifestyle behaviours like smoking and alcohol consumption may exacerbate TB infections (Ncayiyana et al., 2016).

Plans to upgrade informal settlements should therefore include solutions to alleviate some of the challenges faced in informal settlements, as a result of their predisposition to poor living conditions and social and economic exclusion, a view shared by the Socio-Economic Rights Institute of South Africa (SERI) (2018). It was emphasized that 'informal settlements upgrading should not just be about eradication, but should include an understanding of people's existing circumstances and contributing to improving people's lives in a meaningful way (SERI, 2018). In addition, health services should be strengthened to be able to respond to detected cases on time especially during this period of the COVID-19 pandemic (WHO, 2020).

Conclusion

The main purpose of the study was to determine the prevalence of TB in both informal and formal dwellings and to determine risk factors linked with TB prevalence in a suburb in Cape Town, South Africa. It was found that the cases of TB are higher in informal dwellings. The study also found that risk factors such as the type of dwelling one lives in, socio-economic factors as well as household characteristics play a role in the chances of one contracting TB.

Overall, the spread of TB can be reduced by improving the standard of health and building resources in informal settlements. Attention to socio-economic factors including employment, education, and income inequality can reduce prevalence of TB among citizens Social and economic development can reduce the risk for TB infection and disease. Elements such as expanding populations and movement, crowded spaces, unsuccessful regulatory structures which are meant to keep an eye on the state of public health care system and environmental as well as natural elements have been connected by studies to the development of breakouts such as TB and present day communicable diseases such as HIV/AIDS. Health authorities and municipalities can provide capacity building and community assistance services to help in combating the spread of TB. This is especially necessary at this time of the COVID-19 pandemic. Increased integration of TB services at a primary care level together with political attention, civil society mobilisation can also help to reduce deaths from TB.

The current study employed information from secondary sources only and there was no primary information. More studies could be done using primary research techniques.

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Tuning into Heat: Acclimatisation on Construction Site and Horizontal Integration in Major Project Management

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Abstract

Acclimatization is a process in which human body adapts to a hot environment by developing capacities of more efficient heat dissipation and electrolyte retention. International heat stress management standards specify thresholds of up to 5 ^{o}C-WBGT difference for acclimatised and non-acclimatised populations, and a 3-14 days' period for newcomers to take up full workload. Such protocols if literally practised in construction projects would have a massive impact on productivity, and would particularly suffer major projects for uneven work pace and discorded team rhythms. Thus it takes a systemic tune-up to address it in major project delivery. The aim of this research is to explore the actual process of acclimatisation in the complex systemic context of major project delivery. Data were collected through an ethnographic study on a remote site of a megaproject in Australia. We found that inadequate acclimatisation as a major causal factor to heat related incidents on site, but not until added by poor individual situation awareness and behavioural response patterns. On this empirical basis, we attempt to redefine an extended concept of acclimatization for a working population embedded in the work context and personal histories and lifestyles outside of work. From a human-based systems thinking perspective, we further discuss the necessity of horizontal integration in major project delivery where safety is essentially an authentic approach of managing people in projects. We then define a broader concept for OHS management as *the preservation of human lives at work, including quality of life*. With this definition, we can take safety, health, wellbeing and fulfilment on the job under a single care and safety as an attribute of the complex project management system.

KEYWORDS: acclimatization, adaptive opportunity, heat stress, horizontal integration, major projects, systems thinking.

Introduction

The disruption of COVID-19 has forced a shift of thinking in many knowledge domains. To our field, the Hierarchy of Control (HOC) underlying OHS management practices (e.g., Safe Work Australia 2015) is turned upside down. HOC suggested a sequence of prioritizing hazard control choices from elimination, substitution, engineering controls, administrative controls, to PPE as the least effective measure and the last resort. Acting on this belief, initial governmental responses to the pandemic hazard was lock-down and social distancing rules, legitimated by expert advice against wearing a mask. Four months down the path, the economic consequence of shutting down businesses and production activities has been catastrophic, which will eventually impact on the safety and health of a growing jobless population left in idling and isolation. Thus governments turned around to mandate the wearing of masks in order to keep the society running and people economically engaged. The upside down HOC now sees PPE as the most effective control in that it enables businesses operating in hazardous conditions. For OHS management in construction, such a learning curve implies that we need to be freed up from a single-disciplinary safety focus to embrace a broader safety concept, which takes a tune-up of the whole project delivery system. In this study we seek to understand construction workers' heat acclimatization in the complex system of project delivery and its implication on horizontal integration in major project management.

Heat stress on construction workers is a systemic issue for the construction industry (Tymvios et al, 2019). Over the past decade, empirical studies on managing heat in construction projects were undertaken, in which an important step for managing heat stress, acclimatization, has been underexplored. Acclimatization is human body's adaptation process of developing a stronger heat dissipation capacity and therefore more tolerance to heat stress. Acclimatisation is an effective approach to improve safety and productivity in heat, and the lack of it is a major factor accountable for heat illness incidents in construction projects (Jia et al., 2016b). International heat stress standards such as ISO 7243 and ACGIH ©TLVs prescribe environmental thresholds of up to 5 ^{o}C-WBGT difference between acclimatized and an unacclimatized working populations. For the construction workforce, 5 ^{o}C-WBGT difference will have a massive impact on labour productivity. Acclimatization protocols suggested a period of 3-14 days for a newcomer to take up the full workload. Whether this protocol works or not in construction practice, and how, is yet to be explored. In the context of major projects, the project as a complex system would find itself interrupted by uneven work pace and dissonant team rhythm. Through exploration of workers' acclimatization experiences in a megaproject in a hot and humid climate zone in Australia, we redefine an extended concept of acclimatisation, taking into account of adaptation behaviour, to address the embeddedness of the workers in the physiological context of their workplace. We then discuss the systemic tune-up needed for complex project management in trying to manage acclimatisation effectively.

Horizontal fragmentation and the systemic perspective

Fragmentation has been a long-standing characteristic for construction project delivery whereas safety management has particularly suffered from the invisible walls between organisations and professions in a project lifecycle. The OHS professionalism, the legal systems developed on it and the resulted project governance structure fan the flames of horizontal fragmentation (Smyth et al, 2019). As such, safety is educated as a separate discipline and practiced as 'another' job of construction projects, somewhat alienated from the project business (Lingard et al 2019; Jia et al 2017). Fragmentation between organisations in projects and its effect on safety has been indicated in Lingard et al (2011)'s survey in an Australian sample which found principal contractor's supervisors' decisions did not have a direct influence on subcontractors' workers' safety behaviours but through a path via subcontractors' supervisors. As an explanatory note to this survey result, the authors' field work on a megaproject site in Australia observed that a manager came across a worker engaging with unsafe behaviours, only to find himself unable to intervene due to the fact that they belonged to different companies. Similar phenomenon was observed by the first author with an experienced regulator in varied types of projects in Australia, suggesting this is a rather normal construction management practice.

Armchair professor might find such observations hard to believe and argue that since WHS has been so well regulated in Australia, all parties should have been highly motivated to act proactively upon witnessing any unsafe practice on site. Interestingly, such fragmentation is exactly the outcome of the highly developed formal institutional systems in developed countries, where all parties for compliance's sake try to adhere to their own legal obligation and avoid taking up the extra risk of acting beyond it (c.f. a more detailed discussion in Jia et al 2017). In contrast, more holistic managing and caring practice was found in developing countries where formal institutions were not yet developed to the level of mediating how people make sense of safety in their work context (Jia et al 2019b). At this point, developed countries have something to learn from developing countries. An anthropologic approach is needed in construction safety research to reflect more fundamentally on how systemic improvement can be made in managing complex projects.

Acclimatization as a physiological adaptation process

Acclimatization is a heat adaptation process that involves a series of physiological adjustment within the human body. An acclimatized body has an improved ability in dissipating heat through more sweat, better retention of electrolyte and reduced arousal in Plasma renin activity and aldosterone concentration levels (Finberg and Berlyne 1977). Earlier physiological studies found that acclimatization makes human blood able to carry more oxygen (King et al., 1985) and more fluid (Bonner et al. 1976). King et al (1985), for example, found that after 8 days' acclimatization, human body developed an enhanced physical capacity by reducing muscle glycogen utilization. They conclude that acclimatization changed fuel selection within the body during submaximal exercise. Acclimatization can be automatically triggered when a person is exposed to a hot environment or climate, but not always. Physical activities must be carefully controlled during the period of acclimatization to prevent the occurrence of heat illness. In athlete training, artificial acclimatization is sometimes deliberately used to improve the body's functioning in performing highly intense exercises (King et al. 1985). Occupational hygienists typically suggest an acclimatization protocol a period of 3-14 days' gradual increase in exposure to the target level of heat stress (e.g., MOM 2012, AIOH 2013, ISO 7243: 2017). It is also known that acclimatization starts losing after 4 days' away from the exposure and is completely lost after 3-4 weeks (ACGIH 2015: 218).

Acclimatization and thermal thresholds

ISO 7243 (2017) gives separate sets of reference values for acclimatized and unacclimatized workers, e.g., up to 5 °C-WBGT in the 'very heavy' workload category. The ACGIH (2015) provide Threshold Limit Values (TLVs) for acclimatized workers and the Action Limits for unacclimatized workers, up to 3 °C-WBGT difference between the two. In the current construction practice, the work rules are treating all workers as fully acclimatized, although a formal acclimatisation protocol is rarely in use (Arbury et al. 2014, Dong et al. 2019).

Table 1. Threshold values for acclimatized and unacclimatized workers (Unit: °C-WBGT)

Workload [Met (W)]	ISO 7243 (ISO 7243, 2017: 7) Reference values: acclimatized / unacclimatized	ACGIH (2015: 222) (TLV / Action Limit)
Light (180)	30 / 29	31 / 28
Moderate (300)	28 / 26	28 / 25
Heavy (415)	26 / 23	- / -
Very heavy (520)	25 / 20	- / -

Adaptation: physiological, psychosocial and behavioural

There has been a long debate between the rational and the adaptive approaches to modelling thermal comfort (Fanger 1993, Baker 1996, Humphreys and Nicol 1996, Nicol 2004, Candido et al. 2015, de Dear et al. 2018). The rational approach (Fanger 1970; ISO 7730: 2005) assumes a tight coupling between thermal environment and human sensation and satisfaction. It assumes thermal balance within the human body leads to dissatisfaction associated with non-neutral thermal sensation. However, Baker (1996) argues that such deterministic logic only exists in a highly controlled environment such as a climate chamber, where people's adaptive opportunity is deliberately eliminated. In contrast, the natural human being in a free-running building environment will be prompted by any sense of discomfort to take a range of adaptive actions to create and modify their immediate thermal environment. Occupants' adaptive actions include, for example, modification of clothing, change in work pace and therefore metabolic rate (Nikolopoulou et al., 2001), hydration (Baker and Standeven, 1997) and interaction with the physical environment to construct a better local environment (Nicol 2004). Such adaptive actions are almost simultaneous to the perception of the environment, thus become intertwined with the environment itself.

On this basis, the adaptive school lays stress on the embeddedness of the perceiver in his environmental and psychosocial context, and the coupling of adaptive actions altering the perceiver's immediate environment. Humphreys (1978) shows that the perception of indoor thermal comfort is associated with the monthly variance of outdoor temperature. Baker (1996) suggests behavioural and psychological factors play a more important role in thermal comfort than the four environmental factors do; while small adaptive effects add up to make a significant difference on the overall thermal environment that is being sensed and perceived. Baker and Standeven (1996: 176) put forward a model that explains how thermal environment is interrelated with thermal sensation through modification actions that are almost simultaneously prompted by the actors' perception and preference of the thermal environment. The key factor to comfort is thus the presence and extent of 'adaptive opportunity' in the specific environment. Actors' thermal sensation of their local condition is mediated by posture, adjustment of metabolic rate and clothing. The model also shows that thermal sensation does not necessarily lead to satisfaction; the path is moderated by psychological factors.

Relevant to the outdoor environment of a construction site in this study, we are reminded that, between the workplace environment and human thermal sensation, workers are situated in a 'local condition' that varies spatially on site and temporally over the project lifecycle and by seasons, days, hours and minutes. Such differentiation is captured by a socio-ergonomic grounded theory (Jia et al., 2016b) which draws a distinction between 'heat hazards' (heat in the natural and work environment) and 'effective heat risks' (heat at one's immediate environment) (Jia et al., 2016b: 29). Effective heat risks lead to the onset of heat illness, followed by more serious consequences and fatality. This phasing of the heat illness development process allows intervention measures to be mapped into the right timing in their best effectiveness. The model highlights that thermal sensation may not work as a signalling mechanism in the extreme situation of heat stress on construction site where adaptation opportunities are constrained by the work regime. In a structured work setting, thermal sensation is competing with sensations of many other stimuli for actors' attention to trigger adaptive actions. How thermal sensation wins or loses the competition is largely determined by the prevailing institutional logic in the psychosocial environment. Jia et al (2019) found when the whole project team was preoccupied by progress pressure, the warning signals related to personal safety are likely to be overlooked or ignored. In such situation, heat illness incident happens.

Research Methods

The research took an ethnographic approach (Hammersley and Atkinson, 2007) with fieldwork from a megaproject on a remote site in a hot and humid climate zone in Australia. Through triangulation of findings from mix-methods, we try to re-construct an authentic reality on the gestalt of acclimatization through exploration of construction workers' experiences on site. The ethnographic study was conducted by the first author over a period of two weeks in the summer of 2015 and 2017, respectively. The fieldwork generated a large amount of data including on-site heat stress recording, project documents, field notes from interviews and observations. The second author, who was working on the project for long term, did verification on the observation and validation on the authenticated cases. In both field studies, heat stress data were recorded at typical workplaces. Year-round temperature and humidity record from the nearest Bureau of Meteorology (BoM) station was purchased from BoM. After triangulation of multiple sources of data, a grounded theory approach was employed to identify key concepts that explain the data. Some of the findings have been reported in separate papers (Jia et al., 2016a, Jia et al., 2018, Jia et al., 2019a). In this paper, we focus on findings on acclimatization issues.

Results

The megaproject is an LNG onshore facilities construction project, located on the seaside in around 45 minutes' drive from Darwin City in Northern Territory (plus another 45 minutes from site entrance to the project office). At the time of the field studies, there were about 8000 workers working on site daily under 99 subcontractors' project organizations. Except a few local workers, the majority of the workforce worked in a fly-in-fly-out (FIFO) mode, on a roaster of 4-weeks-in-1-week-out. The on-site heat stress level is far over the limit recommended by ACGIH, ISO 7243 or AIOH, and a gap of up to 7.7 ^{o}C between the local temperature and that recorded in the nearest station of Bureau of Meteorology (details reported in Jia et al., 2018). If these standards were literally implemented, there should have been no work activity going on in most of the days in this region. However, the project was implementing a 58-hour working week at the time of study. The gap between the reality and the standards indicates the effect of human adaptation activities. Common to a task-oriented construction site elsewhere in the world, frontline staff's first perception about heat was the operability of the construction material (e.g. the China cases in Jia et al., 2017, 2019b). Similar observations were made by several managers and foremen in this Australian project, "When the weather is too hot, the material (the metal scaffold) can't touched. We must wear gloves." The major strategies of controlling heat stress on site are two folds: provision of cool water and entitlement of 'heat break'.

Is the week-out a source of de-acclimatization?

Initially, the researcher was concerned that the monthly week-out might be a source of de-acclimatization that leads to heat illnesses on site. The ethnographer thus explored around this inquiry with the workers and managers on site.

Ethnographer: *Any issue with the one-week-off when people just come back to work?*

Foreman: *No. Because you know to work slower. Don't keep up on the first day. It took around 2-3 days back to full workload*.

Lack of acclimatization as a cause of heat illness

However, acclimatisation was indeed a major cause of heat illness on site. A foreman stated: "*We got most of these issues with the new guys. They were vomiting.*" An old worker reported that he had heat illness on the third day of coming on site.

Why newcomers are vulnerable to heat illness? A few observations and interpretations were made by foremen, senior management and safety advisors. An immediate observation was:

- "*They were not drinking enough water*."

This was related to a range of off-work activities:

- *"I would mention about afterwork contributing factors of Alcohol consumption and personal activities sports, football, tennis, swimming pool laps …ect and food diet*."

Furthermore, there was psychosocial pressure of working in a team on site:

- "*Newcomers try to prove themselves*."
- "*Newcomers wanted to impress the crew*."
- "*They don't want to be left out. They want to keep up to prove they are productive*."

An overweight worker mentioned that when he was a newcomer, he once fell, lost consciousness:

Ethnographer: *How long did it take you to fully recover?*

Worker: *I recovered at that night. I took fluid and monitor. Then the next day I tried not to keep up. After that I knew the limit of my body. I work slower. Don't rush. It was a lesson to learn. It took 2-3 days back to full workload*.

Time scale for full acclimatization

Exactly how long does it take to develop a full acclimatization to adapt to this hot and humid work environment? A worker suffered from heat illness at 2 pm on a Friday of Week 5 on his commencement of work on site (date: 20 January 2017). Two weeks later, the incident occurred to him again.

thnographer: "*How long does it take to adapt to heat?"*

Foreman: "*Back from the one-week-off, it took 1-2 days to adjust*."

Safety Advisor: "*Newcomers took 2-3 weeks to adapt. They complained about the heat*."

A worker from Sydney: "*Three months*."

A worker from Melbourne: "*I'm here for two years, still not used to it*."

A worker having lived in Darwin for 12 years: "*It took me six years to really adapt to Darwin's climate. It is not only about the body, but also about your life habit, how you eat, and how you respond*."

Safety Advisor: "*Living here for 25 years will be classified as local*."

It was evident that acclimatization did not work as the physiological model suggested. Full acclimatization was achieved in a wide variety of time scales, ranging from zero day to six years. The FIFO workers' one-week-off following every four weeks' on-site work did take re-acclimatization, but was not a major factor to cause heat illness, given conscious self-management was practised.

Psychosocial acclimatization

A worker from Sydney mentioned that he had a heat illness incident at around mid-day, right after lunch, in August. "*I hit the wall, flat out. I was carrying some loads*."

When the ethnographer explored his activities before the incident, he mentioned that he drank overnight. "*For breakfast, I only had coffee and nothing else. I was quite young and fit. I had done this way all the time. Now I work a lot slower to adapt*."

Does this worker have a lifestyle peculiar from the majority of the construction workforce? The answer is NO. When the ethnographer mentioned this to the Project Director, who was from Melbourne, the Project Director said,

"*I did the same, for many years*."

– which indicates the worker's lifestyle is rather an industry norm than an exception.

A young worker from Kent (a dry hot climate zone) was in his Week 3 on site:

"*No heat stress yet. I had once fell down. From that I learned the lesson. I must drink a lot of water*."

In this case, the worker kept himself safe in this environment where many newcomers had acclimatization issues because he had learned a lesson from his 'thermal history'.

A team of three workers formed a buddy group to stay safe in heat, "*We watch each other. If anyone is not right, we tell him to sit down have a shade break*." In this case, the workers adapted to heat through a social approach.

Discussion

Acclimatisation in the psychosocial context of construction work

A number of recently developed scales measure thermal environment with psychometric tools. Isotherms, such as Effective Temperature (ET*) or Standard Effective Temperature (SET), indicate that human sensation genuinely synthesizes aspects of the thermal environment around and adjusts one's expectation on temperature or humidity according to the level of other parameters (Zanni, 2016). The adaptive thermal comfort theory (Nicol and Humphreys, 2002) recognizes that people react to feelings of discomfort to restore their comfort. We shall be aware that within the individual body, the sensation that needs to be mobilized to trigger adaptive action is different from the sensation needed to perceive comfort. Working on a construction site under strong sunlight in a hot weather is hardly comfortable, e.g., as data shown from the same construction site reported in Jia et al (2018), the WBGT values recorded on site far exceeded the action triggering threshold prescribed by ACGIH or ISO 7243 in a normal working day. There is no adaptive opportunity for workers to stay comfort by avoiding physical activities in their designated workplace. On the site of a major project, how effectively can workers mobilise their sensation to respond precisely to a personal safety threshold condition on top of a sensation of discomfort? This is closer to the situation of athlete training or competition (Coris et al., 2004). The population of a certain occupation have more or less collective lifestyle and response pattern, such that the findings of occupational heat illness causalities are different from what was expected from a general public population. Furthermore, we shall be reminded that a large part of human behaviour is rational and nominal (Jia et al., 2017). A person's rational decision of action is constrained by his/her scope of attention, driven by his/her intention and preference (Fishbein and Ajzen, 2010, Goh et al., 2018, Jia et al., 2019a). Thus embedding into construction context, as reported in Jia et al (2016b), people's adaptation behaviour is so intertwined with their psychosocial environment such that some factors, e.g., age, may not predict the same heat strain outcome in a work setting as they do in a laboratory environment. This study sheds more light to the collective characteristics of construction workforce differentiated from that of a general public population; as can be seen from our findings, the lifestyle of having coffee only for breakfast for the morning shift was shared by both the workers and senior management.

Redefining acclimatization

Findings of the study confirm our proposition that acclimatization is a complex adaptation process that needs holistic adjustment in response to climatic, physiological and psychosocial stimuli. The difference between the climate zone where the worker is brought up and the climate zone where the worker works is a factor to be considered. Nonetheless, the adjustment in lifestyle and behaviour is more important than physiological acclimatization. Acclimatisation involves adaptation of personal life habits and response patterns to various stimuli in a holistic situation. Human activity of changing clothing is one of the behavioural responses to thermal discomfort. While physical activity itself will influence the amount of metabolic heat generated within human body and therefore the heat load on human body. Comfort, or even health, is a dynamic equilibrium between the people and their environment. Each person has a calibrated line of a personal thermal neutrality. Acclimatization happens within human body, but if we treat patterns of decisions and actions as part of one's personality, we may extend the periphery of acclimatisation to include adaptive actions. Early research has found that in an environment of ample adaptation opportunities, through adaptive activities, the natural human being makes himself a thermal environment of 1.5 ^{o}C-ET lower than the average of the ambient environment (Haigh, 1981). Taking cold drinks as an adaptation habit takes away 10% of the total metabolic heat at the hottest time of a day (Haigh, 1981), which is also reported in research in more extreme hot conditions by Miller and Bates (2010). Hydration is clearly a major coping strategy adopted by this megaproject. Engaging the psychosocial context, we can define acclimatization as *the personal equilibrium of preserving self-safety in a hot environment, which is adaptable within a range of behavioural freedom*.

Systemic adaptation for PPE

The development of smart cooling vests (e.g., Yi et al 2017) has promised a PPE solution which might enable the workforce to proceed their work without dealing with the acclimatization issues. Related to our findings that workers' personal heat histories and geographical origins that lead to diversity in their acclimatization needs, personalised fitting will be a major challenge for the new PPE to be successfully integrated into construction practice. The fitting work will also need to involve a comparative assessment of local climate and that of the workers' geological origin, incorporated in training for workers alertness at work in wearing the new gears, new hazards incurred by the change and subsequent control measures. That is, the application of the new smart cooling vest in major project delivery will take a systemic tune-up in the project organisation.

Implications for major project management

The exploration into the complexity of acclimatization on construction site brings us back to the origin of safety management in construction projects: effective project management starts from a healthy and productive workforce (Duryan et al, 2020). Project safety management need to start from understanding the total worker (c.f., a recent reference of this concept may be found in Dennerlein et al, 2020). Safety in construction is essentially about a human centric approach of managing people in projects, by which we see the necessity of horizontal integration in delivering major projects (Rowlinson, 2020).

In the safety engineering literature, a socio-technical perspective of systems thinking was developed from experiences in aviation, patient safety, oil & gas, nuclear or chemical safety management, which have a liner engineering process as the core system (e.g., Dekker 2011; Leveson, 2016; Leveson et al 2020). These models no doubt offer great clarity and enhance safety as a discipline, but they may or may not reflect the nature of the system of construction projects. Jia et al (2019b) attempted to draw a distinction between the assumed 'system' based on an engineering core from the complex systemic context where construction safety is operated in, which is more akin to a socio-political system with an uncertain and ambiguous core of human-to-human interaction. A highly realistic depiction that unpacks the complexity of such human-based system of construction practice is found in Sherratt (2016). The findings of this study contribute to our understanding of a human-centred construction practice system, played out through numerous individuals of diverse life styles and personal histories. With this understanding, from an integrated perspective, occupational health and safety in construction may be more broadly defined as *the preservation of human lives at work, including quality of life*. With this definition, we can take safety, health, wellbeing and fulfilment on the job under a single care, and construct safety management as an integrative attribute of the project management system.

Conclusion

This research explores workers' heat acclimatization in the complex systemic context of major projects. Specifically we explored the diversity of individual acclimatization processes in a megaproject organisation in a remote location in Australia, which required 8000 workers rotating in a FIFO mode. Our finding suggests that effective intervention should start from understanding the multiplicity of personal historical contexts and project systemic contexts where the total workers are situated in. Embedded it into personal and organizational contexts, we suggest to redefine acclimatization as *the personal equilibrium of preserving self-safety in a hot environment, which is adaptable within a range of behavioural freedom*. At project level, the results suggest that a single disciplinary approach does not work effectively to ensure workers' safety and health under climatic heat stress, making a case of necessity for horizontal integration in major project management. A well developed and implemented acclimatisation protocol on site would reduce injury and improve productivity on site, but it will take a systemic tune-up for the complex project organisation to make it work. From an integrated perspective, we suggest OHS in construction may be more broadly defined as *the preservation of human lives at work, including quality of life*.

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A Balanced Diet for Construction workers to Improve Safety and productivity

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Abstract

The United Nations (UN) under its Sustainable Development Goals (SDGs) aims to protect labour rights and promote safe and secure working environments for all workers around the world. Although the deadline to achieve the UN SDGs is approaching faster, construction workers around the world are still affecting from a number of factors that highly influence their safety and productivity. Some of these factors are directly linked with the workers' daily food. This paper considers the healthy food and relates it to the productivity and safety performance of construction workers. A qualitative research strategy consisting of a systematic literature review and a semi-structured interview was adopted to accomplish the aims and objectives of this research. A healthy diet from the literature review was identified considering the construction workers' physical activities and energy requirements. The results of face-to-face interviews held with mess managers and construction workers from reputed construction organizations in Oman are reported. The selected workers (50%) consider that their daily food has an impact on their productivity and safety performance. Only 30% of the mess managers reported that they consider health-related factors to make their weekly food menu. 50% of the current food menu of the selected construction organizations in Oman is not balanced for construction workers. The result further reveals that food such as grain, vegetable, fruit, dairy product, lean meat, nuts, seed, fats, oil, and sweets should be part of the daily food to maintain the construction workers in a healthier condition. Construction workers are part of the society, thus any efforts which will improve their well-being need to be done. A healthier worker will not only be more productive but will be useful for the society. As a result of investment in workers' wellbeing, construction organizations will have the benefits of improved productivity and safety.

Keywords: UN Sustainable Development Goals, Management, Project management, Health & Safety, Safety & hazards, Workers performance, Productivity, Diet, Construction Economics.

Introduction

Statistics published by the International Labour Organization (ILO) reveals that construction workers in different developed countries are 3~4 times more likely to die from accidents at the site compared to workers in other industries. In the developing world, There are higher risks (3~6 times more) of death linked with construction work in developing countries (ILO, 2015). Many construction workers suffer and die from work-related diseases developed from past influences to risky materials, such as asbestos and other chemicals. The construction industry is known as one of the world's major industrial sectors, which include sub-sectors such as building, civil engineering, demolition, and maintenance. The construction industry is further reported for a major portion of GDP in different countries. For instance, 6.10% in the U.K., 5.50% in Japan, and 9.0% in Oman (ONS, 2017; SHJ, 2017; NCSI, 2017). Statistics reported in a daily newspaper (Times of Oman) on 9th of June, 2014, noted that a total of 723,000 residents were working in the construction industry. The construction industry is growing rapidly in different developing countries and thus recognized as the main source for providing jobs to different workers. However, at the same time, it is recognized as one of the risky industries. The job of construction workers may include a variety of tasks while they are working on different projects. These projects may be related to building, repair, and maintenance; renovation and demolishing; transportation including the construction of highways, bridges, and airports; and projects related to docks and harbors. Construction workers are exposed to different types of risk during their works such as dust and condensation; stiff working situation; handling heavy load; hot climatic condition; working at heights; excessive noise; vibration and heavy machinery; and different chemicals. It is expected that the global construction industry will reach 14 trillion US$ in 2025 which was 9.5 trillion US$ in 2014, reflecting an overall growth of 67% (Statista, 2017).

In Gulf Cooperation Council (GCC) member countries, the economy is heavily reliant on oil and gas export and contributes up to 50% of the total GDP (Umar and Wamuziri, 2016; Umar, 2017-a, Umar, 2017-b). In recent years, the dip in oil and gas prices somehow affected the GCC construction industry as well (Umar and Egbu, 2018-c). A comparison of the contract awarded in the GCC countries, in the first quarter of 2017 and 2018 shows an overall decline of US $ 5.0 Billion (Ventures, 2018). The construction contract awarded in the first three months of 2017 and 2018, in GCC countries were amounting to US$ 34,444 billion and US$ 29,415 billion respectively. While there is an impact on the construction industry due to the current economic situation, different studies show that construction will be growing in the near future. Umar et al., (2018) while discussing the occupational safety and health regulations, reported that the value of the construction industry in Oman will grow to 6.88 Billion Omani Rial in 2026, which was 2.26 Billion Omani Rial in 2016. Moreover, the construction GDP in Oman is forecast to grow to 15.4% of the total GDP by 2026. Overall, they reported that the construction growth rate is forecasted to be at peak in 2020. Similarly, the total value of the ongoing construction projects in Qatar, in 2018 was US$ 117,440 Million (PQ, 2018). At the same time, the deaths of construction workers in the construction of "2022 FIFA Stadium" which is one of the main ongoing projects in Qatar have attracted the attention of media and international organizations. Some of these reports show the number of construction workers that died in the project has already reached 1,200. Several estimates predicting the number of deaths will reach 4,000 by the end of 2022 when the project will be completed (ITUC, 2014; Ganji, 2016; SM, 2018).

There are several factors that are directly linked with the worker's performance in terms of safety and productively. The effects of these factors are expected to be increasing with the growth of industry if necessary remedial actions that help to increase the safety and productively performance. One of the identified factors which affect the worker's safety and productivity performance is diet. For instance, a report published in the International Labour Organization states that poor diet of workers results in a 20% loss in productivity around the world (ILO, 2005). The report further highlights that the poor diet of workers also results in a number of the other issue which includes morale, safety, productivity, and the long-term health of the workers. The report indicates that only in India, the cost of the poor diet which includes low productivity, sickness, and death is estimated in the range from US$ 10~28 billion or 3~9% of the total GDP. This paper presents the research on a balanced diet that could be suitable for construction workers to enable them to maintain good health and thus contribute effectively towards improved productivity and safety.

The next section provides an overview of safety and productivity in construction.

Safety and Productivity in Construction

A press release of the International Labour Organization shows an estimate of occupational safety and health-related issues cost an annual amount of 4% to the world GDP (ILO, 2013). If the same percentage is assumed for the construction industry and the forecast of the value of spending in the global construction industry is considered, the cost of occupational safety and health in 2019 will be equal to the US $ 0.456 trillion. Similarly, Umar (2016) reported the cost of accidents in the Omani construction industry considering two criteria using the real available data which includes the number of workers in the construction industry and the value of construction projects in a financial year. He concluded that the compensation payment of accidents is about US$ 3.74 million/year based on the number of workers in the construction industry. The reported cost of accidents based on the value of construction projects was estimated at US$ 3.237 billion. The result of another study on the basic causes of accidents conducted by Umar and Egbu (2018), in which they analyzed a total of 623 accidents in a highway construction project, shows that a considerable number of accidents (41%) are directly linked with the workers. They used different statements to reach on the main causes of the accident as “worker”.

Delay in the construction project is a usual phenomenon around the world that occurs due to several internal and external factors which include poor definition and tracking, technical barriers, inadequate resources, changing priorities, wrong project, weather, competitors, and legal barriers (Nicholas and Steyn, 2017). Assaf and Al-Hejji (2006) observed that 30% of the construction project in Saudi Arabia completed on time, the remaining 70% experienced delays. Similarly, the National Audit Office report in the UK shows that 70% of the government construction project delay (NAO, 2003). Workforce related factors such as labour productivity, labour skills, and labour availability are regarded as some of the key delaying factors by many researchers (Kaming et al., 1997; Chan and Kumaraswamy, 1997; Assaf and Al-Hejji, 2006; Sambasivan and Soon, 2007; Umar, 2018).

Many researchers have linked the productivity and safety performance of construction workers with their physical health (Yi and Chan, 2016; Yi and Chan, 2016; Umar and Egbu, 2018-a; Umar and Egbu, 2018-b). There have been several research studies on the physical examination which were carried out among different occupations and industries. Body Mass Index (BMI) and body blood pressure were some of the common factors which were considered in these studies. For instance, BMI was considered in a research study conducted by Kawai et al. (1995) to assess the health profile of 816 white-collar workers in Japan. Umar and Egbu (2018-a) while discussing the heat stress as the main cause of accidents in construction, observed that based on the BMI results “80%” of the participants in their selected sample were overweight or obese. According to Dua et al. (2014), increased BMI being linked with prehypertension may advise that such persons are at high risk of progressing to frank hypertension. A research conducted in Denmark by Gupta et al., (2018) reported the BMI of 147 blue-collar workers from a variety of professions including construction and observed that BMI of 59% of the participants was more than 25. The mean value of the BMI of the selected participants was 26.4$\pm$4.80. Similarly, the mean BMI of 932 construction workers in Hong Kong reported by Yi and Chan (2016) was 24.3$\pm$3.70. Their reported BMI results further reveal that 2.8% of the participants were underweight, 36.1% were overweight and 6.5% were obese. The finding of similar research conducted on 314 male construction workers in the Netherland shows that based on the BMI results, 70% of the participants were classified as overweight and 22.7% as obese. (Viester et al., 2017). The BMI results of different studies, however, clearly reflect that the majority of construction workers are not in their healthy range of BMI, which will have different consequences”. A research study on the relationship of over-weight and hypertension conducted by Julius et al. (2010) suggest that weight gain may pathophysiologically contribute to an elevation of blood pressure. They further noted that the reverse of their findings is also true which means that a person with normal weight with high blood pressure will gain weight in the future.

Research Methodology

The research strategy adopted to achieve the goal of this research was qualitative in nature. Data related to a healthy diet has been extracted from the existing literature using specific keywords such as “healthy diet”, “balanced diet” and “calories requirement”. This exercise aimed to find the characteristics of a healthy diet and then compare it with a healthy diet with the diet of construction workers through a semi-structured interview. The interview was also used as a tool to explore how such a healthy diet can be adopted for construction workers. Similarly, a research study conducted by Umar and Egbu (2018-a) related to the construction workers' health profile found that 80% of the participants in their selected sample were overweight or obese. They further classified 40% of the workers from the selected samples as hypertension based on the result of measured blood pressure. One of the reasons for this could be the diet of these workers. To investigate this, a sample of 20 respondents (10 mess managers/ supervisors and 10 construction workers) from construction organizations registered in Oman in grade I and above and were executing major construction projects, were selected for a face to face interview. Since the purpose of this exercise was exploratory in nature and was aiming to determine the facts around the diet of construction workers in Oman, thus a qualitative approach was considered to be the best fit in this research. Umar and Egbu (2018-c) explained in detail the advantages of face to face interview techniques for data collection. All the participants were asked the interview questions in the same way, so that more accurate and reliable data could be collected.

Results and Discussion

Considering the two research approaches adopted to deliver the aims and objectives of this research, the results and discussion are divided into two main categories aligned to the research methodology. Thus results and discussion from the arising from the existing literature are presented in section 4.1, while the results and discussion of the face-to-face interview are presented in section 4.2.

Results and Discussion (Literature Review)

The results and analysis of the existing literature review suggest that foods which are rich in potassium, magnesium, and fiber can help to control the high blood pressure (Cassidy et al., 2010; Tabassum and Ahmad, 2011; Coleman, 2012; Lynn et al., 2012; West et al., 2012; Chiu et al., 2015). Morgan et al. (1984) regarded potassium as a useful mineral for the human body. Potassium and magnesium are also known as electrolyte substances which produce electrical impulses throughout the human body and help the body to perform some of the important functions such as keeping normal blood pressure, balancing water, nerve impulses, digestion, heartbeat and keeping body pH normal (Robinson and Stokes, 2002). Different types of foods that have a major quantity of potassium, magnesium, and fiber are listed in table 1.

Table 1: Foods Rich in potassium, magnesium, and fiber (Joe, 2017; Goldman, 2017; Men's Journal, 2018).

S.No.	Potassium	Magnesium	Fiber
1	Bananas	Whole Wheat	Raspberries
2	Avocados	Spinach	Avocado
3	White Potato	Quinoa	Chia seeds
4	Sweet Potato	Almonds	Flaxseed meal
5	Tomato	Cashews	Oatmeal
6	Beans	Black Beans	Lentils
7	Dried Apricots	Edamame	Broccoli

8	Yogurt	Peanuts	Cabbage
9	Salmon	Tofu	Apples
10	Spinach	Sesame Seeds	Brussels sprouts

During an online search around a balanced diet using the keyword "balanced diet for construction workers", the researcher came across the Dietary Approaches to Stop Hypertension (DASH) diet (DASH, 2018). The DASH diet plan recommends a variety of foods that are rich in potassium, calcium, and magnesium thus it helps to reduce the blood pressure. The studies conducted by the National Heart, Lung, and Blood Institute concluded that the DASH diet plan help to increase human physical activities reduces blood pressure and cholesterol (NIH, 2018). In the daily DASH plan, foods such as grain, meat, poultry, and fish, vegetables, fruit, low-fat or fat-free dairy products, fats and oil, and sodium are included. There are two different types of DASH diet plans which are developed for men and women linked to their age and activity levels. The DASH plan for men is reported here assuming that the construction industry is highly populated by men workers. The three levels of activities indicated in table 2 are described here.

Sedentary Activity Level

Sedentary activity refers only to those light-intensity physical activities which are part of daily routine. This includes spending a lot of time on the office desk with less walking. For example, this also includes doing exercise at a low intensity which allows breathing normally.

Moderate-intensity activity

This includes activities equal to the walking of 2.4 km to 4.8 km with a speed of 4.8~6.4 km/h. such activity doesn't allow to breath normally thus breathing in moderate-intensity activities is "harder" and persons in such activities are able to make a conversation easily with others.

Active Activity

This activity refers to all those activities equal to walking more than 4.8 km with a speed of 4.8~6.4 km/h. This also includes light-intensity physical activities. In such activities, the heart works at its maximum efficiency. Normally such activities result in sweat after the initial few minutes. Construction workers are the best fit into this category of activity level.

Table 2: Daily Calorie Requirement for Men Based on the Types of Activities (NIH, 2018).

Age in years	Calories Required		
	Sedentary Activity	Moderate Active	Active Activity
19–30	2400	2600 – 2800	3000
31–50	2200	2400 – 2600	2800 – 3000
51+	2000	2200 – 2400	2400 – 2800

Considering the foreigner's workers population in Oman, the National Centre of Statistics and Information data shows that 1231407 male workers out of 1349443 (91.25%) are in the range of 20~49 years (NSCI, 2014). This fact was assumed to be true in the Omani construction industry as well, thus for the count calories the age of construction workers is considered to be from 20 to 49 years and the level of activity was considered as “active” which gives an average 3,000 daily calorie requirements. For such daily calorie requirements (3,100), the DASH diet plan is more appropriate for construction workers.

Result and Discussion (Face-to-face Interview)

As discussed in the methodology section, two different types of respondents were selected to participate in a face-to-face interview. These participants were the mess managers and construction workers. Since the different sets of questions were used for these groups of the interviews, the results and discussion are therefore provided in separate sections. The next section describes the results and discussion of the interviews held with the mess managers.

Result and Discussion (Mess Managers)

All the interviewees (100%) agreed that for the development of a weekly food menu, consultation with workers took place to allow them to show their choice, however, their choice is not guided by health factors. Three interviewees highlighted that they have a variety of workers from different countries, thus the main factor which workers report on the menu improvement is a taste of food of their choice. Some of them request Indian food; some of them request south Indian food which is different from traditional Indian food. Even some of the workers request Arabic food. Thus in a diversity of workers, it is very difficult to consider each request. The final decision on the food menu is driven by the majority. In response to the question that interviewees as mess managers/supervisors consider the health-related factors when developing the daily food menu for their workers; 3 out of ten (30%) respondents reply as “yes” and stated that they do consider such factors and their menu is well healthy. Four interviewees (40%) reported that their organizations have already standardized the food menu considering workers' choice and health factors and now it is adopted in all of their organization projects. They reported that they have three different types of mess at their project site. One is for workers, one is for mid-level staff and one is for senior staff. There are different menus is these messes. This is somehow a normal fact that in most projects the management of the organization provides a different level of facilities to their workforce and most likely they are divided based on their ranks or seniority. However, on the same project, if there are three different messes and when it has different food, thus it indicates that the quality of food will not be the same. All of the interviewees reported that they are not using any association or organization guidelines for the development of their food menu. This however clearly indicates that if these mess managers/ supervisors are not using such guidelines, then how they summarized that their food menu is healthy. When the interviewees were asked to compare their food menu with the DASH food menu for 3100 calories, two out of 10 (20%) interviewees reported that there is a similarity of 80%. Five out of 10 (50%) reported stated that there is a difference of approximately 50% between the two menus. Three interviewees (30%) reported a similarity ranging from 60~65% between two food menus. When the interviewees were asked to compare the cost of DASH menu with their existing menu and report which one could be cheaper and which one could be expensive or there will be no cost different; four interviewees reported that it is very difficult to arrive on the cost as they don’t know at the market price of some items at the moment. Two (20%) of the interviewees noted that the cost difference could be in the range of +10%. One interviewee reported that the cost of the DASH menu will be almost the same as the cost of their current menu. Two interviewees reported that the cost of the DASH menu will be higher (≥20%) than their current menu.

Result and Discussion (Construction Workers)

All the construction workers selected for the interview respondents that their daily food has a major contribution to keep them fit and perform their job effectively. One of the interviewees noted that apart from healthy food, it is also important to have a daily meal on time. He stated that due to the nature of his job, in most cases he is not able to take his daily meal on time especially his lunch. This appears to be an issue on most of the construction sites, especially on highway construction projects. Umar et al (2018), while discussing the occupational safety and health regulation related to the construction industry, highlighted a similar point and stated that afternoon break in summer is made mandatory by the government in Oman.70% of the interviewees reported that the first choice of selecting their daily food is that the food should be healthy and tasty. Two interviewees responded that the food should be healthy, however cooking style some time makes it un-tasty. One of the interviewees stated that he doesn’t use such criteria for selecting the food. When the interviewees were asked about the consultation for making a daily or weekly food menu in their organization; 60% of the respondents replied as yes. 40% of the respondents stated that they have not been part of such consultation in their organization. Three interviewees accepted that daily food had an impact on their daily performance related to productivity and safety. Two Interviewees stated that good food provides us better energy to perform our daily activities. 50% of the interviewees were not sure that the food may have a positive or negative impact on their work and safety-related performance. When interviewees were asked to match their daily food menu with the DASH menu; 20% of the respondents reported that their menu is roughly (90%) the same as the DASH menu. 80% of the respondents noted that there is less similarity (less than 50%) among the items in their menu and the DASH menu. Nine out of 10 (90%) respondents classified the DASH menu as the best food menu for construction workers.

Conclusion

Construction worker's health-related factors such as BMI and hypertension have attracted the attention of many researchers because these factors directly affect the worker's productivity and safety performance. The literature review presented in this paper suggests that the causes of most of the accidents (41%) are directly related to the workers where the health factors have a major contribution to these accidents. Similarly, most of the construction projects encounter delays due to the productivity performance of workers. Most of the studies around human health found that overweight and hypertension is very common among construction workers. In light of these issues, this paper considers the intervention of healthy food that helps workers to maintain their health and could contribute to their safety and productivity. From the literature review, foods that help to reduce blood pressure and maintain a healthy weight are identified considering construction workers’ energy requirement to effectively perform their daily activities. These foods include grain, vegetable, fruit, fat-free or low-fat dairy products, lean meat, poultry, and fish, nuts, seed, and legumes, fats and oil, and sweet and added sugar.

The result of face to face interviews with mess managers from reputed construction organizations in Oman reveals that they consider the choice of the workers in making their daily or weekly food menu. They reported that the workers’ choice of food is not guided by health-related factors. Only 30% of the mess managers/ supervisors replied that they considered health-related factors when they are deciding the food menu for their workers. 50% of the workers reported that the food they take has an impact on their safety and productivity performance. the DASH daily food menu suitable for construction workers was compared with their organizational food menu. All the comparison shows that similarity between their food menu and DASH food menu is less than 50%. Similarly, 80% of the workers reported that the similarity between their food menu and the DASH menu is less than 50%. It is important to note that both samples (mess managers and workers) were from the same organizations. Two mess managers reported that the difference between their food menu and the

DASH food menu could be in the range of + 10%. The other two mess managers reported the cost of the DASH menu is more than (≥20%) from their existing food menu. Although this study provides an insight into food intervention to improve both safety and productivity in construction, the longitudinal study needs to be conducted to reach an actual improvement when a specific food menu is adopted for such construction workers. Overall construction workers are part of the society, thus any efforts which will improve their well-being need to be done. A healthier worker will not only be more productive but will be useful for the society. As a result of investment in workers' wellbeing, construction organizations will have the benefits of improved productivity and safety.

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Improving the Mental Health and Wellbeing of Building and Civil Engineering Workers: Barriers to Flexible Working

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Abstract

Despite the growing research on mental health and wellbeing (MHW) in construction, very little research (if not none) has examined the barriers to strategies such as flexible working arrangements that improve MHW in the construction industry. This research aims to fill this gap in knowledge. The research adopted a systematic literature review where relevant literature was critically reviewed and discussed. The main findings include the high level of diversity in the industry, which makes it challenging to have a flexible working system that meets the work-life balance of construction workers and improve their mental health. Large contracting firms are more likely to adopt formal flexible work arrangements because they have more resources than smaller companies, but micro contracting forms are most likely to adopt the informal flexible work arrangements. Further barriers are the nature of the roles of the practitioners, for example, construction professionals are more likely to be allowed to adopt flexible work system than the tradespersons; Collaborative project delivery arrangement supports flexible work arrangement more than the traditional method. National policies or legislation in some countries such as UK and Vietnam do not adequately support work-life balance strategies such as flexible working; for instance, the regulation in the UK is open to misinterpretation and creates room for employees' exploitation by employers. Evidence shows that this is the first study to examine the barriers to MHW in the construction industry through a flexible working arrangement. There is a need for a shift in workplace culture to support such strategies and the need for tighter legislation and guidance.

Keywords: alternative work arrangement, labour laws, male-dominated workplaces, strategies, work-life balance, working conditions, workers' welfare.

Introduction

Recently, the mental health and wellbeing (MHW) of construction (building and civil engineering) workers have been at the forefront of policymaking and programmes of many organisations, businesses, professional institutions and governments because of the implications of poor MHW on employees, the productivity of organisations and the economy of countries. This growing awareness of MHW (Centre for Mental Health 2017; Sherratt and Turner 2018) has resulted in programmes and charities such as Mates in Mind which focus on the mental health of construction workers, and some unnoticed efforts in projects such as the London 2012 Olympic Park (Sherratt and Turner 2018).

Lingard et al. (2007) found that a compressed workweek (a type of flexible working) improves employee's work-life balance, and project objectives were still met. While there is extensive research on employee work-life balance (for example Lingard et al. 2007) and growing attention on MHW (for example Oswald et al. 2019; Campbell and Gunning 2020; Sherratt and Turner 2018), the systematic literature search of the current study shows gaps in knowledge. There is limited research that examines the barriers to strategies such as flexible work systems to improve employees work-life balance, by extension, the health and wellbeing of workers in the construction industry. While the search is limited to Scopus database, covering the past 20 years, the findings of Bell et al. (2015: 492) supports this — 'At present, there is no academic research investigating the impact and practical challenges of introducing a wellbeing intervention into a construction company or to a construction site'. Oswald (2019) echoes this, recently calling for more research on how MHW can be identified and managed in construction of which flexible working is one. There is limited understanding of the realistic workability of flexible working arrangement in improving workers' wellbeing in the construction industry (Bell et al. 2015). By implication, the barriers are poorly understood, supporting the identified gap of the literature search.

This study examines the MHW of construction workers by illuminating the hidden barriers to improving the condition and broadening the available knowledge. Specifically, it investigates the barriers to improving the MHW of (building and civil engineering) construction workers through flexible working arrangements. Addressing this will have implications to attaining the Sustainable Development Goal 9 — Build resilient infrastructure, promote inclusive, sustainable industrialisation and foster innovation — in that (as Lingard et al. 2007 show) a mentally healthier workforce is more productive. This is the first stage of a large study, the next stage being empirical. There is no consensus on the definition of flexible working, but people define it based on the work pattern or ways of working, e.g. part-time work, flexi-time, working from home, compressed hours, shared working and term-time working (Chartered Institute of Personnel and Development (CIPD) 2019). Gov.uk (n.d.) defines it as a way of working that suits employees need, e.g. working from home and flexi-time. The current study is based on this definition, but zero-hour contracts (despite the benefits to some people) are excluded because of its contentious nature (CIPD 2019).

Context

Mental Health and Wellbeing (MHW) and impact

Mental health issues include anxiety, depression and substance use disorder. Centre for Mental Health (2017) reports that in 2016/17, the aggregated cost of mental health on employers (construction industry workers included) in the UK is £34.9 billion, an increase of 35% from 2006. Specifically, presenteeism — reduced productivity at work — costs £21.2 billion; sickness absence, £10.5 billion; and staff turnover, £3.1 billion. The record of the construction industry on mental health is no exception. A study by the Chartered Institute of Building in 2020 found that in 2019, 27 per cent of construction professional contemplated sucide, 97 per cent claimed to be stressed at least once in the last year (Global Construction Review 2020). These demonstrates missed increase in productivity and profit for businesses and countries which will have implications meeting development goals. Authors such as Lingard et al. (2007) offer further supporting arguments, including that improved employee experiences and work-life balance which will improve MHW, contributes to improved work performance.

Flexible working arrangements, implications for MHW, and policy

A flexible working pattern, different from the traditional method of working, can contribute to addressing the MHW issues (CIPD 2019; Doan and Ngo 2020). The implications include work-life balance, one of Campbell and Gunning's (2020) recommended strategies for improving mental health and wellbeing in construction. For example, working from home will mean that travel time will be reduced or removed, and workers can work with their families. There is evidence that work-life balance strategies such as alternative working arrangements, working closer to home and working the normal hours improved MHW (Geurts et al. 2009; Sherratt and Turner 2018; CIPD 2019; Construction New 2019). Specifically, in all sectors, CIPD (2019) found that in 2019 in the UK, workers who worked flexibly (one of the work-life balance strategies) were most likely to report a positive impact on their mental health than those that did not. From the construction perspective, Construction News (2019) reports that 74 per cent of 1580 respondents (in offices and sites) in the construction industry view that long working hours impacted more on their mental health and wellbeing. The highest of the 13 factors; 64.1 per cent claim that is working away from home impacted on their MHW (also see Kivimaki et al. 2015 for the negative impact of long working hours on cardiovascular diseases (CD). In support, Sherratt and Turner (2018) exemplify that travel time, working away from home, long working hours negatively affect and influence construction workers' health and wellbeing in the UK and Australia. See Geurts et al. (2009) for findings on the Netherlands also reported later in this paper.

Besides, the nature of the activities of the industry needs consideration. For example, according to Kivimaki et al. (2015), occupational factors such as overtime, high job strain, low social support were observed to be positively associated with CD. The MHW is exacerbated by the construction activities, organisational structure and culture of the industry (Campbell and Gunning 2020; Sherratt and Turner 2018). Flexible work is mainly used in assisting workers in meet their family responsibilities (Fernandez, 1986 in ibid) and have implications for social inclusion, longer employment period especially for the elderly (Doan and Ngo 2020).

According to CIPD (2019), while Eurostat reports that there have been a significant underlying shift to flexible working across the 28 European Union (EU) countries in the past five years, UK was behind Netherlands and Germany for part-time workers and behind Netherlands and Sweden for those that work from home in 2017. However, the UK was above the average across the EU28 (ibid).

Flexible working has statutory backing in some countries. For example, in Great Britain there is the Flexible Working Regulations 2014, in South Africa, Section 6 of the Employment Equity Act, 1998 requires no discrimination against persons on the various grounds including family responsibility and Section 7 of Basic Conditions of Employment Act, 1997 requires employers to regulate employees time regarding family responsibilities. Doan and Ngo (2020) also report National policies that address flexible working in Vietnam. While these policies have positive implications for improving MHW of workers, there is still a need for improvement in terms of implementation.

Methodology

The research was based on a systematic literature review of relevant literature. Extensive searches on Scopus were conducted on 27 June 2020. Table 1 shows the keywords of the searches covering the year 2000 to 2020 and the output. Following the search, the abstract and titles of all the 66 articles were scrutinised, narrowing it down to 12. The abstracts and titles were further securitised, and only five (direct or indirectly) relevant papers were selected. For example, Bryce et al. (2019) addressed flexible working for female engineers in the civil construction industry in Australia, hence had indirect implications for the study. Nevertheless, none of the papers addressed the research question of this study suggesting that the topic and is under-researched.

Table 1: Systematic literature search results

Keywords	Location	Limit to subject areas	Output
'Flexible' AND 'Working' OR 'Flexitime' AND 'Construction' AND 'industry'.	Abstract	Engineering; Environmental Sciences Business, Management and Accounting; Social science;	66
'Flexible' AND 'Working' OR 'Flexitime' AND 'Construction' AND 'industry' AND 'Welfare' AND 'mental health'.	Abstract, title, keywords	Engineering; Business, Management and Accounting; Social science; Environmental Sciences	0
'Flexible 'AND 'Working' OR 'Flexitime' AND 'Construction' AND 'industry' AND 'Welfare' AND 'mental health' AND 'Wellbeing'.	Abstract, title, keywords	Engineering; Business, Management and Accounting; Social science; Environmental Sciences	0

Searching only Scopus database eliminates the consideration of publications not indexed therein. This was complemented by the citation approach, where references of books and relevant articles were searched for leads to papers or books that can be used. This is consistent with papers such as Umeokafor et al. (2018). It resulted in adding Lingard et al. (2007), and CIPD (2019) based on the authors' knowledge. In total, seven publications were analysed to address the research question. There are many empty reviews — systemic reviews conducted with no studies meeting their inclusion criteria — which are acceptable in academia (Yaffe et al. 2012). Using Cochrane Library, which hosts over 4500 systematic reviews, Yaffe et al. (2012) strongly demonstrate that the number of studies used in a systematic study does not limit the findings. Consequently, arguments that using seven academic publications in the current research limits the findings should be with caution and/or perhaps flawed. The exclusion criteria include publications before the year 2000, publications outside the subjects in Table 1, non-peer-reviewed publications. However, the inclusion criteria include publications in the subject areas in Table 1, publications with the keywords in the locations in Table 1; publications written in the English language; and peer-reviewed publications. While reading the material questions that were asked include 'what is happening here?', 'what is missing here?' 'Do these directly or indirectly bar flexible working systems?' 'If yes, what are the implications for MHW of construction workers?'

Findings, Analysis and Discussion

The summary of the findings is presented in Table 2. In being interrelated and subject to empirical validation, the roles of people in the construction industry, norms and values, the features of the industry and legislation are emphasised in the study (Table 2).

Culture

Authors show that the male dominance of the construction industry and other characteristics result in long working hours and weekends being a culture with implications for MHW (Lingard et al. 2007; Bryce et al. 2019; Francis et al. 2013: 369). This is exacerbated by the less childcaring responsibilities that men have (Bryce et al. 2019). Consequently, flexible working is of low priority to them (Bryce et al. 2019). Additionally, the construction industry has been criticised for its 'macho' work culture (Bridges et al. 2019), which may result in men viewing flexible working arrangement as a sign of weakness. All these do not attract and retain women in the industry who could contribute to clamouring for flexible working arrangements more than men (Lingard et al. 2007) because of the assumed high level of childcare responsibilities they have than men (Bryce et al. 2019). They are not ideal for all gender, especially women (Bryce et al. 2019). According to Bryce et al. (2019), women view that part-time work has negative implications for their career progression hence would not accept it when offered. So far gender bias and long working culture are barriers to flexible working.

Table 2: Summary of the barriers to adopting flexible working to improve the MHW of construction workers

Themes	Subthemes	Factors and supporting evidence and sources
Culture	Rigid long working hours culture	A strong culture of working for long hours (Bryce et al. 2019) and weekends (Lingard et al. 2007); is a culture of the industry due to its features (Francis et al. 2013).
	Gender bias culture	The male-dominated industry thus long working (Lingard et al. 2007; Francis et al. 2013; Bryce et al. 2019), not also ideal for all special women (Bryce et al. 2019).
		Negative implications of flexible working on the career progression of women (Bryce et al. 2019).
People	Workers' perception and choice	Flexible working is not the priority of many workers (CIPD 2019), especially men (Bryce et al. 2019)
		Lack of demand for flexible working arrangements by employees (CIPD 2019; Brown et al. 2011).
		Workers not adopting flexible working arrangement because of perceived financial loss (Brown et al. 2011; Lingard et al. 2007) and its implications on career progression (Bryce et al. 2019).
		Resistance by workers because of perceived unfair difference in workload among them when working flexibly (Lingard et al. 2007).

Characteristics of the industry	Male-dominated industry	A male-dominated industry where men have less childcaring responsibility than women hence care less for flexibility (c.f. Bryce et al. 2019).
	Type of sector	Public sector offers more flexible working than the private sector (CIPD 2019: 10); Private sector offers less flexible working to employees than public sector employers (Francis et al. 2013).
	Size of organisation	Micro firms allow more informal flexible working than others; large firms offer more formal flexible working than others (CIPD 2019: 8).
	Nature of role and employment	Nature of career impacted on flexible working (Bryce et al. 2019); Professional roles get more flexible working that the non-professional (CIPD 2019).
		The higher pay of job, the more likely there will be flexible working (CIPD 2019).
		Office roles mostly work part-time than non-office roles (Bryce et al. 2019).
		Nature of employment (permanent, self-employed causal) works (Druker and Croucher 2000; Lingard et al. 2007).
	Nature of activities and industry	Nature of activities in the industry — construction ranks low in industries that flexible working can take place (CIPD 2019); Few construction organisations in Australia would adopt work-life balance initiatives (Lingard et al. 2007).
		The nature of construction activities, e.g. site works means that working from home may not be possible for respective employees (Francis et al. 2013); features of the industry result in long hours (ibid).
Organisational factors	Perception and priority of the organisation	Employers have a negative perception of part-time work (Druker and Croucher, 2000; Bryce et al. 2019).
		The priority of organisations because of the benefits (Druker and Croucher 2000)
	Procurement method	Project delivery arrangement — compressed week work is more likely in a collaborative project alliance than in traditional procurement (Lingard et al. 2007).
	Lack of organisational support	Lack of available role models (Bryce et al. 2019).
		Lack of opportunity to negotiate an alternative working arrangement with the employer (Lingard et al. 2007)
		Limited or lack of support from employers in the industry (Doan and Ngo 2020)
	Counterproductive flexible working arrangement	Counterproductive flexible work arrangements — e.g. impacts on work-life balance rather (Brown et al. 2011; Lingard et al. 2007).

		Lack of Flexicurity — Lack of employment and social security in the flexible labour market and relations, organisation (Doan and Ngo 2020).
Policy and legislation	Limitations in policies and legislation	Policy/legislation reaching its limit (CIPD 2019) Limitations in national policies (Doan and Ngo 2020) and legislation. The exploitation of national policies by organisations (ibid).

People

The study shows that people play a key role in the success of a flexible working arrangement aimed at improving MHW. For convenience, the factors in Table 2 are categorised into the subtheme, workers' perception and choice. Elsewhere in this paper, there are discussions of the roles of employees' perceptions on the success of work-life balance strategies. Table 2 shows that the offer of flexible working arrangement to employees does not guarantee acceptance by workers. Understandably, when workers feel that such strategies result in loss of wages (Lingard et al. 2007) or lack of career progression or are poorly designed to meet their needs, they are less likely to take up the offer. In this case, the onus is on employers, trade unions and the government to provide an enabling environment to facilitate this. While these may explain the lack of priority of flexible working arrangements to some workers, the wrong perception of flexible working being for the weak may also be an explanation, highlighting the need for more sensitisation of construction workers on the importance of work-life balance to their health.

Characteristics of the industry

There is evidence that the (building and civil engineering) construction industry are less likely to adopt flexible working than other industries (Table 2). Typically, of the 14 industries in the UK surveyed by CIPD, Construction industry ranked 9th with 51 per cent of workers being in one form of flexible working arrangement in 2016 (CIPD 2019). Industrial sectors such as public administration (80 per cent), education (76 per cent) and, information (75 per cent) reported that flexible working was more common than distribution (33 per cent) and transportation (34 per cent) which ranked the lowest (CIPD 2019). Few organisations in the Australian construction industry implemented work-life balance initiatives (Lingard et al. 2007).

A critical look at the paragraph above submits that the nature of the activities may explain this. To illustrate, the nature of construction activities means that working from home will not always be possible, but other types of flexible working such as job sharing, part-time, compressed hours, flexitime, staggered hours and annualised hours may depend on factors such as procurement strategy (Lingard et al. 2007). However, education and public administration activities can accommodate remote working, compressed hours or other types of flexible working. While transportation and distribution can accommodate limited forms of flexible working arrangements such as weekend working more than others such as public administration, though this presents its own MHW challenges as Brown et al. (2011) found, it may be attractive to some employees for childcare and education reasons.

Nevertheless, these industries lagging, including construction, can do more because of many reasons. For example, the advancement in technology, through presenting its challenges, have made working remotely more feasible for many professions (Francis and Lingard 2012). Other possible explanations, such as culture are covered elsewhere in this paper.

There is evidence that the types of sector (private or public) impacts on employee's wellbeing (Table 2). CIPD (2019) and Francis et al. (2013) establish that private-sector employees reported less flexible working arrangements than public sector employees. Francis et al. (2013) established that private-sector employees experienced more difficulty managing family responsibilities, greater conflict in combining work demands and family responsibilities, and worked longer hours than the public sector employees; all were in the construction industry including public sector employees that were managing subcontractors in physical construction projects. This is where there is evidence in the literature of the impact of working arrangement on work-life balance, the ability of the worker to meet family responsibilities which all have implications for their MHW. In the Netherlands, Geurts et al. (2009) found that while flexible working reduced the effects of long hours and supported work-family balance; long hours and overtime significantly impacted on employee's ability to balance work and family responsibilities. They also observed positive results work-family balance when employees work from home. Employees are more likely to commit to organisations when employers commit to work-life balance initiatives (Francis, 2003). Noteworthy, some of these mental health issues are pre-employment-related but may be exacerbated by those caused by employment. Some pieces of legislation (e.g. the equality ones or related clauses) impose obligations on employers to consider MHW factors or employees with MHW issues. The extent to which employers (for example contractors) can mitigate the mental health issues that are pre-employment vs those as a result of the employment (especially through strategies such as flexible working) may differ for many reasons. Nevertheless, further exploration is required.

The point in Table 2 that pay rate has implications for the MHW of workers as it determines whether they work flexibly is worrying, just as the nature of employment being a factor are reported in CIPD (2019). Similarly, Druker and Croucher (2000) and Lingard et al. (2007) found that casual workers, self-employed workers do not take up alternative working arrangements that will provide work-life balance. Typically, permanent workers are most likely to work flexibly than self-employed persons (Druker and Croucher 2000) or salaried employees (Lingard et al. 2007). This is because wage employees and self-employed workers are paid for the hours they work hence will lose if work hours are reduced as some flexible working such as compressed week hours may do (ibid). This calls for an alternative mechanism that will address this, such as production-based remuneration, not time-based on-site (Lingard et al. 2007). This may present challenges such as cutting corners (which pose health and safety risks) if the performance indicators and assessment methods are not robust.

Organisational factors

The evidence in Bryce et al. (2019) and Doan and Ngo (2020) shows that the negative attitudes of employers and the implications of flexible working impact on the request or the ability of workers to take up flexible working hence MHW is poorer in the industry. This is exemplified in the more passive policies in the construction industry on flexible working than other industries in Vietnam (Doan and Ngo 2020). Further, Bryce et al. (2019) show that 73 per cent of female construction workers in their study either agreed or strongly agreed that part-time working had or would hurt their career; and 4.2 per cent of them would miss out career opportunities. However, 60.8 per cent of managers did not agree with the latter (ibid). The disagreement does not mean flexible working is offered (Bryce et al. 2019).

Consequently, it can be argued that the construction workers may not opt for flexible working to ensure that career progress is maintained and view employers as unsupportive. Conversely, it can be argued that Bryce et al.'s (2019) finding is based on women only, who are already underrepresented in the industry. Hence it is not a true reflection of what is happening. A counter-argument is that the lack of flexible working is a key barrier to women working in the construction industry (ibid).

Brown et al. (2011), Doan and Ngo (2020), and Lingard et al. (2007) note that flexible work arrangements that are counterproductive as they impact on work-life balance are in. Typically, Brown et al. (2011) found that employers provide flexible work arrangements that impact an employee's leisure times rather than work-life balance, including affording them 'time away'. Doan and Ngo (2020) report national policies that fail to provide employment and social security in the flexible labour market and relations, organisation. This shows that employers and policymakers need to support workers more in this regard (Bryce et al. 2019), including ensuring that the work-life balance strategies are worker-focussed. Lingard et al. (2007) and Doan and Ngo (2020) report the lack of support where employees do not have a say in the design and negotiation of flexible work arrangement. When roles are not developed to be supported by flexible working, it does not attract enough workers but just some. It also indicates the non-inclusion and consultation of workers in developing flexible work arrangements. The classic motivational theory argues that the involvement of workers in decision making concerning their jobs and the business, in general, improves their performance and that of the organisation as they work smarter and harder (Cotton 1993). While the worker's needs may not always align with organisational agenda hence, it is not suitable for business, the findings on benefits of employees' satisfaction for the organisational performance call for more nuanced strategies to carry employees along.

Table 2, the findings on collaborative project delivery arrangement also being a determinant of functional, flexible work arrangement than the traditional procurement (Lingard et al. 2007) call for the attention given the high popularity of the traditional procurement arrangement. Similar calls can be extended to other procurement methods given the strategic roles that integrating health, safety and wellbeing (HS&W) into procurement strategies play in improving HS&W and other project outcomes (Umeokafor et al. 2020).

Policy and Legislation

Table 2 shows that the implications of policies, national and international for flexible working are reported in studies. For example, focusing on elderly workers in Vietnam including those in the construction industry, Doan and Ngo (2020) observe that the national policies in Vietnam are limited to just actors at the local level, they are not flexible, preventive and activating as expected. Doan and

Ngo (2020) call for a fundamental shift in the national policy to address the inequality towards older workers. The same arguments can be extended to other aspects of inequality, such as gender bias in Table 2 in countries where such legislation is absent or dysfunctional. Analogously, CIPD (2019) note the ability of policies in the UK to drive flexible working has reached its limit because of lack of increase in that mode of working over the past 15 years pre 2016. Possible explanations include that the alternative methods of employment such as the increased self-employment may offer what flexible working is unable to offer.

Furthermore, vague or flexible rules (e.g. employers considering requests on a reasonable basis) as against the perspective rules of the Flexible Working Regulations 2014 may have implications for the rate at which employers offer flexible working. This is because in some cases, it may be hard for employees to prove that a rejected request or an alternative offer of a type of flexible working arrangement was on reasonable grounds. Hence, in 2018, CIPD (2019) calls for a new flexible working policy framework but welcomes the taskforce on flexible working established by the UK government. However, the involvement of stakeholders e.g. trade unions, employers are more likely to enable achieving the objective than a 'speculative breakthrough driven by legislation' (CIPD 2019).

Conclusions and Recommendations

While a case is made for improved business and project performance when workers have work-life balance (including through flexible working), this study also investigated the factors that hinder the implementation of flexible working strategies for MHW. The systematic literature review conducted shows that the main factors that hinder the implementation of flexible working strategies for MHW include cultures in the industry (such as working long hours and weekend), lack of interest from workers and limitations in policies and legislation. However, the onus is on the organisation to do more to support workers in balancing work with life. It also emerged that public sector employers are more likely to offer flexible working arrangements than their private sector counterparts. The study shows relationships among the factors highlighted in Table 2. For example, while the nature of work activities in the building and civil engineering construction industry (such as site roles) cannot be remote and maybe cheaper to undertake some during the day except where night and weekend works are inevitable, the industry can do more to support other types of flexible working. However, the attitude of employers towards flexible working and the fear of the implications of adopting this for the careers of workers complicates the strategy. The implications of the findings of the research include the need for a shift in workplace culture to support such work-life balance strategies and the needs for tighter legislation or guidance in some countries.

Also, construction workers need more education and awareness on the importance of work-life balance on their health, a key recommendation for construction companies and trade unions. Building and civil engineering companies should involve and consult with workers in the development and implementation of flexible working arrangements to meet workers' and organisations' needs and make it more acceptable and attractive to them with little negative implications. Policymakers should support this with legislation where absent. Where possible, building and civil engineering companies and trade unions should encourage flexible working arranagements that is worker-focussed.

Furthermore, propositions emerging from the research include that more construction workers are likely to request for flexible working if designed to meet their needs. Also, construction organisations are more likely to support workers in flexible working programmes if they see the benefits. Polices are more likely to be effective if revised with stakeholders (including trade unions) and employers involvement. The extent to which employers (e.g. building and civil engineering companies) can mitigate the pre-employment mental health issues vs employment-caused ones (especially through strategies such as flexible working) requires further research hence recommended. Such research by extension will assess pre-employment mental health issues vs employment-caused ones towards understanding the implications. Further research to test the factors outlined in Table 2 are recommended. In particular, the extent to which the factors impact on the strategies for improving the MHW of construction workers is unknown, especially whether human-related factors impact more than industry-features related factors. This will offer insight into the dominant factors that influence the implementation of flexible working strategies for MWH, towards enabling organisations, academics and the industry to channel resources to address the barriers appropriately. Also, the suggested relationship or association between the factors and the extent of correlation needs to be tested. Just like other systematic reviews, the current one has limitations including that focusing on peer-reviewed publications means that little or no government reports are covered hence a risk a bias. But the citation approach contributed to addressing this by including a report.

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Work Relationships, Sense of Purpose, Perceived Workload and Positive Emotions: Towards Work Engagement of Project Professionals

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Abstract

Work engagement has been recognised as a strong indicator of work performance, while relationships in the workplace with co-workers and supervisors has been found to have a positive impact on work engagement. However, there is limited knowledge in the construction literature on how work relationships lead to work engagement. Drawing from the field of positive organisational behaviour, this paper explores how workload, sense of purpose and positive emotions could build the underlying mechanism between work relationships and engagement of project professionals. Using scales from the ASSET model, data were collected in an online questionnaire survey. A total of 183 valid responses were analysed using structural equation modelling. The results showed that work relationships are positively related to sense of purpose and negatively related to perceived workload, while workload and sense of purpose are positively associated with positive emotions and work engagement. Positive emotions are a mediator in the relationship between workload and engagement, and in the relationship between sense of purpose and engagement. This study highlights the pivotal role of workload and sense of purpose in increasing the positive emotions experienced by employees, and the concomitant experience of greater work engagement with the organisation.

Keywords: ASSET**;** work relationships; perceived workload; sense of purpose; positive emotions; work engagement

Introduction

The literature suggests that engaged employees have higher job satisfaction, lower absenteeism, lower turnover, and better organisational commitment and performance (e.g., Salanova *et al.*, 2003; Schaufeli and Bakker, 2004). Therefore, organisations are keenly interested in enhancing work engagement. A well-known psychometric model that includes the construct 'work engagement' is the ASSET model (Faragher *et al*., 2004; Robertson and Cooper, 2010). This model enables us to understand the impact of work relationships on engagement, which we expect to be positive when work relationships are supportive. The construct 'work relationships' generally refers to the interactions between employees and their managers and between employees and their co-workers, which interactions may be supportive or negative.

Work engagement is an emerging area of study in which scholars have started to explore the antecedents and consequences of work engagement. For example, Demerouti *et al*.'s (2010) study of a single South African organisation, in which 40% of the respondents worked in its construction division, found work autonomy and pressure to affect construction employees' work engagement, and their engagement to affect organisational commitment and mental health. Lorenta *et al.* (2014) indicated that the personal resources (i.e. efficacy, mental and emotional competency) positively affected construction workers' engagement. Although Cheung and Cui (2017) found that the work relationships between co-workers and supervisors are contributing factors of construction professionals' work engagement, there is limited research on depicting the underlying mechanism of the relationships. Drawing from the field of positive organisational behaviour, this paper explores how sense of purpose, positive emotions, and perceived workload play a role in the relationship between work relationships and engagement for project professionals who play a critical role in delivering construction projects successfully.

Literature Review and Hypotheses Development

Work Engagement (EG)

Despite the lack of clarity around the definition and measurement of work engagement, there is broad consensus among researchers and practitioners that 'engagement' may be conceptualised in terms of the concepts of "attachment, commitment and organisational citizenship" (Robertson and Cooper, 2010, p.326).

Work engagement is most likely to engender positive behaviour in employees that is likely to result in improved performance beneficial to the employer organisation (Robertson Cooper, 2010).

Work relationships (WR)

Poor and unsupportive work relationships with co-workers and/or superiors have consistently been found as sources of work stress that negatively affect work engagement, while good and supportive relationships can help individuals to better cope with stress and thus be better engaged at work (Khairuddin and Nadzri, 2017; Johnson and Cooper, 2003; Schaufeli and Bakker, 2004).

Perceived workload (WL)

As early as the 1970s a link was established between work overload and signs of psychological stress (French and Caplan, 1972). It has also been found that a high workload has a negative impact on work engagement (Demerouti *et al.*, 2010). High workload occurs when an individual feels that his or her work tasks are difficult and more than he or she can accomplish, either within a given time frame, or at all. However, research has also shown that the work relationships between individuals and their supervisors and co-workers can affect their perceived workload. For instance, Bowling *et al.* (2015) suggested that when perceived support from supervisors and co-workers increases, employees perceive workloads to be lower, which could positively affect their work engagement levels.

Therefore, it is hypothesised that:

H1: *Project professionals' work relationships (WR) are negatively associated with perceived workload (WL).*

***H2:** Project professionals' perceived work relationships (WL) are positively associated with work engagement (EG).*

Positive Emotions (PE)

Workload is often regarded as a common work stressor in modern work environments (Bowling *et al.*, 2015). Based on the Affective Events Theory (Weiss and Copanzano, 1996) and the Stressor-Emotion Model of Counterproductive Work Behaviour (Spector and Fox, 2005), high perceived workload induces negative emotions. In line with this theoretical framework, previous studies have provided evidence for negative associations of high perceived workload with positive emotions (Ilies et al, 2007).

According to the Broaden-and-Build Theory (Fredrickson, 2001), positive emotions build people's physical, social, intellectual, and psychological resources, thereby building resilience and higher levels of life satisfaction (Cohn *et al.*, 2009). It also expands the attention to broader perspectives, helps individuals generate more creative ideas and actions, supports more inclusive teams, and promotes more flexible mind-sets (Cohn *et al.*, 2009) – all of which are essential to enhance work engagement. Therefore, it is hypothesised that:

***H3:** Project professionals' perceived workload (WL) is negatively associated with positive emotions (PE).*

***H4:** Project professionals' positive emotions (PE) is positively associated with work engagement (EG).*

Taking Hypotheses 2, 3 and 4 into account together, it is logical to assert that high perceived workloads lead to lower levels of positive emotions, which in turn negatively affect project professionals' work engagement. Thus, the following hypothesis is proposed:

***H5:** Project professionals' positive emotions (PE) mediates the relationship between workload (WL) and work engagement (EG).*

Sense of Purpose (SP)

The effect of positive emotions is enhanced by an overall "sense of purpose", that gives direction and meaning to people's actions (Fredrickson *et al.*, 2003). Sense of purpose has also been referred to as "work experienced as particularly significant and holding more positive meaning for individuals" (Rosso *et al.*, 2010, p.95). Judgement of meaningfulness depends on a variety of factors such as the extent to which work aligns with an individual's values and identities (e.g., Rosso *et al.*, 2010). However, the perception of meaningfulness does not solely depend on individual fulfilment. Recent research on work relationships suggests that giving to others (in both directions, between individuals and co-workers or supervisors) leads to a significant increase in perceptions of meaningfulness (Colbert *et al.*, 2016). Consequently, individuals with good work relationships would be more inclined to find her or his work meaningful.

On a theoretical level, research has shown that meaningful work has a positive impact on work engagement. For example, Holbedche and Springett (2003) noted that people strive to find meaning at work, and once they do so from a professional perspective, they tend to experience increased engagement. Further, when individuals regard their work as meaningful, it means they have made a positive evaluation of the worthwhile nature of their work activities, which is likely to trigger their positive emotions reactions (Yeoman *et al.*, 2019). Therefore, it is hypothesised that:

H6: *Project professionals' work relationships (WR) are positively associated with sense of purpose (SP).*

H7: *Project professionals' sense of purpose (SP) is positively associated with work engagement (EG).*

H8: *Project professionals' sense of purpose (SP) is positively associated with positive emotions (PE).*

Taking Hypotheses 4, 7 and 8 into consideration, it is logical to assert that high levels of sense of purpose lead to higher levels of positive emotions, which in turn positively affect project professionals' work engagement. Thus, the following hypothesis is proposed:

H9: *Project professionals' positive emotions (PE) mediates the relationship between sense of purpose (SP) and work engagement*

The hypothesised method is depicted in Fig. 1.

Method

The epistemological assumptions underpinning this study are of a positivist nature. Moreover, the analysis and interpretation of the data adopted an objectivist / determinist ontological paradigm in that it is possible that the constructs of interest are partially or completely determined by the organisational environment.

Participants and setting

Data were collected by means of an online questionnaire survey administered to project managers registered with the Association for Project Managers (APM). A total of 183 valid responses were subject to data analysis. No inducements were offered to participants. Ethics clearance was obtained from the University of Cape Town and the University of Manchester. Questionnaires were available in English. Members were emailed by the APM, provided with a URL for online access to the questionnaire, and asked to participate. Participants were briefed on the nature of the study, assured that their participation was entirely voluntary and anonymous, and informed that they could withdraw at any time. Participants who provided informed consent then proceeded to complete the questionnaire.

Measures

Work relationships (WR), workload (WL), sense of purpose (SP), positive emotions (PE), and engagement (EG) were all measured using the scales in the psychometrically validated ASSET model of workplace wellbeing (Faragher, Cooper and Cartwright, 2004; Robertson and Cooper, 2010).

For the WR scale, example items include: "My boss is forever finding fault with what I do" and "My relationships with colleagues are poor". For the WL scale, example items include: "I am set unrealistic deadlines" and "I do not have enough time to do my job as well as I would like". Regarding their Psychological Wellbeing, respondents were asked how often, during the past three months, they had felt like what was expressed in the questionnaire statement. Examples of the statements are as follows: (i) SP sub-scale – "My current job goals are specific" and "I am committed to achieving the goals of my job"; and (ii) PE sub-scale – "Inspired", "Enthusiastic" and "Contented". In the EG scale, example statements include – "I feel that it is worthwhile to work hard for this organisation" and "If necessary, I am prepared to put myself out for this organisation".

Survey items used either a 5-point (very slightly or not at all, a little, moderately, quite a bit, very much), or a 6-point (strongly disagree, disagree, disagree, slightly agree, agree, strongly agree) response scale. The WR, WL, SP, and EG scale items used a 6-point response scale, and the Positive

Emotions scale items used a 5-point response scale. In all cases higher scores represent higher levels of the construct of interest.

Statistical analysis and evaluation of the PLS models

The data were analysed using IBM SPSS Ver. 25.0 for Macintosh (IBM Corporation, 2013). A variety of descriptive and bivariate analyses were performed. Given the *reflective* (effect) and *formative* (causal) nature of the indicators in the hypothesized research model, an alternative method to CB (covariance based)-SEM was adopted; namely, Partial Least Squares (PLS) SEM. A reflective indicator is an observed variable that is assumed to be an *effect* of a latent construct. The underlying construct is assumed to cause the values that manifest in the observed variable. The latent construct is said to determine its reflective indicators (Bollen, 1984). In contrast, a formative indicator is a variable measuring an assumed cause of or a component of a latent construct (Petter *et al.*, 2007). The CB-SEM assumption that all indicators are reflective can result in serious modelling errors that produce inappropriate results (Chin, 1998). This is particularly germane to behavioural research where mixed models - those comprising both reflective and formative indicators - are common. Hence our choice of PLS-SEM (PLS). In our hypothesised research model, all constructs are reflective, with the exception of WR which is formative (i.e., a mixed model).

Hair *et al.* (2017, p.106) provide useful guidelines for the evaluation of PLS-SEM models, both measurement and structural. In PLS, model fit indices are of little relevance given that the method is not covariance-based.

(a) Evaluation of measurement models

(i) Reflective measurement models: Internal consistency (Cronbach's alpha) and Composite reliability; Convergent validity (indicator reliability and average variance extracted (AVE)); and Discriminant validity.

(ii) Formative measurement models: Convergent validity; Collinearity between indicators; and Significance and relevance of the outer weights.

(b) Evaluation of structural models

Coefficients of determination (R^2); Predictive relevance (Q^2); Size and significance of path coefficients; f^2 effect sizes; and q^2 effect sizes (derived from the Q^2 measures of predictive accuracy).

Results and Discussion

Participant characteristics

Fifty-five% of participants were women. Fifty-seven% were unmarried. The mother tongue of respondents was mostly English (44%), followed by Mandarin (32%) and 'other' (18%), French (2%) and Cantonese (1%). The language of work was English (63%), followed by Mandarin (25%), 'other' (7%), French (2%) and Cantonese (1%). Most respondents emanated from Europe (55%), followed by Asia (38%), Africa (4%), North America (2%) and Australia/Oceania (1%). Most reported working in the UK (48%) and China (23%). Respondents described their job functions as being project or programme managers (22%), academics or trainers (16%), with the rest describing themselves as project planners and project administrators (62%). Respondents described their roles in organisations as partners/owners/directors (22%), registered professional employees (28%) and employees (50%). Experience within their current organisation was as follows: not exceeding five years (47%); six to 10 years (24%); and 11-15 years (17%). A minority (13%) had been with the same organisation for at least 20 years. Twenty-two per cent of participants reported working less than 40 hours per week. Most (26%) reported working 41-50 hours per week, with 24% reportedly working 51-60 hours per week. A minority (7%) reported working in excess of 60 hours per week. Time spent travelling to and from work each day was reported by 27% as less than one hour, by 30% as one to two hours, and by 33% as exceeding two hours.

Missing value analysis

Missing value analysis indicated that missing items were missing completely at random (MCAR), and that the proportion of the sample with missing values on all of the items of interest was less than 1%. The low frequency of missing values meant that these could be imputed using the estimation-maximization (EM) algorithm (Graham, 2012).

Correlation analysis

All correlations were significant (one-tailed) $p \leq 001$. The direction of all associations was positive. The magnitude of the associations varied between small (.10 to .29), medium (.30 to .49) and large ($\geq .50$). Notably, the strength of the relationship between EG and each of WR, SP, and PE was large, as were the relationships between WR and WL, and between SP and PE. All other relationships were medium.

Evaluation of the reflective measurement model

Loadings of individual items to their respective constructs were strong (>.70), with the exception of PE2 (.61) and EG3 (.63) where the loadings fell slightly below the threshold. Indicator reliability was good (>.50) in all instances, again with the exception of PE2 (.37) and EG3 (.39). The average variance extracted (AVE) measures were all well above .50. Composite reliability ranged from .88 to .93, well within the upper bounds of acceptability. Internal reliability (Cronbach's alpha) was good to excellent, ranging from .82 to .91. Finally, discriminant validity was demonstrated for all constructs, ranging from .79 to .85.

Evaluation of the formative measurement model

The analysis yielded mixed results. To assess convergent validity required testing whether the formatively measured construct (WR) is highly correlated with a reflective measure of the same or similar. The Communication and resources (RC) construction, itself a sub-set of the '6 Essentials' was used for this purpose. The analysis yielded a path coefficient of .756, which is above the threshold of .70. The indicators also indicated an absence of collinearity VIF<3). Outer loadings were strong and significant. However, individual outer *weights* (and associated 't'-values) were disappointing. Specifically, only two of the indicators were significant; WR4 (p<.000) and WR5 (p<.01). These results point to the need for detailed psychometric analysis of this construct, using a larger dataset. Given the inconclusiveness of these results, WR was retained in the model.

Evaluation of the structural model

The structural model is depicted in Fig. 1. Having confirmed that the construct measures were reliable and valid, evaluation of the structural model was undertaken. The (inner) VIF results demonstrated that all combinations of endogenous constructs and corresponding exogenous (predictor) constructs indicated an absence of collinearity (VIF<3). The R^2 values of all constructs are significant. WL (.501) and EG (.667) may be considered moderate, whereas the R^2 values of SP (.271) and PE (.395) are somewhat weak. The f^2 values for all combinations of endogenous constructs and corresponding exogenous (predictor) constructs indicated that WL has a medium effect on PE (.095) and EG (.112). The remaining effects were strong.

Overall, all the hypotheses are statistically significant with *p*-values less than 0.05. Therefore, all the hypotheses are accepted except for H3 because we found a positive association between WL and PE instead of the hypothesised negative relationship. The strongest paths in the model were WR to WL (-.708), WR to SP (.520), SP to EG (.479), and SP to PE (.498). Finally, regarding predictive relevance (Q^2), using $PLS_{Predict}$ indicates that the values for each of the endogenous constructs are well above zero: WL (.459), SP (.234), PE (.208), and EG (.246) – providing support for the model's predictive relevance regarding the endogenous latent variables. The q^2 statistics corroborate this. The structural model was deemed tenable.

Conventionally, WL was identified by previous literature to have a negative direct relationship on PE, but we found a positive relationship instead. This could probably be explained by the recent studies which pointed out that WL and PE is not a simple direct relationship (e.g., Schusterschitz *et al.*, 2018). Indeed, the relationship can be moderated and mediated by different personal factors. For example, Gardner and Parkinson (2011) concluded that optimistic individuals can cope with high perceived workload better. Therefore, the effect of workload on positive emotions depends on an individual optimism level. It is suggested that future research can look into introducing moderators and mediators to further investigate the relationships.

In addition, the mediation effects of PE in H5 and H9 were examined by bootstrapping 2000 times in PLS, which showed the effects are statistically significant. That implies PE is a critical factor that explains why WL and SP could affect EG. This finding aligns with the Broaden-and-Build Theory (Fredrickson, 2001), positive emotions build people's physical, social, intellectual, and psychological resources, thereby building high levels of work engagement. This, again, highlights the important role of PE on EG. In addition, it implies that organisations should be aware that WR, WL and SP can directly and indirectly affect one's PE and thus his or her levels of EG.

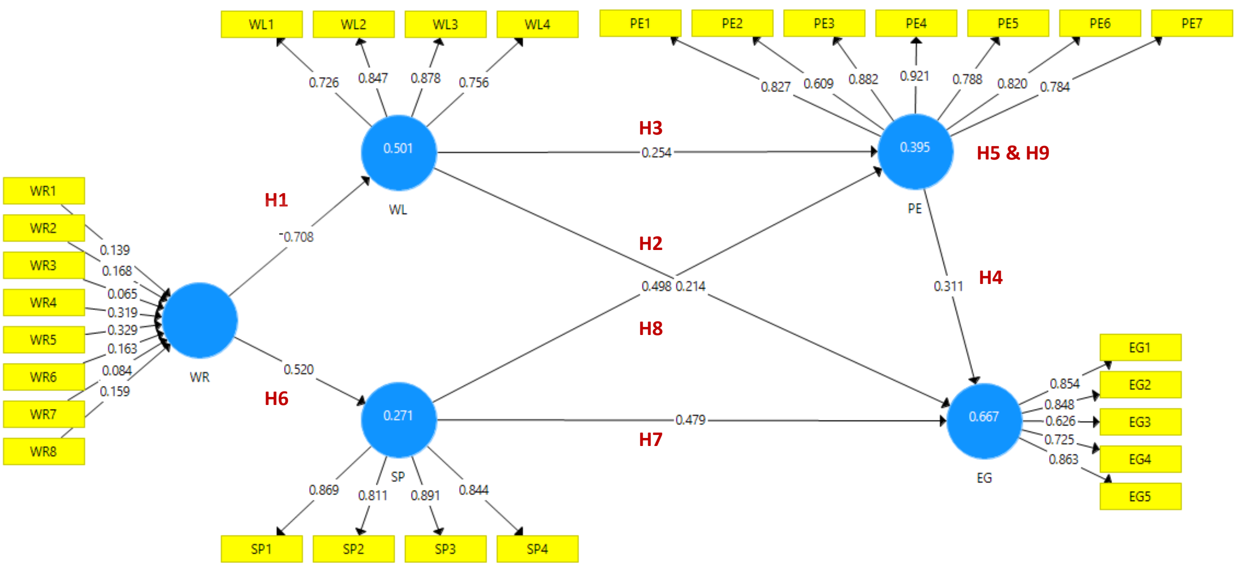

Fig. 1 The structural model results

Conclusion

Work engagement is an important predictor of work performance, while work relationships have been found to impose significant impact on one's engagement at work. Yet, there is limited knowledge on the underlying mechanism in the construction industry, which could hinder the industry to develop more effective and evidence-based interventions and advance theory building of work engagement in the construction context. This study explores how perceived workload, sense of purpose and positive emotions could explain how work relationships affect the work engagement of project professionals. The results showed that work relationships are positively related to sense of purpose negatively related to workload, while perceived workload and sense of purpose are positively associated with positive emotions and work engagement. Positive emotions are a mediator in the relationship between perceived workload and engagement, and in the relationship between sense of purpose and engagement. This study highlights the pivotal role of perceived workload and sense of purpose in the outcome of positive emotions among employees, and the concomitant experience of greater work engagement with the organisation.

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Impact of construction work environment on quality of life of ageing workforce

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Abstract

Purpose: The birth of an ageing population has been one of the most significant social transformers in the twenty-first century with the implication in all sectors, including the construction industry. Consequently, there have been advances in knowledge about elders living in built facilities; however, research about the older workforce that played vital roles in building these facilities is still in its infancy. This research aims to understand the impact of the construction work environment (CWE) on the quality of life (QOL) of the older workforce.

Design/methodology/approach: The study adopted a quantitative approach and data was sourced from 38 older construction workers in Edinburgh, Scotland using a questionnaire. World Health Organisation QOL-Brief guidelines, bivariate correlations and multiple regression modelling were employed to achieve the aim of the study.

Findings: The salary of older workers, payment structure, shift-work pattern and career opportunities and advancement positively impact the QOL of the older workforce in the construction industry.

Practical implications: The findings suggest that the construction firms should avoid using age to fix the starting salary, and the salary of older workers should compensate for the deteriorating ageing changes the older workers experience. Also, older workers' shift pattern should be flexible and convenient. More importantly, the construction firms should maintain structured career opportunities and advancement system for the older workforce.

Originality/Value: The study will promote active ageing among older construction workers. The developed model builds on and supports the active ageing framework developed by the World Health Organisation on age-friendly cities and community. The study further confirms the validation of the WHOQOL-BRIEF assessment instrument, adding considerably to the reliability of the instrument.

Keywords: ageing, construction industry, construction work environment, older workforce, quality of life.

Introduction

The twenty-first century is experiencing an unprecedented birth of an ageing population due to the decrease in fertility and increase in life expectancy. The construction industry workers are also ageing; most of the current workers are baby boomers (CIOB, 2015; Choi et al., 2013). The ageing population are mostly prone to multiply and increasing physical impairments such as vision, hearing, strength, balance, and response time (Barlow and Venables, 2004). Although these impairments might affect their overall productivity, it is imperative to adopt strategies that amend the losses accompanying ageing, and critical attention should also be given to strategies that will reinforce recovery, adaptation and psychosocial growth (WHO, 2018a). Construction companies that rethink their perceptions and implement strategies that improve the quality of life (QOL) of the older workforce will be in the best position to gain maximum benefit from the changing demographics (Choi, 2015). The changing demographics will demand an adjustment to the current work environment, practices, policies and procedures to fit the ageing workforce thus promoting healthier, safer, more comfortable and more productive workforce for the growing largest population (Choi, 2015). Research has proved that the person (older workforce) and the environment (construction work environment) does not only affect the outcome of an individual but also interact with others to affect their outcomes (Kreiner, 2006).

Albeit several researchers have studied the QOL of the older adults, most of their studies were limited to the QOL of older adults residing in built facilities such as care homes (Haugan et al., 2020; Leung et al., 2017; Samah et al., 2013). Surprisingly, their research failed to consider the older workers that played vital roles in building these facilities. No wonder there is an increasing number of older adults moving to care homes – the poor QOL due to the current work environment could plausibly be one of the reasons. This can be worse in the construction industry which is described as tough, heavy and physically demanding (Leaviss et al., 2008; Schwatka et al., 2011; Eaves et al., 2016). The construction work environment (CWE) is unfavourable for workers of all ages; however, this environment can only catalyse the deteriorating ageing changes of the ageing workers (Eaves et al., 2016). While there is close to adequate research about the built facilities and the QOL of elderly, research about the construction work environment (CWE) and the QOL of the older workers is still in its infancy. This draws us to the main aim of this study – to understand the impact of the CWE on the QOL of the older construction workers.

Quality of life and construction work environment

Table 1: Quality of life domains

Domain	Sub-domain
Physical health	Activities of daily living
	Dependence on medicinal substance and medical aids
	Energy and fatigue
	Mobility
	Pain and discomfort
	Sleep and rest
	Work capacity
Psychological health	Bodily image and appearance
	Negative feelings
	Positive feelings
	Self-esteem
	Spirituality/Religion/Personal beliefs
	Thinking, learning, memory and concentration
Social relationships	Personal relationships
	Social support
	Sexual activity
Environment	Financial resources
	Freedom, physical safety and security
	Home environment

	Opportunities for acquiring new information and skills Participation in and opportunities for recreation/leisure activities Physical environment (pollution/noise/traffic/climate) Transport

Source: WHO (2018b)

Researchers, policy-makers, clinicians and the wider public believe that the health of a population or an individual is significantly determined by the population or individual's QOL (Åström et al., 2018; Cramm and Nieboer, 2016). As a result of this, QOL has become an ideal health assessment for the ageing populace (WHO, 2018b). The WHO defined QOL as an individuals' perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns (WHO, 2018b). A person's QOL is assessed in four main domains, as described in Tables 1.

The environment is a critical determinant of the QOL of its workforce (Olivos and Clayton, 2017; Leitão et al., 2019). The rationale is to improve the person-environment fit by identifying facets in the CWE that affects fit between the older workers and the CWE. The CWE facets are the approaches, support services, adjustments, practices, policies and procedures that organisations implement which can positively or negatively impact the health, safety, comfort, productivity and QOL of the older workers (Torku et al., 2019; Choi, 2015). The CWE is categorised in five facets, as described in Table 2.

Table 1: Construction work environment

Domain	Domain Facets
Organisational-Psychological	Payment structure Career opportunities/advancement Salary Management plan and style Attitudes of management Job security/employment tenure Environmental control Shift-work patterns
Physical	Performing repetitive tasks Manual handling of heavy materials Performing wet task Task allocation/schedule approach
Functional	Engagement in more skilled, but less physically demanding task
Policies and Practices	Personal protective equipment Protection from environmental exposures such as heat, dust, noise and weather Employment flexibility
Auxiliary	Tools and equipment Social networks (opportunity to socialise) in the workplace

Source: Torku et al. (2019)

Methods

Using convenience sampling technique, the researchers first contacted eleven ongoing construction projects in Edinburgh, Scotland, to participate in the study. However, only five of these projects agreed to participate in the study. Furthermore, purposive sampling technique was used to select older workers among all worker in the five construction projects that agreed to participate in the study.

Older construction workers refer to participants who were aged 40 years and above (Leaviss et al., 2008; Buckle et al., 2008). A total of 100 questionnaires were administered to the older workers, and 38 completed questionnaires were retrieved, representing a response rate of 38%. Albeit the sample size was relatively small, statistical analysis could still be performed because according to the generally accepted rule, with a sample size of 30 or above, the central limit theorem holds (Ott and Longnecker, 2010). 100% of the respondents were older workers according to the definition of the study. The survey results further indicated that 89.4% of the respondents have been working in the construction industry for more than ten years. The participants in the study occupy several roles in the construction industry — these included project managers, site managers, clerk of works, health and safety managers, quantity surveyors, contractors, bricklayers, carpenters, electricians, mechanical engineers, labourer, and plumbers.

Respondents were asked to assess their satisfactionn with the CWE facets and how they feel about their QOL, health and other areas of their life using a five-point Likert scale. The WHOQOL-BRIEF assessment instrument was adopted to assess the QOL of older workforce. The WHOQOL-BRIEF consist of four main domains, as shown in Table 1. The physical health domain comprises of seven items; the psychological health domain comprises of four items, the social relationships domain comprises of three items, and the environment domain comprises of eight items and an additional two items representing the overall QOL and general health. Each domain is made up of questions for which the scores vary between 1 and 5. Bivariate correlations and multiple regression modelling were employed to understand the impact of the CWE on the QOL of the older construction workers.

Results

Reliability analysis

The internal consistency of both CWE facets and the QOL domains were confirmed using Cronbach's alpha reliability analysis. The Cronbach's alpha value for CWE facets and the QOL domains was above 0.7. This implies that there is an excellent internal consistency and reliability with the dataset and the measuring instrument adopted for assessing QOL (Field, 2005).

Pearson correlation between CWE facets and QOL domains

Pearson correlation coefficient was used to determine the strength of the relationship between the CWE facets and QOL of the older workers. Pearson correlation test is a parametric statistic which can be used with Likert scale responses with small sample sizes and are sufficiently robust to yield unbiased conclusion even when statistical assumptions—such as a normal distribution of data—are violated (Norman, 2010; Jamieson, 2004; Sullivan and Artino Jr, 2013). The Pearson correlation coefficient value ranges from +1 to -1, depending on whether the relationship is positive or negative. A value of 0 indicates that there is no relationship between the CWE facets and QOL of the older workers. Values between (+/-) 0.1 to 0.3 indicates small strength of the relationship, values between (+/-) 0.3 to 0.5 indicates medium strength of relationship and values between (+/-) 0.5 to 1.0 indicates large strength of the relationship. Although a large effect relationship is preferable, a medium effect size is acceptable in psychology and medical-related disciplines (Stice et al., 2004). The Pearson correlation analysis presented in Table 3 indicates that organisational-psychological environment has a strong strength, positive, statistically significant, relationship with, physical health ($r = .529$, $n = 38$, $p = .001$), psychological health ($r = .532$, $n = 38$, $p = .0011$), environment ($r = .547$, $n = 38$, $p = .000$) and a medium-strength, positive, statistically significant relationship with General QOL ($r = .421$, $n = 38$, $p = .009$).

Multiple regression analysis between CWE facets and QOL domains

Multiple regression analysis was used to extend the understanding of the relationship that exists between the CWE facets and QOL of the older workers and the predictive impact of the independent variables (CWE facets) on the dependent variables (QOL of older workforce). Five multiple regression models, as shown in Table 4, were developed using stepwise method. Multicollinearity inspection was conducted using variance inflation factor (VIF) values. According to Hair et al. (2010), VIF values greater than 10 suggest the presence of multicollinearity in the data. The VIF values were less than 1.148 (Table 4) confirming that the data does not show multicollinearity.

Table 3: Correlation analysis between CWE facets and QOL domain

CWE facets		QOL domains				
		Physical health	Psychological health	Social relationship	Environment	General QOL
Organisational-Psychological	*r*	**.529****	**.532****	.107	**.547****	**.421****
	p	.001	.001	.522	.000	.009
Payment structure	*r*	.381*	.310	.345*	.317	. .325*
	p	.018	.059	.034	.053	.046
Career opportunities/advancement	*r*	**.437****	**.463****	.242	**.544****	.300
	p	.006	.003	.143	.000	.067
Salary	*r*	.009	.001	.780	.007	.000
	p	.009	.001	.780	.007	.000
Management plan and style	*r*	.267	.309	-.082	.249	.270
	p	.105	.059	.623	.132	.101
Attitudes of management	*r*	.258	.169	-.010	.216	.125
	p	.118	.310	.954	.193	.455
Job security/employment tenure	*r*	**.462****	**.453****	.272	**.537****	.362*
	p	.003	.004	.099	.001	.026
Environmental control	*r*	.394*	.401*	-.118	**.467****	.293
	p	.014	.013	.482	.003	.074
Shift-work patterns	*r*	**.560****	.603**	.010	**.499****	.366*
	p	.000	.000	.951	.001	.024
Physical	*r*	.385*	.141	.121	.235	.109
	p	.017	.400	.471	.156	.515
Performing repetitive tasks	*r*	.310	-.002	.207	-.035	-.036
	p	.058	.990	.213	.834	.831
Manual handling of heavy materials	*r*	.338*	.121	.064	.164	.098
	p	.038	.469	.703	.324	.558
Performing wet task	*r*	.283	.113	.130	.260	.087
	p	.085	.498	.438	.115	.604
Task allocation/schedule approach	*r*	.344*	.239	.000	.407*	.217
	p	.034	.148	.998	.011	.190
Functional	*r*	.020	.209	.063	.271	.173
	p	.906	.207	.709	.100	.299
Engagement in more skilled, but less physically demanding task	*r*	.020	.209	.063	.271	.173
	p	.906	.207	.709	.100	.299
Policies and Practices	*r*	.303	.295	-.061	.243	.130
	p	.064	.072	.716	.142	.438
Personal protective equipment	*r*	.173	.091	-.057	-.011	.029
	p	.299	.586	.736	.947	.861
Protection from environmental exposures such as heat, dust, noise and weather	*r*	.014	.120	.092	.021	-.122
	p	.931	.472	.583	.900	.465
Employment flexibility	*r*	.403*	.371*	-.134	**.422****	.296
	p	.012	.022	.424	.008	.071
Auxiliary	*r*	.305	.381*	.066	.340*	.137
	p	.063	.018	.696	.036	.413

Tools and equipment	*r*	.160	.309	-.172	.159	.034
	p	.336	.059	.301	.341	.839
Social networks (opportunity to socialise) in the workplace	*r*	.342*	.354*	.212	.395*	.179
	p	.036	.029	.201	.014	.284

Note: *. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed). *r* = Pearson correlation *p* = Sig. (2-tailed) N = 38

Model 1 indicates that general QOL is significantly impacted by salary; explaining 29.6% of the variance. In Model 2, shift-work patterns significantly impact the physical health of older workforce; the model explained 31.3% of the variance. In Model 3, psychological health was significantly impacted by shift-work patterns and salary; the model explained 45.5% of the variance. In Model 4, the social relationship was significantly impacted by payment structure; the model explained 11.9% of the variance. The final model – Model 5 shows that the environment is significantly impacted by career opportunities/advancement. The relationship between CWE and QOL of the older workforce is presented in Table 4 and depicted in Figure 1.

Table 4: Multiple regression analysis models for CWE facets and QOL

Model		B	S.E.	Sig.	VIF	R	R^2	ANOVA	
								F	Sig.
1	**General QOL**	⟵	**Construction work environment facet**						
	Constant	3.064	1.238	.018		.545	.296	15.172	.000
	Salary	1.309	.336	.000	1.000				
2	**Physical health**	⟵	**Construction work environment facet**						
	Constant	20.186	2.008	.000		.560	.313	16.405	.000
	Shift-work patterns	2.343	.579	.000	1.000				
3	**Psychological health**	⟵	**Construction work environment facet**						
	Constant	11.373	2.456	.000		.675	.455	14.615	.000
	Shift-work patterns	1.828	.501	.001	1.148				
	Salary	1.629	.674	.021	1.148				
4	**Social relationship**	⟵	**Construction work environment facet**						
	Constant	7.106	1.902	.001		.345	.119	4.856	.034
	Payment structure	1.113	.505	.034	1.000				
5	**Environment**	⟵	**Construction work environment facet**						
	Constant	21.612	2.524	.000		.544	.296	15.130	.000
	Career opportunities/advancement	2.631	.676	.000	1.000				

Note: S.E.= standard error; Sig. = significance; VIF = variance inflation factor.

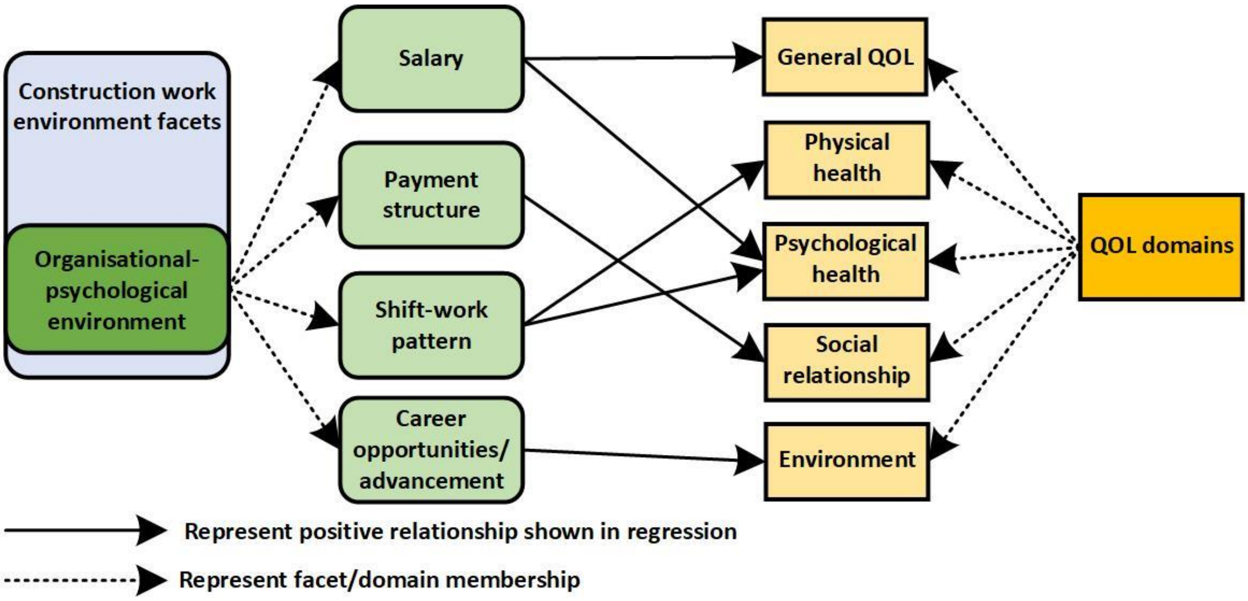

Figure 1. Relationship between CWE and QOL of the older workforce

Discussion

Surprisingly, the physical, functional, policies and practices and auxiliary environments of the construction industry have no predictive impact on the QOL of the older workers in the construction industry. The CWE facet that significantly impacts the QOL of the older workforce falls within the organisational-psychological environment of the construction industry. The organisational-psychological environment has the potential to positively or negatively affect the mental well-being of the older workforce. A dissatisfaction in these factors can lead to constant mental stress for the older workforce (Boschman et al., 2013).

Salary satisfaction among older worker increases their overall QOL and general health. A low salary or a salary that does not compensate for the deteriorating ageing changes of older workers will negatively affect their overall QOL and general health. Salary satisfaction also affects the psychological health of the older workforce. Older workers that are satisfied with their salary experience positive feelings about their self-esteem. The level of satisfaction older workers feel about shift-work pattern affects their physical health and psychological health. Older workers with dissatisfied shift-work pattern experience decrease in energy and weak with fatigue; mobility; pain and discomfort; sleep and rest; and work capacity. On the contrary, older workers that perceive their shift-work pattern to be satisfactory are most likely to experience better physical health. Akin to this is the role shift-work pattern plays in improving the psychological health of the older workforce. The shift-work pattern that fits with the older workers improves their self-esteem, personal beliefs, thinking, learning, memory and concentration.

Furthermore, the payment structure has the potential to positively or negatively affects the social relations of older workers. The construction industry is well known for rewarding speed and time for completion, such as piecework payment (Leaviss et al., 2008). Piecework payment may be less attractive to the older workers but more attractive to younger and physically fit workers. The findings of this study reveal that payment structure that met the need of the older workers positively impacts their relationships, social support and sexual activity which are prerequisite for a better QOL. An increase in the social relationship among older workforce promotes better health, well-being, happiness, better QOL and subsequently, increased longevity (Portero and Oliva, 2007; Sarason et al., 2001). The findings of this study revealed that career opportunities and advancement positively influence the environment of older workers. It can be deduced that older workers that are satisfied with their career opportunity and advancement in the construction industry feel confident about their financial resources; freedom, physical safety and security; engaging in recreation and leisure activities; and are eager in acquiring knowledge, information and developing new skills which result in a better QOL.

Recommendations

Practical implications

The findings of this study confirm that the CWE facets have a significant positive impact on the QOL of the older workers. Albeit salary is a significant facet that positively contributes to the QOL of the older workers; the older workers in the construction industry seem not to be very satisfied with their salary. The construction firms must avoid using age to fix starting salary as this is an unlawful practice. More importantly, the salary of older workers must compensate for the deteriorating ageing changes they experience. Although some may argue that the construction industry is very competitive and its rather financially impossible to make compensation for the deteriorating ageing changes of the older workforce, the study recommends that both construction firms and clients should bear this cost and make provision for it right from the onset of every project. A decline in physical abilities of older workers should not necessitate a reduction in their salary. The findings of the study reveal that older workers that are satisfied with their salary experience positive feelings about their self-esteem with a slower rate of decline in thinking, learning, memory and concentration abilities. This study substantiates Leaviss et al. (2008), Lynch et al. (2000) and Takim et al. (2016) who proposed that salary inequality and discrimination treatment affect CWE.

The payment structure for the older workforce should not be determined by the speed and time of completion of a task. Payment structure should take into consideration the physical slowness of older workers. An environment that rewards speed is unfavourable for older workers who are experiencing increasing physical impairments which affects their speed. The study recommends that payment structure based on day rate will be more favourable for the older workers than piecework-based payment structure. The findings of this study reveal that payment structure that fit the need of the older workers positively impact their relationships, social support and sexual activity which are prerequisite for a better QOL. The construction industry is known for its long working hours. However, as workers age, they would prefer a flexible and convenient shift pattern. The shift-work pattern should be easy for older workers to follow and should cause the minimum stress to the older workers. The study brought to the limelight that flexible and convenient shift-work pattern increases the physical health, reduces fatigue, pain and discomfit experienced by the older workforce. Although shift-work may be favourable to older workers; it could be very challenging to implement due to the nature of construction projects. As a result, shift work is less common in the construction industry than industries such as manufacturing. For shift-work to be successful, it has to be planned carefully, and the construction industry must learn from other industries.

The construction firms regardless of size should develop and maintain structured career opportunities and advancement system for the older workforce. Although older workers might have different career aspiration, there are nevertheless facets of the CWE that management of construction firms can implement to enhance older workers advancement opportunities. The study recommends management to empower older workers, enhance older workers' skills sets, engage them in tasks that lead to changing of their roles in the construction industry, and to recognise their achievements through promotions. The findings of the study prove that the older workers that are satisfied with their career opportunity and advancement in the construction industry feel confident about their financial resources, freedom, physical safety and security.

Research implications for future research

The following recommendations for future research were made with regards to the limitations of the study. The study recommends a more in-depth qualitative research approach, such as interviews, to cross-validate the findings of this study. Also, due to the cross-sectional nature of this study, it is worthwhile to replicate similar study using longitudinal research design in other geographical areas for comparison and to extend the understanding of the correlation and predictive power between QOL and the CWE facets. A follow-up assessment should be conducted on the QOL of the older workers after the implementation of the findings of this study to report on any positive or negative changes to their QOL. Researchers are encouraged to harness the current advances in sensing technology to retrieve unbiased, continuous data on older adults' physiological, emotional and cognitive states in order to understand the facets of the CWE that influence the older adults' state of being.

Limitations of the research

Readers, management and decision-makers in the construction industry should be aware that the findings of this cross-sectional study are constrained by a limited sample size of the older workers and the possibility of common method bias due to the self-report survey instrument adopted. However, this should not invalidate the findings and conclusions of the study because reliable measures were taken to mitigate the likelihood of this bias. Firstly, all the older workers were purposively selected across five different ongoing construction projects and were aged 40 years and above at the time of the survey. Secondly, 89% of the older workers have been working in the construction industry for more than ten years, meaning that they had in-depth knowledge about the CWE facets. Thirdly, Cronbach's reliability test also confirmed the reliability of the measuring scale adopted for the study.

Conclusions

Against the backdrop that the CWE needs to be modified to fit the deteriorating ageing changes of the older workforce, this research aimed to understand the impact of the CWE on the QOL of older workers. The WHOQOL-BRIEF assessment instrument was adopted to assess the QOL of the older workers using five-point Likert scales. The WHOQOL-BRIEF consist of four main domains. The physical health domain, the psychological health domain, the social relationship domain and the environment domain. Pearson correlation coefficient was used to determine the strength of the relationship between the CWE facets and QOL of the older workers. Multiple regression analysis was used to extend the understanding of the relationship that exists between the CWE facets and QOL of the older workers and the predictive impact of the independent variables (CWE facets) on the dependent variables (QOL of the older workers). The findings of this study revealed that the salary of older workers, payment structure, shift-work pattern and career opportunities and advancement significantly impact the QOL of the older workers in the construction industry. Future researchers are recommended to replicate a similar study using longitudinal research design in other geographical areas for comparison and to extend the understanding of the correlation and predictive power between QOL and the CWE facets.

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Gender Diversity: An Analysis of the Organisational Situation of Construction Sites in Brazil

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Abstract

The Construction Industry has a great relevance to the global economy due to its contribution to the creation of jobs. So, it is important to discuss the social role of the engineer as an agent of social transformation in the work environment, as well as the importance of diversity within organizations. The construction site is favorable to social interactions and susceptible to discrimination, since it has historically been a predominantly male environment. This situation led to the lack of studies and specific laws that consider the need to an environment focused on diversity that guarantees healthy working conditions, well-being and dignity for employees. Especially those who do not identify with heteronormativity and / or with the gender assigned to them at birth. This paper seeks to provide discussions about the gaps in the regulations on construction sites, through the diversity of gender and sexual orientation present in society. Therefore, an overview of the current state of knowledge in this specific area was carried out, as well as a structured analysis of Brazilian standards that dictate working conditions and the environment in the construction industry, as a way of identifying existing weaknesses and possible improvements. As a result, a reflection was made on how studies focused on the Construction Industry are based mainly on a Western vision, focused on the dichotomy between man and woman, without representation, acceptance or respect for gender diversity and sexual orientation. An analysis of the standards related to the working conditions and physical structure of the construction sites was carried out. A disregard for specific situations was identified, such as the use of sanitary facilities, as well as good practices for inclusion and creation of an environment favorable to diversity.

Keywords: Gender; Diversity; Construction site; Equity

Introduction

Gender inequality and discrimination is a global issue, regardless of the area of employment and the geographical location. The construction industry, however, stands out for having great relevance in the global economic structure (being responsible for a considerable part of the generation of jobs), and for having a work environment very susceptible to discrimination. According to Silva and Tomasi (2013), the construction site is a space where there are several social relationships that can lead to discrimination, as it is a male predominant sector. This environment favors the lack of debates and programs that support discussion on gender diversity.

According to Cremasco (2014), it is essential that the engineer develops a systemic view of the world, in order to recognize himself as an agent of social transformation. It is the obligation of the engineer to have ethical responsibility, during decision making, the effects of their actions in honoring the right of individuals and fulfilling duties, avoiding harm to others. As stated by Tonini and Dutra (2009), the contemporary engineer needs to acquire a posture that allows him to transcend borders, allowing the access of goods and services to a marginalized portion of the population. As reported by Reed and Coates (2003), engineers can contribute to the inclusion of groups excluded from society. Through the insertion of minority groups in the job market, the engineer can transform realities, making people who suffer from prejudice and exclusion find a respectful, safe and welcoming work environment, where they can improve their technical skills.

Brazil, in particular, has a peculiar outlook. According to data from the Brazilian Chamber of Construction Industry (CBIC, 2019), Construction Industry was responsible for about 124 thousand, of the 841 thousand formal jobs created in the country in 2019 despite the 27% drop in GDP over the past 5 years. Therefore, it is an important generator of jobs in the region. On the other hand, the country still has a general reality of gender inequality and discrimination and the Brazilian laws for construction sites are obsolete in the face of civil rights of the various existing genders.

In this context, this study aims to systematically analyze the regulations on construction sites in force in Brazil regarding issues related to gender diversity. To this end, a bibliographic review was carried out on gender studies within the workspace in general, - in order to understand the situation of the insertion of minorities in the workplace - and the construction environment. Then, it carried out a structured analysis regarding this subject of Brazilian standards that affect working conditions at the construction site, with an opportunity to identify existing deficiencies and possible improvements.

The results obtained are expected to contribute to the development of discussions on the topic within the construction sector, in addition to bring awareness to engineers regarding their impact on society and how they can be agents of change, since they actively participate in the hiring process. It is also expected to contribute to future actions to improve the standards applied to the environment of construction sites, in order to provide a socially fair and responsible environment, open to individuals of any gender and biological sex.

Context

Gender studies: concepts and current panorama in Brazil

Gender studies serve to understand how sexual characteristics are understood and represented socially, since they are inserted in environments that present rules and social representations (Louro, 1997). The construction of our identity as men and women is not a biological factor, it is social, since the definition of man and woman should not be determined by chromosomes or genital conformation, but by the way that the person affirms themselves socially (Jesus, 2012). Gender only exists through social relationships (Louro, 1997).

In 2016, the New York Human Rights Commission began to recognize 31 different types of genders, which can be used in professional and official spheres. However, in Brazil, only in 2018, the Federal Supreme Court (STF) authorized transsexuals and transgender people to change their civil name, without undergoing sex reassignment surgery. Nowdays, Brazil legally recognized two genders, the cisgender - individuals who identify with biological sex - and transgender - those who do not identify with biological sex.

In 2019, the STF decided to allow the criminalization of homophobia and transphobia. Any harmful acts against homosexuals and transsexuals must be framed in the crime of racism. This decision made Brazil the 43rd country to criminalize homophobia, a very important decision, since, according to Avelar (2019), discussions on the topic become more relevant in Brazil, as it is the world leader in crimes against sexual minorities. On the other hand, it is emphasized that the International Labor Organization (ILO, 1968) defined discrimination in convention 111, as “any distinction, exclusion or preference based on race, color, sex, religion, political opinion, national ancestry or social origin, which has the effect of destroying or altering equal opportunities or treatment in matters of employment or profession". It is noticeable that, even before the criminalization of homophobia or transphobia, the law already forbid discrimination in the workplace, but this does not prevent many individuals from suffering daily with LGBTQIA + phobia, because, until 2018, transgender was seen by the World Health Organization (WHO) as a mental disorder and that even today there is no specific legislation that defends and protects the rights of the LGBTQIA + community.

Homophobia and transphobia are present in different social spheres (e.j. home, school, workplace). According to Rocha and Sousa (2017), the fact that a person does not identify with their biological sex causes embarrassment and shows injustice to them. In this way, there is a portion of society diminished, such as the transgender population, due to the lack of opportunities in the workplace and homosexuals who, according to Ferreira (2007), choose to hide their sexual orientation and restrict themselves to repressed behavior to suit the hostile work environment.

Little is discussed about fighting gender inequality in the workplace in general, and it is important to reflect on the inclusion of individuals who deflect heteronormativity and identify or not with the gender assigned to them at birth (Silvério, 2017). As stated in Barreto and Lira (2017), access to paying job opportunities for the transgender population (transvestites and transsexuals) is constantly denied, implying an increase of this group in prostitution. For Ferreira (2007), the homosexual and bisexual orientations are omitted in discussions about managing diversity, even though prejudice is constant in the lives of gays, lesbians and bisexuals. Nunes (2017) presents data from a survey conducted in 2015 with 10,000 employers in Brazil, of which 7% of companies say they would not hire homosexuals and 11% would only hire if there were no such men in power.

Society is even more heterogeneous, demanding organizations to adapt to those changes (Pereira and Hanashiro, 2010). Companies put at risk factors like time, money and efficiency by ignoring diversity management (Bedi, Lakra and Gupta, 2014). It is essential that companies think about programs, policies or practices in favor of diversity, regardless of race, gender and others (Fujimoto, Hartel and Azmat, 2013). Changes must go beyond hiring, they must include training on diversity and studies on conflict management, preventing the growth of the rate of replacement and interpersonal confrontations between members of the organization (Peci and Sobral, 2008).

In addition to the perspective of social inclusion, Agrawal (2012) analyzes diversity as a tool for creating competitive advantage on the market. To the author, the fair and equal treatment of employees produces high motivation to the team. Marques (2008) states that factors such as prejudice and discrimination can be harmful to the diverse management. Respect for diversity must be done because it is morally correct and, when bringing this mentality into the work environment, both performance and profits will show improvements. Dike (2013), shows how discrimination affects the worker's ability to perform work. Mendes (2004) states that many organizations present approaches aimed at managing diversity as a way to improve their image.

The presence of public gender policies is fundamental as a way of coping with the persistent inequality in the country (Nascimento, 2016). Despite advances in regarding to gender inequality or disrespect for the human rights of women, the situation of inequality in Brazil still persist, making it necessary to create effective gender policies, as well as the action of social movements, through the union of forces between civil society and the State. Martin (2014) reports that the way leaders manage diversity influences the way the work environment deals with the subject.

Construction sites: Working conditions and gender studies

The construction site is the working environment built within the workspace, where all the necessary steps are taken to materialize a construction. Because of this, several social relationships happen within this space, which, according to Silva and Tomasi (2013), can increase discrimination because it is a predominantly male field, showing great resistance to women's work. In Brazil, Regulatory Norms (NR), numbers 18 and 24, focused on health and safety in the work environment, address the conditions of installation and use of living areas. NR-24 (ABNT, 2019) deals specifically with this topic, while NR-18 (ABNT, 2020) responsible for guidelines at construction sites, details a topic exclusively on this matter. Despite having experienced a complete adaptation and new structuring, both make a mistake on issues related to gender and sex. NR-24 (ABNT, 2019), in requirement 24.2.2, explains that sanitary facilities must be separated "by sex", while NR-18 (ABNT, 2020), in requirement 18.5, hides any reference to gender or sex, describing the quantification of sanitary devices and informing the need to provide urinals, the element being exclusive for males.

Here, two gender studies on the construction site stand out that indicate the lack of sanitary facilities for women as the main excuse of management for not hiring them (Lombardi, 2017; Regis et al, 2019). Lombardi (2017) discusses feminization processes within the housing construction segment of building. As final considerations, the author identifies the presence of numerous episodes of gender discrimination, moral and sexual harassment. Since most of the interviewees do not consider them as such and see it as what must be passed on to be accepted in this male and sexist professional culture. Regis et al (2019), on the other hand, carried out an analysis on the working conditions of women at the construction site. The authors identified situations faced by construction workers, such as losses in the hiring process, real lack of professional promotions and sexual division in the work environment. On the other hand, they also identified situations, in which women showed pride in their work in construction, despite the existence of aspects that discourage job searching in this environment, such as the normalization of harassment and the diminishing idea that women in this line of work are actually looking for a man.

Most of the studies on gender in the environment of the construction site analyzed are limited to studying the prejudices, gaps, difficulties and struggles faced by women in the workspace. In addition, it should be recognized that among the 17 sustainable development objectives (SDGs) established by the UN, there is the objective of achieving gender equality and empowering all women and girls (SDG number 5). Within the Construction Industry, this objective may represent the promotion of sound initiatives and policies to promote gender equality and the empowerment of women at all organizational levels in the sector, and to end all forms of gender discrimination that can exist in the diverse and distinct existing work environments, guaranteeing the full and effective participation of women, as well as equal opportunities for leadership at all levels of decision-making.

In a smaller number, researches were identified with a broader approach to the concept of gender in this work environment. Silva et al (2016) addresses the influence of diversity on productivity in construction organizations and analyzes the low incidence of homosexual employees, people with disabilities and elders in construction. Barnard et al (2017) makes a study with LGBTQ employees who work in construction and researches the introduction of the queer community through the relationship with colleagues, the differences between working in the office and on the construction site, the safety of the work environment and connection between gender and sexuality. Chan (2013) presents a study on masculinities in the construction sector, in which he discusses differentiated masculinities and their impact on workers' personal and professional lives, through the implementation of Queer theory as a way to discuss equality and diversity in the construction sector.

It is noted that several studies aimed at analyzing the working conditions of construction workers indicate that construction site managers tend to limit themselves to the requirements of the applicable standards (Lombardi, 2017; Regis et al, 2019), which demonstrates the importance of these instruments in encouraging changes in the field in the search for a fairer and more welcoming work environment for all employees, regardless of their gender and biological sex.

According to Guillardi (2006), the growth in companies that adopt social responsibility in Brazil is mainly due to the pressure exerted by customers and the perception of being a positive practice for business, due to improved image, increased sales and productivity. In this context, there is the existence of the SA8000 standard, the first international certification of social responsibility, published in 1997 and based on the International Labor Organization (ILO), the Universal Declaration of Human and Child Rights of the United Nations (UN). The standard seeks to certify compliance with laws in the workplace. Therefore, adopting SA8000 certification means that the organization respects its employees and is concerned with ensuring a healthy and inclusive work environment.

Method

This research has an exploratory character and was developed in two stages: Bibliographic review (Stage 1) and Systematic analysis of the standards (Stage 2).

The first stage consisted of a bibliographic research on the subject, gathering knowledge both in the historical and general scope on gender studies, as well as in the context related to the physical and organizational structures of the construction sites in view of the diversity of genders. The search terms used in the literature review were a combination of two or more of the following expressions: “gender”, “diversity”, “gender diversity”, “diversity management”, “queer”, “sexual orientation”, “gay”, “Lesbian”, “transgender”, “LGBT”, “inclusion” and “equality”, associated with “construction site”, “construction”, “civil engineering”, “construction industry” or / and “building”. From the reading of the abstracts, 83 articles were pre-selected. Then, only articles that involved interviews with construction site workers or from construction sectors were selected and read in full. At this stage, 30 national and international works related directly to gender studies at the construction site in the last 10 years were identified. Of this total, nine national articles were selected and analyzed in greater depth to identify the aspects of analysis used in the second stage of the work (Table 1).

Table 1: Selected Research

Selected research	Authors identification	Method	Analysis type	Construction sites analyzed	Sample quantity	Sample typology
Lombardi (2017)	SR1	Semi-structured interviews	Qualitative	-	81	Management and employees
Landerdahl et al (2015)	SR2	Semi-structured interviews	Qualitative	1	8	Employees
Santos et al (2016)	SR3	Semi-structured interviews	Qualitative	-	62	Management and employees
Romcy (2013)	SR4	Unstructured interviews	Qualitative	1	16	Management and employees
Rocha (2017)	SR5	Semi-structured interviews	Qualitative	4	15	Employees
Regis et al (2019)	SR6	Structured interviews	Qualitative	-	17	Management and employees
Silva et al (2016)	SR7	Semi-structured interviews	Qualitative	6	12	Management and employees
Barnard et al (2017)	SR8	Unstructured interviews	Qualitative	-	16	Employees
Chan (2013)	SR9	Semi-structured interviews	Qualitative	-	9	Management and employees

Analysis of Results

Table 2 presents an overview of the analysis variables adopted by the gender studies identified.

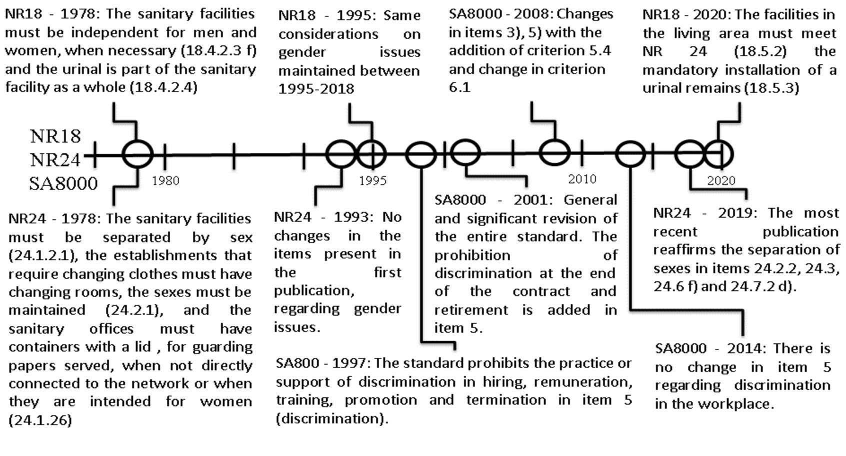
In relation to the topics covered in the interviews, the research by Lombardi (2017) contemplates the following matters: gender discrimination, exploitation at work, moral and sexual harassment, relationship with colleagues and leadership, motherhood, safety and reduction and underestimation of technical capacity. Landerdahl et al (2015) prioritized the work process, relationships with other colleagues and what it is like to work in construction. Santos et al (2016) analyzes direct work with women in the construction sector, considering the professional relationship, position, discrimination about the place and role of women and men in the workspace. Romcy (2013) seeks to understand relationship between genders, work hierarchies, social differences and interaction strategies. Rocha (2017) observes the task distribution, qualifications and insights about the work in construction. Regis et al (2019) assesses the acceptance of women's participation in construction sites, well-being; facilities, gender awareness and good practices. Silva et al (2016) considers in their observations the relationship between colleagues, gender diversity and discrimination in the construction sector. Barnard (2017) contemplates the relationship with colleagues and leaders in the work environment, sexual orientation, discrimination and presents practices of inclusion in construction. Chan (2013), through the study of masculinities, observes the gender diversity in the sector, harassment, discrimination through the relationship with colleagues and leadership and brings practices of inclusion into the construction environment.

Table 2: Comparative analysis of the analysis variables

Analysis variables	Comments	SR1	SR2	SR3	SR4	SR5	SR6	SR7	SR8	SR9
Diversity management	Actions and measures that focus on gender diversity in the workplace in the construction sector.	X	X	X	X	X	X	X	X	X
Harassment and Security	Feeling of insecurity of the individual due to inadequate structure, humiliating actions and embarrassing practices that lead to sexual and moral harassment.	X				X	X	X	X	X
Discrimination	Practices that differentiate a group or individual according to gender and sexual orientation, involving aspects such as motherhood, sexist distribution of work, gender roles and diminishing technical capacity.	X	X	X	X	X	X	X	X	X
Relationship with peers and leaders	Social relationships coexistent between coworkers and leaders	X	X	X	X	X	X	X	X	X
Good practices	Measures that consider the inclusion of diversity in the construction environment.		X			X	X		X	X

Figure 1 presents an analysis of the evolutionary process of the requirements of NR-18 (ABNT, 2020), NR-24 (ABNT, 2019) and SA8000, highlighting those that refer to gender issues.

Figure 1. Evolutionary process of norms on gender issues



It is observed that little has been indicated of the evolution of NR18 and NR24, regarding the management of gender issues. Currently, NR18 (ABNT, 2020), in its article 18.5.2., shows that the facilities must "comply, when suitable with the measures of NR24 (Sanitary and Comfort Conditions in the Workplaces)", while article 18.5.3. requires the installation of 1 urinal for every 20 (twenty) workers, which does not apply for female workers.

Table 3 indicates the principal requirements in NR24 and SA 8000 related to gender diversity. Table 4 lists the analysis variables identified in the bibliography with the conditions regarding gender issues in the current versions of the NR 18 (ABNT, 2020), NR24 (ABNT, 2019) and SA8000 standards.

It is possible to observe that the regulatory standards (NR18 and NR24) present an apparent insertion of women in the work environment and in the Construction industry by indicating the need to separate sanitary facilities between men and women. However, the lack of obligation results in workplaces with bathrooms only for male workers (Lombardi, 2017; Regis et al, 2019). Nothing is mentioned in the measures regarding gender, only biological sex. The indication of only two genders in the regulation, such as "men" and "women", shows how Brazilian culture and the work environment are tied to a narrow understanding of gender, excluding other parts of the population that do not identify with the dichotomies presented, as the trans population.

Table 3: Requirements in NR-24 and SA 8000

NR24	SA 8000
"The minimum proportion of a sanitary facility must correspond each group of 20 (twenty) workers or fraction, separated by sex." (24.2.2); "In establishments with commercial, administrative or similar functions, with up to 10 (ten) workers, only one individual toilet facility in common use between the sexes may be provided, provided that privacy conditions are guaranteed." (24.2.2.2); "The toilet bowls must have toilet paper with support and container for disposing of used paper, when it is not allowed to be disposed of in the toilet bowl itself, the container must have a lid when it is destined for women." (24.3.d).	"The organization must provide a safe and healthy work environment and take effective measures to prevent potential health and safety incidents and occupational injuries or illness that may occur, those being associated with or happening during the course of work. " (3.1); "The organization must not engage in or support discrimination [...], based on race, national, territorial or social origin, social class, birth, religion, disability, sex, sexual orientation, family responsibilities, marital status, association with union, political opinion, age or any other condition that could lead to discrimination ... " (5.1);
"Kitchens must have their own toilet for the exclusive use of workers who handle edibles, separated by sex." (24.6.f) "Dormitory accommodation must be separated by sex." (24.7.2.d)	"The organization must treat all personnel with dignity and respect. The organization should not engage in or tolerate the use of corporal, mental or physical coercion and verbal abuse of people. No aggressive or inhuman treatment is allowed." (6.1)

Table 4: Relationship between the variables and the NR18, NR24 and SA8000 standards

Analysis variables	Comments	Analysis of the applicable regulatory aspects
Diversity management	Lombardi (2017) presents an account of an engineer, whose workmate did not want to hire an intern to work on the construction site and used as a justification the fact of not having a bathroom for her. Regis et al (2019) presents an intern's report on a project that stated that the need to find a bathroom for her occasioned in reluctance to hire her.	NR 18 (ABTNT, 2020) states that sanitary facilities should be independent for men and women, when necessary. The lack of obligation in the standard makes situations identified by Lombardi (2017) and Regis et al (2019) even more present within the Construction.
Harassment and Security	Lombardi (2017) brings an account of an engineer works who experiences the undermining and underestimation of her abilities repeatedly, an act that characterizes moral harassment. Rocha (2017) noted that all the constructions visited had establishments separated by sex, and the dressing room was the most comfortable place for women.	NR18 (ABNT, 2020) and NR24 (ABNT, 2019) do not refer to harassment in the workplace nor do they address practices to make the environment safer for minority groups. According to Rocha's report (2017), the works comply with the anticipated in NR 18 and NR 24, creating a favorable environment for the insertion of women within the sites.
Discrimination	Romcy (2013) brings the testimony of a construction engineer who heard in interviews that they preferred a man to a woman for the job, despite their qualifications. Chan (2013) presents the report employees who were discriminated against after disclosing their sexual orientation at work.	According to these reports, organizations do not comply with the anticipated in items 3 (Health and safety), 5 (Discrimination) and 6 (Disciplinary practices) of the SA8000 standard. Regulatory standards NR18 and NR24 do not refer to this topic.
Relationship with peers and leaders	Regis et al (2019) presents the report of professionals who claim not to have a lot of relationship with colleagues, as it is a masculine environment. Barnard et al (2017) presents the	According to these reports, organizations do not comply with the provisions of items 3 (Health and safety), 5 (Discrimination) and 6 (Disciplinary practices) of the SA8000

	report of a gay man who became completely ignored by his co-workers when they learned about his sexual orientation.	standard. Regulatory standards NR18 and NR24 do not refer to this topic.
Good practices	Barnard et al (2017) brings the report of a trans man who sees the workplace as a safer place than his home and who, had it not been for the support he received, would have become more of a suicide statistic for transgender people.	It is possible to observe how the work environment can be a place of inclusion and respect, going according to item 6 (Disciplinary practices), of SA8000, creating an environment open to diversity. Regulatory standards NR18 and NR24 do not refer to this topic.

It is necessary to insert topics in the regulatory standards regarding inclusion and support for diversity, in order to make the construction environment more comfortable and with a greater sense of belonging for workers. In addition, the mental health of members must be studied within the conditions of safety and well-being at work, since discrimination affects the work environment and the worker's performance, which could result in physical and psychological damage. Item 18.14 of the NR18 regarding training could determine the anticipation of training for all members in order to make the work environment a welcoming and inclusive place. NR24 should prohibit discriminatory practices in the workspace and living areas, as well as mandatory SA8000 certification in the construction sector and in the work environment.

Conclusions

Most of the analyzed works contain qualitative research methodologies focusing on the perception of the worker, based on data collected in semi-structured interviews and all addressing gender diversity in Construction and analysis of gender roles, however a large part focused on presence of women at the construction site. Through the study of NR18 and NR24, it is noticeable its obstacle before diversity both in the job market in general, and within the construction sites. The existing context allows situations of disrespect and prejudice towards professionals due to biological sex, sexual orientation and gender roles. Despite the existence of SA8000, which addresses discrimination in the work environment, it has a voluntary character, therefore, the lack of mandatory standards nurtures harmful and sexist workspaces without diversity.

Here, there is a need for studies aimed at preparing the construction industry for adequate management of existing gender diversity, in order to identify good practices for the insertion of all groups. It is necessary to transform the construction industry into an inclusive environment, of diversity and equality, which can transform realities by employing a large amount of labor, without basing its hiring on factors such as race, gender, sexual orientation, age, religion, disability or any other aspect. It is understood as fundamental to update the current norms, to promote the inclusion of gender in the sector, foreseeing here homophobia and transphobia as a crime of racism, in order to create within the construction sites a nurturing environment for all people.

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Barriers to Social Support in the Mental Health and Wellbeing of Construction Workers in Emerging and Developing Economies: A Systematic Review

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Abstract

The purpose of this research is to examine the barriers to social support in mental health and wellbeing in emerging and developing economies' (EDEs) construction industry. Social support plays a pivotal role in the mental health and wellbeing (MHW) of the people including construction professionals and improves work efficiency, productivity and business performance. However, the barriers to providing it has received little attention. Using systematic literature review where Scopus and ScienceDirect were searched complemented with the citation approach, relevant literature was critically reviewed, analysed and discussed. The barriers to social support occur at four levels namely individual, community including family, organisational and national. While there is a lack of social support for MHW, lack of awareness of what MHW encompasses remains one of the key barriers to support from communities. This tends to be exacerbated by the lack of adequate MHW awareness programmes in EDEs. Social support in MHW is also hindered by the lack of adequate legislation and regulatory framework, which in some cases may be discriminatory. This discrimination against some workers is also reported at community and organisational levels. A key theme that emerged is the lack of enabling platform for social inclusion and relationship of which without these, there cannot be social support in MHW. The study contributes to the body of literature in MHW in EDEs, especially in relation to social support in MHW of construction workers which is underexamined. In improving MHW in EDEs there is a need for improved awareness at the grassroots level with a focus on re-engineering cultural, national and organisational beliefs toward it. The revision of the national policy and legislation will support mental and wellbeing in many EDEs.

Keywords: social inclusion, social exclusion, social network, psychological wellbeing, psychosocial.

Introduction

Workers drive the economy of countries and organisations, especially in the construction (building and civil engineering) industry (Maqsoom et al. 2018). The industry is fundamental to meeting the Sustainable Development Goal 9 — Build resilient infrastructure, promote inclusive, sustainable industrialisation and foster innovation. However, psychosocial stressors (stressors from the psychological and social aspect of work) including social relationships, job content and the high load from it and, methodology of work organisation, require a lot from workers socially and mentally and impact on productivity (Maqsoom et al. 2018). This results in suicide and mental health illness such as depression and anxiety. Studies such as King et al. (2019) report a higher risk of suicide in the construction industry when compared with other industries in Australia. This is echoed by the Chartered Institute of Building— the number of construction that contemplated suicide in 2019 is 27 per cent (Global Construction Review 2020). Mental health also has economic implications. For instance, in 2016/17, £34.9 billion was lost to the poor mental health of workers in the UK because of presenteeism, sickness absence and staff overturn (Centre for Mental Health 2017).

While studies (for example Alrasheed 2015; Alsubaie et al. 2019; Pidd et a. 2017) show that social support improves and sustains the mental health and wellbeing (MHW) of people including construction workers, Love et al. (2011) found a co-relationship between social support for construction workers and, their work efficiency and improved productivity. Similarly, Yuan, et al. (2018) show that strong social support has positive influence on work efficiency and productivity. Additionally, there is a consensus that social support theory is one of the theories that explain the psychosocial stressors in relation to construction workers in that 'social relationship affected the health and performance of a person' (Maqsoom et al. 2018: 1882).

However, construction workers (including those in EDEs) lack social support for their MHW (Alrasheed 2015; Alsubaie et al. 2019), migrant workers in EDEs report worse cases (Alrasheed 2015). Social support exists in a social network at societal level (Government on construction site), family and/or friends' level (social relationship with others) and organisational (between construction companies and workers) (Alrasheed 2015; Yuan, et al. 2018; Maqsoom et al. 2018). Despite the imperativeness of social support for the MHW of construction workers and implications for work efficiency and improved productivity, there is limited understanding in some areas in this regard. For example, the reasons for the limited and/or non-existent social support for the MHW of construction workers are poorly understood and has received very little (if not no) attention in research in EDEs. As a result, focusing on EDEs, the study examines social support in mental health and wellbeing toward unearthing the barriers to provision to construction workers in regard to their MHW. Gaps in knowledge in the area are also highlighted, showing possible empirical enquires.

Drawing on House (1981), Heaney and Israel (2008: 190) define social support as '…the functional content of relationships that can be categorised into four broad types of supportive behaviours or acts': Emotional support; Instrumental support, Informational support and Appraisal support. The intention of offeror or sending of social support is to help the recipient; hence an intentional positive interaction between them (Heaney and Israel 2008).

Context

Social support and Mental health and well-being

Heaney and Israel (2008) and Cutrona and Suhr (1992) observe that social support is a component of social network with four types of support in it: emotional support where nurturing [e.g. love, empathy, trust and care] are provided; informational support occurs when message (including knowledge and fact) in terms of advice, suggestion or other information for addressing a problem is provided [e.g.

advice to how to carryout work where recipient has limited skills which is reduced productivity hence causing stress]; instrumental support is where aid and services which directly assist the person in need is provided but must be tangible [e.g. financial assistance]; appraisal support relates to constructive feedback and affirmation — the information that the person in need will use for self-evaluation [e.g. pointing out strength that the recipient may have overlooked which will help them]. However, all can come from one source or relationship (Cutrona and Suhr 1992). By implication, the above submits that in the absence of functional relationship between the parties, a platform to stimulate and instigate the relationship, trust, communication and, a good understanding of the recipient, there will be no effective social support.

There is evidence that low social support from the community or workplaces has negative implications for the health and wellbeing of people but, strong social support has positive implications for the MHW of people. For example, Pidd et al. (2017) found that workplace social support moderates the effect of workplace bullying and job stress on the psychological wellbeing of young construction apprentices in Australia. By implication, this indicates that with adequate support in the workplace, the workers are mostly likely to be better equipped to deal the workplace bullying and job stress that have negative implications for their psychological wellbeing (Pidd et al. 2017). The same is applicable in many EDEs. For example, in the Saudi Arabian construction industry, Alrasheed (2015) observe that while there is limited social support from the community, workplace and the government for construction workers, migrant workers from EDE experience humiliating hostility from the community, government policies and workplaces.

Methodology

The research question of the study was addressed through systematic review of literature. Following discussions between the authors, keywords for the search were agreed. Table 1 presents a flow diagram of the process followed by the papers used in the review. The search was conducted on 06 July 2020 and 11 July 2020 using two databases, Scopus and Science Direct.

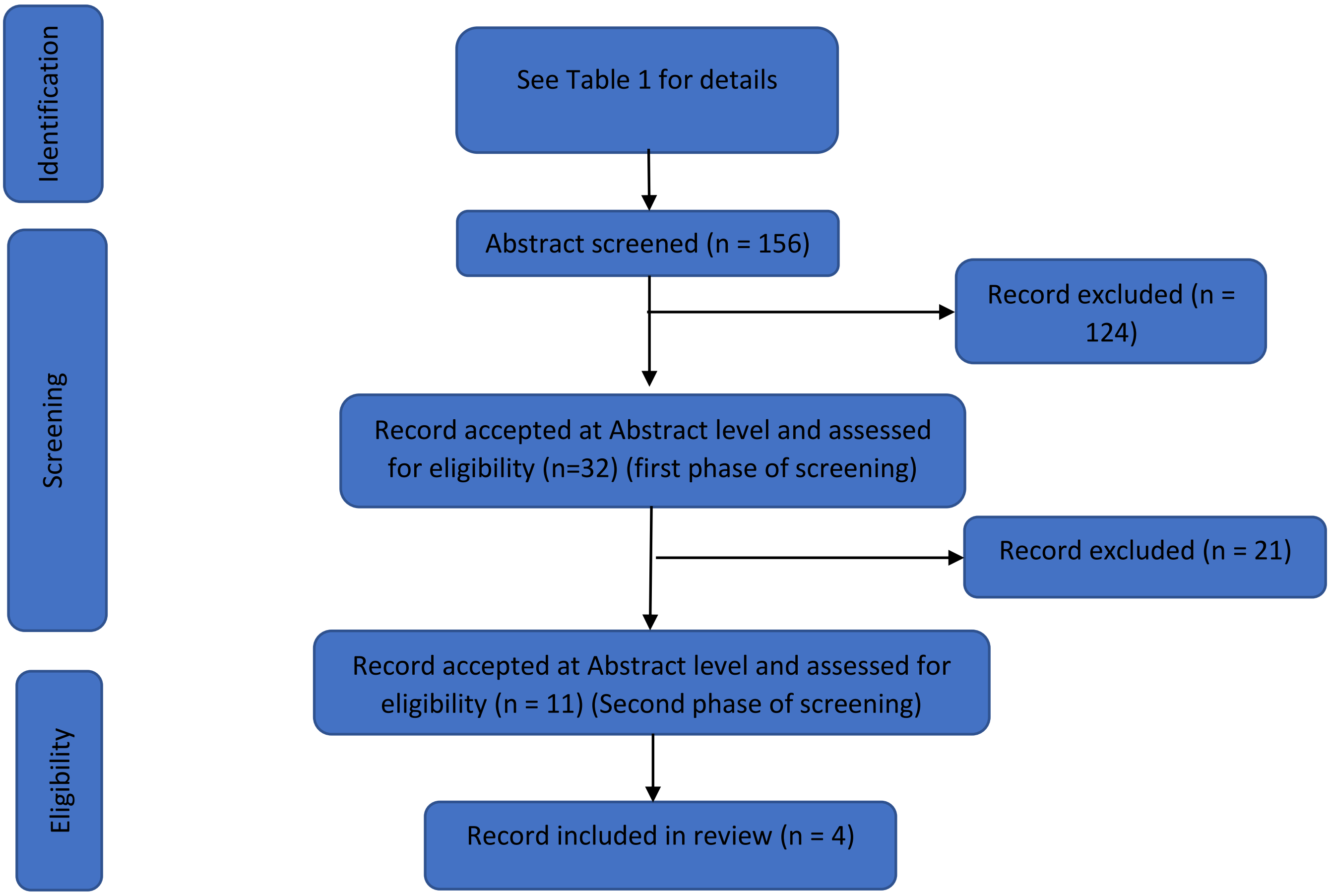

Figure 1: Flow diagram of study selection of papers used for the systematic review.

Searching two databases from 2001 till 2020 and 2011 till 2020 means that relevant publications in Web of science, Google Scholar and PubMed and outside this range of year will be omitted. While two databases are still enough to offer adequate insight into the subject, the citation approach aimed at complementing this. In the citation approach, the references of materials (e.g. books and journal articles) are searched towards finding relevant materials that can be used. Author such as Umeokafor (2018) have adopted this approach to complete the systematic literature search.

Table 1: Identification section for Figure 1

Search approach/ Database; (Search date)	Keywords; location of search; and n: no before limits where applicable)	Limits: PUBYEAR; DOCTYPE and Subject area; Country; n= no after limits
Science Direct (06 July 2020)	‘Mental AND health’ and ‘Mental AND Wellbeing’ and ‘Construction AND Industry’ in TITLE-ABS-KEY (n- 1123)	2011 to 2020, Top cited journals, Safety Science, Social science and medicine’. (n= 62)
Citation approach	(n=6)	NA
Scopus (06 July 2020)	‘Mental AND health’ and ‘Mental AND Wellbeing’ and ‘Construction AND Industry’ on TITLE-ABS-KEY.	2001 till 2020; ‘Business, management and accounting’, ‘Engineering’, social science’ and ‘Environmental sciences’. (n= 14)
Scopus (11 July 2020)	‘Social AND support’ OR ‘social AND inclusion’ AND ‘mental’ AND health’ AND ‘construction’ AND industry’ AND ‘developing’ AND ‘countries’ OR ‘mental’ AND ‘wellbeing’ in TITLE-ABS-KEY	2000 to 2020; conference papers and journal articles. (n=1)
Scopus (11 July 2020)	‘Social’ AND ‘support’ OR ‘social’ AND ‘inclusion’ AND ‘mental’ AND ‘health’ AND ‘construction’ AND ‘industry’ in TITLE-ABS-KEY	2000 till 2020; ‘Business, management and accounting’, ‘Engineering’, social science’ and ‘Arts’. (n=8)
Scopus (11 July 2020)	‘Social AND support’ OR ‘social AND inclusion’ AND ‘mental’ AND ‘health’ AND ‘construction AND ‘industry’ OR ‘mental’ AND ‘wellbeing’ in TITLE-ABS-KEY (n=2839)	2000 to 2020; conference papers and journal articles; ‘Business, management and accounting’, ‘Engineering’, social science’ and ‘Environmental sciences’; for countries see * (n=65)

*Hong Kong, India, South Africa, Taiwan, Mexico, Pakistan, Brazil, Malaysia, Ghana, Uganda, Nigeria, Ethiopia, Saudi Arabia, Colombia, Kenya, Sri Lanka, Philippines, Viet Nam, Zimbabwe, Bangladesh, Nepal, Cameroon, Kuwait, Malawi, Qatar, United Arab Emirates, Argentina, Georgia, Jamaica, Palestine, Rwanda, Chad, Cuba, Guatemala, Indonesia, Iraq, Lesotho, Namibia, Paraguay, Peru, Puerto Rico, Senegal

In all, four studies were included in the reviews (Figure 1). It is tempting to argue that using four studies for the review is too small hence the findings are limited. Such arguments should be with caution as there are many systematic reviews that have been conducted with no studies meeting their inclusion criteria hence empty reviews (Yaffe et al. 2012). Yaffe et al. (2012) offer a treatise on this including demonstrating that the number of studies used in systemic review does not make the study limited and the empty reviews is a culture and acceptable in academia. However, they acknowledge the risk of bias and the risk associated for users including decision makers. While Yaffe et al. (2012) focuses on 'Cochrane Library is the largest and perhaps best recognized global collection of health care evidence, currently hosting more than 4,500 systematic reviews in its Cochrane Database of Systematic Reviews (CDSR)' the same arguments can be made for the current study and the built environment research.

The argument should not be misconstrued as soliciting for empty reviews or review of small sample, rather that the number of studies that meet the criteria for inclusion should not hinder a systematic review. However, the methodology including the search criteria and keywords should be detailed. The review of the literature was conducted thematically, and the summary of the findings presented in Table 2. While reading the materials used for the review, implicit and explicit meanings were sought. Questions asked were not limited to: What is happening here? What is missing here? What implications do these have for the provision of social support in terms of the MHW of construction workers? What are the barriers to social support in MHW? The analyst has little preconceived ideas of possible codes; hence started with this.

Findings, Analysis and Discussion

Profile of literature used in review

Although limited to two databases, Table 2 shows the extensive search and outputs. However, the relevant studies are limited suggesting the gap in knowledge in the area. Table 2 also submits the areas covered by the literature despite a broad search of developing countries and limiting another search to 42 EDEs as shown in Table 1. Umeokafor (2018) shows that a lot of academic in EDEs, especially Africa, publish in conferences and journals which may not be indexed in Scopus and may not even be peer-reviewed. The implication is that these studies will not be captured in a systematic review as the current study. Understandably, academics in some developing countries face challenges and barriers such as low acceptance rate in high raking journals and the long peer-review and publication period (Adjei and Owusu-Ansah, 2016).

Table 2: Studies used in the review

Author details	Title	Scope and type
Alrasheed (2015)	A socio-ecological framework for improving the psychological health of foreign workers in developing countries: the case of Saudi construction industry	Saudi Arabia, PhD Thesis
Maqsoom et al. (2018)	Intrinsic psychosocial stressors and construction worker productivity: impact of employee age and industry experience	Pakistan, Journal article
Yuan, et al. (2018)	Evaluating the impacts of health, social network and capital on craft efficiency and productivity: A case study of construction workers in China	China, Journal article
Peng and Chan (2020)	Adjusting work conditions to meet the declined health and functional capacity	Hong Kong, Journal article

	of older construction workers in Hong Kong	

Discrimination

While discrimination against mentally ill people is extensively reported in literature (for example Hall et al. 2019), it is revealing that this is also a barrier to social support for the MHW of construction workers. For example, Alrasheed (2015) found legislative-support discrimination against migrant workers from EDEs in Saudi Arabia and discrimination by locals and unions. In particular, migrant workers in dire need of social support for the MHW do not receive this because government laws restrict local community organisations from offering services to foreign workers irrespective of their condition (Alrasheed 2015). Importantly, migrant workers including experts make up 76 per cent of employed people and 80 per cent of the private sector in Saudi as at mid-2018 (De Bel-Air 2018).

While Saudi Arabia is infamous for discrimination (Jessup n.d), the extent of discrimination in other EDEs may need to be examined but there is evidence of gender discrimination in OSH legislation in some EDEs (Ncube and Kanda 2018). However, the level of discrimination in some EDEs may be lower than reported in Saudi. The discriminatory legislation in EDEs may be attributed to their outdated nature and the little attention that OSH receives. Countries such as South Africa have anti-discriminatory legislation.

On a different point, the lack of concern from the trade unions who are supposed to protect the interest of the workers is worrying (Table 3). The points so far show the need to understand, through empirical examination, the extent to which the various sources and levels of discrimination of workers impact on social support with regards to MHW.

Table 3: Summary of the findings

Themes	Subthemes	Factors and supporting evidence and sources
Discrimination	Inequality	Little concern from unions for migrant workers as against non-migrant (Alrasheed 2015).
		Discrimination against migrant workers by locals (Alrasheed 2015).
	Discriminatory policies and legislation	Government laws prevent local community support organisation from offering support to migrant workers in dire need (Alrasheed 2015)
Policy and Regulation	Legislation and regulation	Unsupportive Government laws (Alrasheed 2015).
		Lack of relevant legislation that support such (Alrasheed 2015).
		Lack of adequate regulation of existing legislation (Alrasheed 2015; Yuan, et al. 2018)
		Lack of adequate governmental support (Yuan, et al. 2018)

	Inability of co-workers to support	Inability of co-workers (especially the older ones) to support the less experienced ones through advance and guidance because of limited experience (Maqsoom et al. 2018).
		Lack of commitment to organisation by senior staff (Maqsoom et al. 2018).
	Lack of cohesion and interaction	Lack of cohesion among co-workers in work group because there is a lack of work-related problem discussions casually (Maqsoom et al. 2018).
No Platform for socialisation or relationship		Lack of interaction between workers and supervisor (Peng and Chan 2020)
		Lack sustained socialisation because limited interaction in project team or organisation (Yuan, et al. 2018)
	Lack of communication	Lack of communication (Yuan at al. 2018; Peng and Chan 2020)
	No enabling environment	No enabling environment for workers to form social support groups in organisations and nationally (Alrasheed 2015).
		Limited support from organisation or employers for social support programmes of activities (Yuan, et al. 2018).
		No designated support source (Peng and Chan 2020). Lack of confidence in source of social support (Peng and Chan 2020).
		Lack trust may not provide the environment for interaction (Peng and Chan 2020)
Stakeholder factors	Ignorance of locals and organisations.	Disregard for migrant workers by locals because of ignorance and poor understanding; Disregard from organisations (Alrasheed 2015)
	Low priority for unions and government	Little concern from unions for migrant workers as against non-migrant (Alrasheed 2015).
		Lack of interest from the government (Alrasheed 2015; Yuan, et al. 2018)

Policy and Regulation

Studies such as Umeokafor et al. (2014) and Ncube and Kanda (2018) demonstrate that EDEs lack adequate occupational safety, health and wellbeing legislation and regulatory environment. While they are fragmented, overlook some pertinent areas and are outdated, the expectations of International Labour Organisation and World Health Organisation expects are yet to be codified at national level in some the occupational safety and health (OSH) legislation (Ncube and Kanda 2018). As a result, the related findings in the current study as Table 3 shows is expected but disappointing. For example, Yuan, et al. (2018) observe that lack of adequate regulation that should drive social support in MHW through more enforcement (e.g. health checks) and adequate legislation. Similarly, lack of legislation and regulatory framework that address MHW is reported Saudi Arabia (Alrasheed 2015). The discriminatory feature of the extant or associated legislation are already reported (Table 3) and discussed in the preceding paragraph in detail including that similar discriminatory legislation are in some other EDEs (Ncube and Kanda 2018). Granted the evident role of policymakers and governments in ensuring adequate OSH regulatory framework and legislation, there is the need for companies to pay more attention to supporting the workers in various ways such as health promotion and training and ensure that workers have adequate working hours (Yuan, et al. 2018).

No Platform for socialisation or relationship

The findings of Maqsoom et al. (2018) suggest that older and/or experienced workers are only able to help when they have the ability. Typically, they found that younger or less experienced workers face challenges in work because of lack of skills and experience hence the older and/or more experienced ones offer advice or guidance to them where they can. However, the older workers’ expectations are limited and realistic such as not expecting a reduction in workload from co-workers. If these younger workers do not receive the relevant support at work, their work efficiency is most likely to reduce which makes them feel stressed (Maqsoom et al. 2018).

This highlights a possible shift in employer responsibilities to older workers at best and exploitation of the older workers by the employers at worst. It is naïve to argue that the workload of the older workers will not increase which is already reported as high; they would appreciate a similar support as the younger ones. Given this obligation that the older workers have for the younger ones, it is likely that when they are unable to help, it may affect their mental health. It will be good to understand whether the support the older workers offer is because of working culture or morality.

Maqsoom et al. (2018) found that lack of young (inexperienced) workers ‘feeling valued, cared for and supported by their supervisor or co-worker’ is a psychosocial stressor. Hence, the question is why would workers not get this from their supervisor or co-worker? Many factors may account for this which may make workers (supervisors included) less committed to work. For example, studies such as De Witte and Naswall (2003) evidence a negative association between job insecurity and workers’ commitment to organisation. In other words, if employers feel insure in their jobs, they are likely to be less committed to the organisation. Similarly, conflict and/or ambiguity in roles may lead to role stress for supervisors resulting in some function being ignored or poorly performed (Maqsoom et al., 2018). The same is applicable to work related fatigue for the supervisor, due to excessive workload (Useche et al., 2017) which was established to result in reduced job performance with implications for the mental health and wellbeing of the workers including supervisors (De Vries et al. 2003). There is the need to test whether the level of worker satisfaction with organisation determines whether they will support other co-workers. It will also be insightful to know if worker satisfaction determines their level of satisfaction with social support and at which level.

Lack of cohesion or interaction between the workers and employers or the person acting on behalf of the employers is also an important barrier to social support in MHW. Studies indicate that there needs to be a close relationship between the parties of which without adequate cohesion and interaction, this will not occur as the enabling environment for social support is not created. For example, Maqsoom et al. (2018) found that lack of cohesion among co-workers in work group occurs because there is a lack of work-related problem discussions casually. Similarly, in Yuan et al. (2018), it was observed that lack of sustained socialisation because of limited interaction in project team or organisation does not enable the relevant environment for social support in MHW.

This relationship cannot exist if there is lack of trust and confidence. The implications of the findings of Peng and Chan (2020) include that some barriers to social support to MHW in construction include the level of workers' confidence in the sources of support, the level of reliability of the information thereof, the proximity in the source of support and the willingness of the supporter (the supervisor) to help when needed. If there is strong support from organisation or employers for social support programmes of activities, the right environment will be created (Yuan, et al. 2018). This source of support and information must also be clear and accessible to the workers (Peng and Chan 2020) to encourage the workers and make them have a sense of belonging. However, it is important to ensure that any social support is worker-focused both in terms of design and implementation. The points so far also highlight the role of relationship between the workers and supervisor and trust hence no environment for interaction. Possible propositions include that the higher the level of trust between supervisor and worker, the more likely the collaboration or relationship in social support will improve the MHW of workers.

Stakeholder factors

The findings of the review show that social support is at four levels, individual, community (including family), organisational and national which is consistent with the points made elsewhere in this paper. It suggests that roles of multiple stakeholders at different levels exist, but there is little evidence to suspect any complexity in the interactions where applicable. Most importantly, the findings point to the disappointing counterproductive activities of those that should be protecting the MHW of workers; rather they have failed the workers. Specifically, in the study of Alrasheed (2015), there is evidence of disregard for migrant workers by locals because of ignorance and poor understanding of the nature of work they do and the imperativeness of social support to them. This is also seen in companies as the workers experience inhumane treatment e.g. using abusive words (Alrasheed 2015). However, while it can be argued that the local and organisations exist in a system in Saudi that had failed the workers hence nothing is expected, it is important to point that such condition may not be applicable in the other parts of EDEs.

This also shows lack of interest which also was reported against other stakeholders, the trade unions and government (Table 3). Other studies also echo the limited attention on OSH including MHW from the government in EDEs (Umeokafor et al. 2014). This limited attention (if from government agencies) mainly focuses on occupational health, preventing attention on barriers to social support outside the work environment. However, some EDEs have social protection programmes that focus on improving the mental health of people. For example, Angeles et al. (2019) found that unconditional cash grant can improve the MHW of youths in Malawi. This scheme is part of a larger social protection scheme in the Sub-Saharan Africa (Angeles et al. 2019). Consequently, it cannot be argued that this lack of support is widespread in EDEs; neither is it expected to be worse in poorer EDEs as Saudi Arabia and Malawi have opposite development status. The latter is the world's least developed countries while Saudi Arabia is the largest economy in the Middle East. Also, China is a larger economy but poor governmental interest in the MHW of workers is also reported. This shows the need for country-specific studies to provide more accurate responses. A possible explanation is that the MHW of people is a top priority to the Malawian government, but the reverse may be the case for Saudi Arabia.

Conclusions and Recommendations

In meeting the United Nations Sustainable Development Goals including Goal 9, the mental health and wellbeing of people including construction workers need more attention. Aimed at identifying the barriers to social support in mental health and wellbeing in developing economies' construction industry, the study found that workers take-up the responsibilities to support co-workers when employers fail to do it. Social support is hindered by inadequate legislation and regulatory framework which can even be discriminatory against some workers e.g. migrant workers. The review shows that while some governments are unsupportive in improving workers MHW through social support, some are in the driving seat. However, the study indicates that the level of priority of MHW determines the level of support and whether they will support MHW with social support program. Further, the study emphasises the role that enabling environment plays in driving social support hence a barrier if unavailable. Typically, lack of trust and communication between workers and supervisors result in lack of cohesion between them hence relationships, a prerequisite for social support in MHW, will not be created. The need for organisations to support workers to form social groups in organisations and for the government to support this at national level is also a factor. There are also stakeholder related barriers such as ignorance from locals and organisations and the neglect from trade unions who are supposed to promote the protection of workers.

Given the positive implications of MHW for improved business performance and economies of countries, businesses and government should strive to educate themselves of these benefits and exploit them. There is the need for subtle strategies to get governments in EDEs more involved in MHW of worker, a recommendation for researchers. While a case has been made in the study for the 'limited' number of papers used in the review, it also shows the little attention that the area has received calling for more research. Hence, country-specific studies are recommended where all the factors in Table 3 will be surveyed to support or refute them. Further studies can also test the propositions and hypotheses noted in many places in the study. For example, working cultures in the construction industry does not influence the social support that older workers offer the younger ones. Also, the higher the level of trust between supervisor and worker, the more likely the collaboration or relationship in social support that will improve the MHW of workers.

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Mindfulness-based Stress Reduction Workshop: Reducing Stress and Improving Coping Behaviours of Construction Professionals

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Abstract

Construction professionals (CPs) often encounter stress during the work in the construction industry, which consequently induces different negative consequences at both individual and organization levels. Mindfulness-based stress reduction (MBSR) has been widely adopted for patients and various professionals. In order to investigate the impact of MBSR on the CPs in the industry, an intervention study consisting of 8-week workshop was conducted. A questionnaire survey was administered to two groups (a MBSR participant group, and a control group) before and after the MBSR workshops. The findings revealed that seven out of eight mindfulness characteristics items and two out of three coping behaviours items received significantly higher scores, while three out of five physical stress items got significantly lower scores among the MBSR participants in comparing with the non-MBSR participants. The results of the Pearson correlation also shown that mindfulness characteristics had direct influences on the CPs by reducing their physical stress and improving their coping behaviours. The study demonstrated the pivotal importance of MBSR training on CPs for reducing their stress by improving their mindfulness characteristics and coping behaviors. It is, thus, strongly recommended to introduce the MBSR program in the construction industry.

Keywords: Construction professional; Coping behaviors; Mindfulness characteristics; Stress.

Introduction

The construction industry is typically considered as challenging, threatening, and stressful (Wu et al., 2018). The complicated nature of construction projects including tight schedules, multi-deadlines, limited budgets, and poor workplace have been witnessed to exacerbate the stress level of construction professionals (CPs) (CIOB, 2006; Leung et al., 2014). Physical activities and demanding tasks are common in the construction industry (Abdelhamid and Everett, 2002). The difficulties faced by CPs are relatively much higher than other professionals in other jobs (Pinto et al., 2016). They need to contribute a large amount of physical effort in various construction tasks, for instance, surveying, executing, and operating the construction activities at different sites (Leung et al., 2014). Therefore, it is common for them to experience physical health issues, such as headaches, high blood pressures, high heart rate, and so on (Leung et al., 2008; Mellner et al., 2005). Indeed, these physical stress symptoms may be further harmful at both individual and organizational levels (Cooper and Dewe, 2008; Gatti et al., 2014).

In fact, a recent document indicated that 12.8 million days were lost in 2019 due to work-related stress, depression, or anxiety (Health and Safety Executive, 2019). In order to manage this stress, coping strategies are necessary for CPs to improve their physical and mental health (Erdem et al., 2017). In current decades, coping with stress via mindfulness practices has been well accepted by both clinical psychologists and medical doctors (Baer et al., 2004). Many previous studies have reported the effectiveness of mindfulness-based stress reduction (MBSR) workshops in the improvements of health, resiliency, performance, reduction of stress, and so on (Carmody and Baer, 2009; Levy et al., 2012). However, these beneficial impacts of the MBSR workshop on coping behaviors and physical stress among CPs in the construction industry have yet to be identified. Therefore, an innovative stress management strategy is needed urgently. Hence, the present study aims to reduce physical stress and improve coping behaviors of CPs through a MBSR workshop.

Mindfulness-Based Stress Reduction (MBSR)

Mindfulness is defined as an intentional effort to pay attention *non-judgmentally* on the *present moment* (Kabat-Zinn, 1994). It is featured by a focused and non-judgmental monitoring of present perceptions, emotions, and feelings without wandering in the past and future thoughts (Garland, 2007). Mindfulness could be measured in a broad concept with many characteristics, including *observation, curiosity, description, attention, beginner's mind, non-judgment, letting go*, and *decentering* (Kabat-Zinn, 1994; Leung et al., 2016). MBSR programs have been recognized as the most successful interventions for reducing participants' pain, stress, depression, and other physical health issues (Li and Bressington, 2019). Additionally, it has shown effectiveness in several psychological and physical health symptoms of professionals and the general public (Dobie et al., 2016; Simpson et al., 2019). Although many studies have reported that the practice of mindfulness leads to a substantial reduction of stress and improvement of wellbeing (Chiesa and Serretti, 2009; Garland et al., 2011; Jalali et al., 2019), it is little known for the CPs in the construction industry. Traditionally, MBSR workshops take the standard eight-week training program (2.5 hours/week), in which participants learn various mindfulness skills through both formal and informal mindfulness practices (Kabat-Zinn, 1994). The weekly class includes both mental and physical exercises, such as body scan, sitting meditation, hatha yoga, and mindfulness in daily activities (Hyland et al., 2015; Leung et al., 2016), which help the participants to tranquil their mind intentionally, and eventually to achieve inner peace (Ospina et al., 2007).

Physical Stress

Normally, stress refers to physical and emotional responses that appear when the demand on an individual exceeds with the available resources to cope with it (Leung et al., 2006; Liang et al. 2018). *Physical stress* arises due to physiological reactions that persist against stressful situations and result in high blood pressure, heartbeat rate, headaches, laziness, and so on (Azher et al., 2014; Leung et al., 2012). It is common for the CPs to work in a poor environment, for instance, annoying noise, dirty sites, extreme temperatures, inappropriate lighting, and so on, which can affect their physical health (Leung et al., 2009). Physical stress is still dominant in the construction industry and causes problems on the health and performance of the CPs. Several researches show that physical stress, such as high blood pressure, high heart rate, yawning, headache, and become drowsy have been reduced through MBSR (Li et al., 2019; O'Doherty et al., 2015).

Coping Behaviours

According to prominent transactional stress and coping model, appropriate coping can reduce the stress level of an individual (Chan et al., 2012; Lazarus and Folkman, 1984). This theory claims two main features of coping behaviours: problem-based coping and emotion-based coping (Hewstone et al., 2007). In the overall coping process, appraisal plays a key role. Primary appraisal followed by secondary appraisal decides the available resources, and efforts needed to cope with the events (Liang et al., 2018; Park, 2005). The initial evaluation of threatening event is primary appraisal (Ben-Zur, 2019), whereas secondary appraisal will assess available coping resources to control the stressful situations (Leung et al., 2014). The coping process comes into action when it seems suitable to deal with the circumstances (Chan et al., 2018). Therefore, coping behaviours refers to cognitive and behavioural efforts made by an individual for managing the external and internal demands (Haynes and Love, 2004; Lazarus and Folkman, 1984). It includes positive reappraisal (i.e., *rediscovering important things in life*), emotional support seeking (i.e., *leaving things open for somewhat*), and escapism (i.e., *refusing deep thinking*) (Chan et al., 2014).

Conceptual Model

Based on the literature review, a conceptual model for the Mindfulness Characteristics– Coping Behaviours–Physical Stress has been developed for CPs (see Figure 1). It demonstrates that mindfulness characteristics are related to the physical stress and the coping behaviors of CPs.

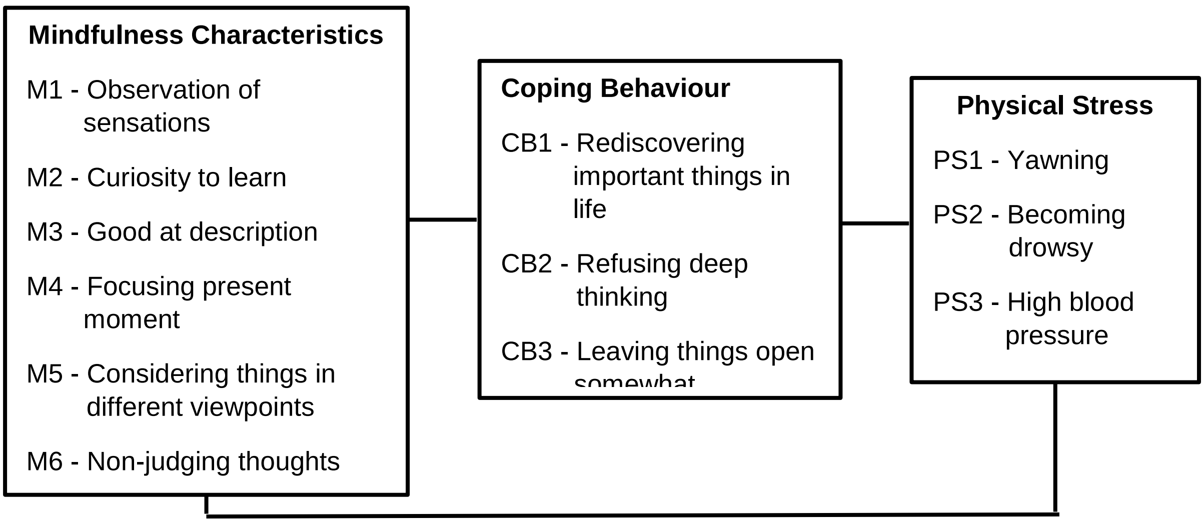


Figure 1 Conceptual Mindfulness Characteristics–Coping Behaviours–Physical Stress Model

Research Method

This research aimed to examine the impact of mindfulness characteristics on CPs via an intervention study. CPs were recruited to participate in MBSR training adopted from Mindfulness-Based Stress Reduction (MBSR) training workshop (Kabat-Zinn and Hanh, 2009). Participants in the standard 8-week MBSR training workshop (2.5 hours per week) were requested to conduct mindfulness practice at home for 30-45 min every day based on a CD (i.e., guided mindful practices in each week). Those who joined the 8-weeks full MBSR training workshops were considered a sample group, while a similar group of CPs who did not participate in the workshop was treated as a control group.

To secure better reliability, a validated questionnaire survey was used. A final set of questionnaires was designed consisting of 4 sections: demographic information, mindfulness characteristics (Baer et al., 2004; Walach et al., 2006), physical stress (Greenberg, 2017), and coping behaviors (Chan, 2011; Lazarus and Folkman, 1984). All members graded the levels of agreement using a seven-point Likert-type scale ranging from 1 (strongly disagree) to 7 (strongly agree). Participants in both groups were requested to answer the identical survey before and after the workshop, i.e., self-administer questionnaires. An *independent samples t-test* was carried out to find the differences in mindfulness characteristics, coping behaviors, and physical stress items. *Pearson correlation* was also used to examine the strength and direction of the relationships among items using SPSS version 26.0.

Results

Independent *t*-test

An independent samples t-test was conducted to identify the differences of mindfulness characteristics, coping behaviors, and physical stress between the MBSR group and the control group (see Table 1).

Table 1 t-test for Mindfulness Characteristics, Coping Behaviors, and Physical Stress

	Items	Pre-MBSR				Post-MBSR			
		Mean (P)	**Mean (NP)**	**Mean Dif.**	**Sig. (2-tailed)**	**Mean (P)**	**Mean (NP)**	**Mean Dif.**	**Sig. (2-tailed)**
	Mindfulness characteristics								
M1	Observation of sensations	4.308	1.702	1.713	0.238	5.846	3.231	2.615	**0.000**
M2	Curiousity to learn	4.154	1.463	0.967	0.507	5.231	3.231	2.000	**0.000**
M3	Good at description	3.539	1.561	1.536	0.042	4.615	3.308	1.308	**0.019**
M4	Focusing present moment	4.308	1.437	1.038	0.107	5.462	3.769	1.692	**0.002**
M5	Considering things different viewpoints	5.000	1.528	1.437	0.882	5.077	4.308	0.769	**0.049**
M6	Non-judging thoughts	4.231	1.166	0.961	0.754	4.615	4.308	0.308	0.502

M7	Letting go distress thoughts	4.385	1.557	0.776	0.818	5.000	3.539	1.462	**0.002**
M8	Experiencing self-separate from thoughts and feelings	3.692	1.437	0.870	0.120	4.846	3.615	1.231	**0.011**
	Coping behaviours								
CB1	Rediscovering important things in life	4.615	1.261	1.301	0.451	5.692	4.077	1.615	**0.001**
CB2	Refusing deep thinking	3.846	1.573	1.013	0.883	4.308	3.462	0.846	0.082
CB3	Leaving things open somewhat	5.154	0.987	0.961	0.055	5.308	4.385	0.923	**0.021**
	Physical stress								
PS1	Yawning	4.077	1.656	1.506	0.542	3.308	4.462	-1.154	**0.021**
PS2	Becoming drowsy	4.077	1.441	1.423	0.787	2.923	4.308	-1.385	**0.013**
PS3	High blood pressure	3.385	1.502	1.772	0.723	3.000	3.462	-0.462	0.507
PS4	High heartbeat rate	3.000	1.414	1.750	0.278	2.692	4.000	-1.308	**0.037**
PS5	Headache	2.923	1.188	1.871	0.092	3.154	3.923	-0.769	0.289

Notes: Bold text represents significant difference at 0.01 & 0.05 level (2-tailed); P=participant; NP=nonparticipant.

Before the training workshop, there was no any difference between the two groups. However, significant differences in most of the measurable items (mindfulness characteristics, coping behaviours, and physical stress) were revealed after the 8-week MBSR workshop. Among eight mindfulness items, seven items (except non-judging thought) showed significant differences between sample and control groups. The mean scores of all seven mindfulness items for MBSR group were significantly higher than the control group. Similarly, two items of coping behaviors (i.e., *rediscovering important things in life*, and *leaving things open somewhat*) were also scored significantly higher for the MBSR group than the control group. Interestingly, mean scores of all the physical stress items were reduced for MBSR participants in comparing with the control participants. Three physical stress items including *yawning*, *becoming drowsy* and *high heartbeat rate* were significantly reduced after the MBSR workshop.

Pearson's Correlation Analysis

In order to investigate the strength and direction of the relationships among mindfulness characteristics, coping behaviors, and physical stress items, Pearson correlation was adopted (see Table 2). The results showed that, out of eight mindfulness items, seven items demonstrated significant relationships with the three items of coping behaviors and the five items of physical stress. *Observation* of sensations (M1) is significantly related to CB1 and CB3, while *Good at description* (M3) and *Focusing present moment* (M4) associated with all coping behaviour items (CB1-CB3). *Curiosity (*M2), *Considering things in different viewpoints* (M5) and *Letting it go* (M7) significantly linked to both CB1 and CB2, while *Experiencing self-separate from thoughts and feelings* (M8) only associated to CB2.

On the other hand, *Observation* of sensations (M1), *Considering things in different viewpoints* (M5), and *Experiencing self-separate from thoughts and feelings* (M8) are significantly negatively associated with all physical stress items (PS1-PS5). *Good at description* (M3) and *Letting it go* (M7) negatively related to PS1-PS5 except for PS3, while *Curiosity* (M2) only has a significant relationship with one physical stress item (PS5). Out of the three coping behaviour items, only *rediscovering important things in life* (CB1) is significantly linked to all physical stress items (PS1-PS5).

Table 2 Correlation between mindfulness characteristic, physical stress, and coping behaviors

Note: "M" refers to Mindfulness; "CB" represent Coping behaviors and "PS" refers to Physical stress

** Correlation is significant at the 0.01 level (2-tailed).

	Items	CB1	CB2	CB3	PS1	PS2	PS3	PS4	PS5
M1	Observation of sensations	**0.623****	0.265	**0.403****	**-0.338***	**-0.341***	**-0.576****	**-0.395****	**-0.500****
M2	Curiosity to learn	**0.429****	**0.425****	0.194	-0.158	-0.147	-0.236	-0.054	**-0.488****
M3	Good at description	**0.470****	**0.307***	**0.431****	**-0.297***	**-0.352***	-0.251	**-0.404****	**-0.287***
M4	Focusing present moment	**0.554****	**0.303***	**0.503****	-0.113	-0.232	-0.194	-0.236	-0.128
M5	Considering things different viewpoints	**0.596****	**0.314***	0.270	**-0.405****	**-0.362****	**-0.447****	**-0.304***	**-0.405****
M6	Non-judging thoughts	0.107	0.130	0.207	0.031	-0.108	0.054	0.001	-0.053
M7	Letting go distress thoughts	**0.446****	**0.368****	0.219	**-0.412****	**-0.368****	-0.230	**-0.460****	**-0.489****
M8	Experiencing self-separate from thoughts and feelings	**0.458****	0.157	0.190	**-0.403****	**-0.363****	**-0.279***	**-0.375****	**-0.355****
CB1	Rediscovering important things in life	1.000	-	-	**-0.575****	**-0.595****	**-0.455****	**-0.410****	**-0.462****
CB2	Refusing deep thinking	0.305*	1.000	-	-0.361**	-0.139	-0.056	-0.119	-0.337*
CB3	Leaving things open somewhat	0.263	0.052	1.000	0.076	-0.133	0.006	-0.042	0.000

* Correlation is significant at the 0.05 level (2-tailed).

Discussion

The present study reveals that the MBSR training is an effective intervention and produces a significant improvement in coping behaviours as well as the reduction in the physical stress of CPs (see Figure 1). The distinctive effect of the MBSR workshop on CPs is discovered in the findings. There is no difference found between sample and control group in their mindfulness characteristics, coping behaviours, and physical stress before the MBSR workshop. However, after the MBSR training, majority of mindfulness characteristic items, including *observation to sensations*, *curiosity to learn*, *good at description*, *focusing present moment*, *considering things in different viewpoints*, *letting go distressing thoughts*, and *experiencing self-separate from thoughts and feelings*, are considerably enhanced, and three out of five physical stress items (*yawning*, *becoming drowsy* and *high heart rate*) are decreased among the MBSR participants in comparing with the control group. Similarly, this mindful training also helps in the improvement of two coping behavior items (i.e., *rediscovering new things in life* and *leaving things open to somewhat*) of the CPs (see Figure 2).

Mindfulness Characteristics and Physical Stress

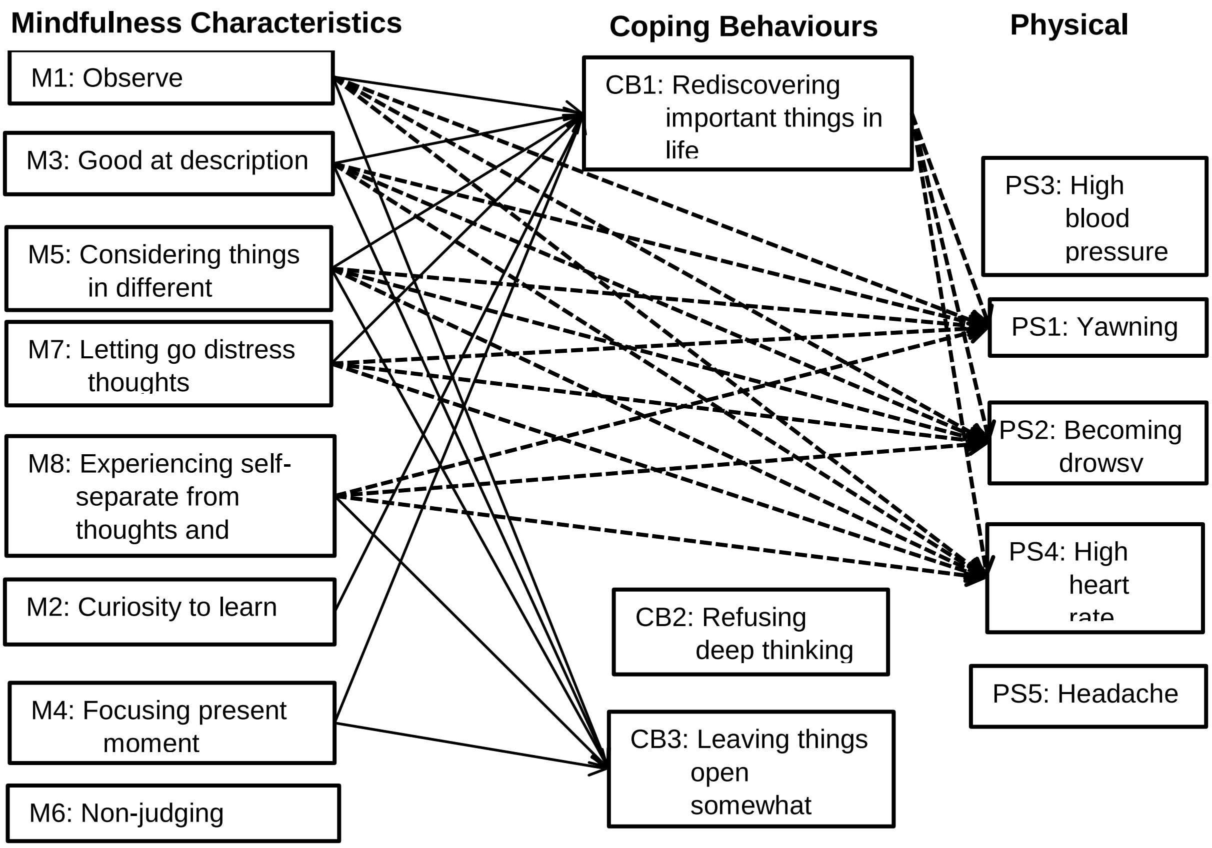
Interestingly, after MBSR workshop, CPs have successfully reduced their physical stress including *yawning, becoming drowsy,* and *high heartbeat rate*. Indeed, the process of *active observations*, *expression of feelings into words*, *beginner's mind*, *letting go distress thoughts,* and *decentering* are those constructive cognitive processes for empowering and transferring negative thoughts into positive meanings (Garland et al., 2009). This meaningful understanding of stressful life events leads to a significant reduction in physical stress by mindfulness characteristics *via* MBSR (Garland et al., 2011; Hewstone et al., 2007). Therefore, MBSR participants can manage their demanding, complicated, and multi-tasks through keen observations, good communications, different ideas, non-reactive thoughts, and present focus, which consequently reduce their physical stress.

Furthermore, mindfulness practices support participants to hold severe emotions and feelings, which can relieve suffering. It is believed that changing the perception of CPs to see the complaints in a new light reduced their stress without keeping on the past and/or future worries (Carlson, 2012). Therefore, various physical stress symptoms of CPs, such as high heart rate, yawning, and drowsiness are subsequently decrease after the MBSR workshop (Delizonna et al., 2009; Simpson et al., 2019). In fact, mindfulness training involves breathing, attention control, emotional acceptance, etc., to alleviate the negative impacts of stress on physical health. Furthermore, many positive features of mindfulness play an important role in the mitigation of stress. For instance, *focusing on the present moment* enable CPs to alert their body conditions and dangers, as well as prevent unnecessary use of physical efforts in their tasks. Thus, it can be claimed that MBSR workshop has cultivated numerous positive behaviours among the participants in comparing with the non-participants.

Mindfulness Characteristics and Coping Behaviours

Positive relationships were revealed between the six items of mindfulness *and* a positive reappraisal coping item (i.e., *rediscovering important things in life*). MBSR has enhanced the positive reappraisal by cultivating careful observation, well-expressed emotions, different viewpoints, letting go attitude, curiosity, and focused mind. These mindful characteristics can reframe the issues and rediscover the important things at the job of CPs (Garland et al., 2009). Ultimately, through such a cognitive process, a stressful event can be altered into beneficial and valuable meanings (Garland et al., 2011). In fact, mindfulness characteristics can assist CPs to think in broader aspects, enabling to assess available information and the situation more objectively and non-judgmentally, to manage their stress. In short, mindfulness practice has helped the CPs to reorder their priorities in life, to maintain the coping, and to reduce the stress (Desrosiers et al., 2013; Hewstone et al., 2007).

On the other hand, emotional support seeking item was improved after the MBSR workshop, while majority of mindfulness characteristics have played a vital role in this increment. All the participant CPs have improved their describing skills via the MBSR, which empowers their confidence to seek emotional support from others (Hampton et al., 2018). It is believed that good communication can help to express their feelings more easily, clearly, and confidently with their close one to relax themselves (Leung et al., 2016). Additionally, other features of mindfulness, including attentive observations, different perspectives, and more focused mind have facilitated CPs to secure trust and attachment with their colleagues (Khaddouma et al., 2017), and eventually ease in emotional support seeking (Shaver et al., 2007). Therefore, it can be claimed that MBSR workshop has improved coping behaviors through enhancing mindfulness characteristics.



Notes: significantly negative relationship demonstrated by t-test and correlation;

significantly positive relationship demonstrated by t-test and correlation.

Recommendations

After the MBSR workshop, many mindfulness characteristics were improved, particularly describing ability. Through the MBSR workshop, CPs got an effective platform to enhance their communication ability. It is believed that describing skills can reduce conflicts and misunderstandings during communication with colleagues (Burgoon et al., 2000). Therefore, construction companies are suggested to organize informal sessions and competitions, which involve deep observations, out of box thinking, and curiosity (for example physical games, chess, board games, etc.) once a week at the workplace. In such informal activities, CPs can express their personal feelings and difficulties both verbally and non-verbally. It will not only enrich their describing and communication abilities but also strengthen their relationships among employees. Ultimately, these attributes will refresh the CPs mind and body, and help to release their stress.

Drowsiness and yawning can be recognized as a lack of activeness and attention towards the jobs, which can mitigate the performance of CPs. After the MBSR workshops, CPs have reduced these attitudes. Indeed, mindfulness training has many beneficial effects, such as improvement of regulated attention, reduction of wandering mind, enhancement of acceptance, and so on (Modesto-Lowe et al., 2015). Additionally, stretching practices like yoga will serve as an exercise. It can diminish the influence of many physical health problems, such as high blood pressure, heart disease, and obesity (Fletcher, 2011). Hence, the MBSR training workshop should be adopted in every occupation, especially in the construction industry, for tackling physical health problems and improving stress management.

This study collected data only during an eight-week intervention workshop (i.e., two and a half months), but we were unable to establish the long-term impact of MBSR. A longitudinal study is suggested in the future study for addressing potential barriers associated with long-standing practices to comprehend the variations on the same subject over a long period (Murphy, 2012). In addition, the use of only self-report survey data may involve the risk of social desirability and the inevitable bias in the findings and, thus, more objective approaches should be studied in the future. However, it should be noted that several measures were adopted in the study in order to ensure the reliability of the items including extensive literature, factor analysis, and reliability test. This study only developed the Mindfulness-Coping Behaviours-Stress model for CPs. Further studies can be done to investigate the impact of MBSR on the management of stressors and the performance of CPs. Triangulation of measures and appropriate control will empower more exploratory investigation for unidentified variables. Future studies are encouraged to use a triangulation research method including longitudinal, experimental, and self-report measures together. Additionally, large sample sizes are required to confirm the impact of MBSR practice for different construction personals.

Conclusions

This research has identified the impact of MBSR workshops on CPs, particularly for reducing their physical stress and improving coping behaviours. The efficacy of intervention can be noticed before and after the workshop. In the commencement of the workshop, there is no difference between the control and sample group. However, MBSR participants have considerably increased their mindfulness characteristics, improved their coping behaviours and decreased in physical stress. It shows that mindfulness including observation of sensations, curiosity to learn, good at description, focusing present moment, considering things in different viewpoints, letting go distress thoughts and experiencing self-separate from thoughts and feelings have played the pivotal role in improving coping behaviours and reducing the physical stress of CPs. The results revealed the positive changes and confirmed the effectiveness of mindfulness training on CPs. The construction companies are suggested to offer various platforms for CPs to deal with stress. Hence, it is recommended to organize an informal gathering, social activities, and regular stress management workshop like MBSR training. Such a programme will not only reduce their stress but also help to cultivates various positive approaches, for example, communications, broaden views, attention, and so on. Future studies should include triangulation method with a large sample size to further strengthen the impact of the MBSR workshop in stress management.

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Impacting Construction Health and Safety Performance Using Virtual Reality - A Scoping Study Review

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Abstract

The exploitation of technology has been explored by many leading industries to enable more efficient work practices and improve safety performance. Virtual reality (VR) is one such technology that has progressed in its practical application within many sectors such as aerospace and healthcare. As construction remains to be a hazardous industry and continues to represent high fatality statistics, the application of virtual reality would appear to be beneficial in assisting safety management in this sector. This review aims to provide an overview of the extent to which the impact of VR on construction health and safety performance has been explored. This review follows the five-stage scoping review framework developed by Arksey and O'Malley. The review concludes that the exploration of VR to specifically impact health and safety performance is limited. The identified studies tend to focus on isolated components of health and safety management, such as safety training. Although training is an essential aspect of safety promotion it is not the only aspect to consider in a safety management system. Thus, the need to explore how VR may impact other areas of health and safety management and its impact on safety performance merits further empirical research.

Keywords: health and safety, immersive technology, scoping study review, virtual reality.

Introduction

The construction industry is unique in how it operates (Li et al., 2015), it is also complex (Babalola Ifedolapo et al., 2015; Eiris Pereira et al., 2019; Getuli et al., 2018; Li et al., 2015), project driven (Bassioni et al., 2004; Kumar, 2015) and resistant to adopt new technology. Health and safety is vital to the performance of a project (Shen & Marks, 2015) however the construction industry remains to be one of the most hazardous of all industries in the world (Li et al., 2018; Mohammadi et al., 2018; Sunindijo & Zou, 2014) and has gained a poor reputation in this regard. Although significant improvements have been made regarding health and safety performance within the UK, the industry is high risk and continues to represent high fatality statistics (Hafsia et al., 2018; HSE, 2018a). The UK construction industry alone recorded 30 fatalities in 2018/19, a statistic (although much improved and the lowest on record) was placed as one of the highest of all industries. Moreover, when considering these statistics in terms of fatal injury rates, in 2018/19 the construction industry accounted for 1.31 fatalities (per 100,000 workers) (HSE, 2019). The nature of construction does however involve hazardous (HSE, 2018b; Xie et al., 2006) and dynamic processes (Getuli et al., 2018; Li et al., 2015; Mohammadi et al., 2018; Whitlock et al., 2018) and while various control measures are often in place, operatives can still be exposed to risk (Phoya, 2017). Therefore, exploring innovative methods of managing safety risk has been a topic of development, in particular the exploitation of advanced digital technology for this purpose.

The term ‘virtual reality’, initially coined by Jaron Lanier in 1987 (Greuter & Roberts, 2014; Maples-Keller et al., 2017; Srivastava et al., 2014), uses head mounted displays and hand controllers to allow the user to immerse within computer-generated interactive environments. The specific use of VR has been adopted by many industries since its initial development in the 1950’s. These include aerospace, military, education (Freina & Ott, 2015), automotive, sports (Lee & Kim, 2018), engineering and healthcare (Fertleman et al., 2018; Gallagher, 2018; Maschuw et al., 2010; Olasky et al., 2015). With the uptake of this technology apparent within literature in these major sectors, the focus of this scoping review is to explore the extent to which the impact of VR on health and safety performance has been explored in the construction sector. This scoping review aims to identify gaps in literature and make recommendations for further studies in this field.

Methodology

This scoping review follows the framework developed by Arksey and O'Malley (2005). Davis et al. (2009) suggests that the purpose of a scoping review is to explore and convey the breadth and depth of a field in order to provide clarity. O'Brien et al. (2016, p. 1) states that the aim is to “comprehensively map evidence across a range of study designs in an area, with the aim of informing future research practice, programs and policy”. Arksey and O'Malley (2005) also highlight that a scoping review “needs to achieve in-depth and broad results” which can be undertaken to determine if a systematic review is feasible. This method also identifies research gaps in existing literature were no studies have been conducted. A scoping review maps key concepts, which could be part of a reviewing process or seen as a method on its own merit. This method would aim to broadly identify relevant existing literature irrespective of the research methodology and the quality of the studies (Levac et al., 2010). From further understanding of the research topic and its literature, additional refining of research terms can be undertaken. This scoping review followed Arksey and O'Malley’s (2005) five numbered stages and its presented according to these stages, these are:

Stage 1: *identifying the research question*

Stage 2: *identifying relevant studies*

Stage 3: *study selection*

Stage 4: *charting the data*

Stage 5: *collating, summarizing and reporting the results.*

Scoping Study Review

Stage 1: Identification of the Research Question

In order to commence the scoping review a research question was identified. This question should assist in identifying the width of the subject area and which key search terms to use. The following question was used in order to assist this scoping review:

‘What is known from existing literature about the impact on health and safety performance within the construction sector when utilising virtual reality?’

Stage 2: Identification of Relevant Studies

To identify relevant studies, a search strategy was developed (Arksey & O’Malley, 2005). To begin, key search terms were extracted from the research question. For this review the terms extracted were ‘health and safety’, ‘construction’ and ‘virtual reality’. In order to assess the scope of the research, the well-established academic electronic databases ‘Discover’ and ‘Google Scholar’ were used. Following the works of Wang et al. (2018), Boolean terms (such as AND, OR) were also used to refine the search and to provide more relevant results. Identified in table 1, six separate searches were entered into the database using variations of the search terms.

Table 1: Search Strategy

	Terms Searched in Advanced Search	Total Searches Found
1	"virtual reality" AND construction AND safety	12,577
2	"virtual reality" AND construction AND health AND safety	6,627
3	("virtual reality" OR VR) AND construction AND health AND safety	12,136
4	("virtual reality" OR VR OR "immersive techn*") AND construction AND (health OR safety)	42,285
5	"virtual reality" AND construction AND health AND safety AND performance	5,151
6	("virtual reality" OR VR) AND construction AND (health OR safety)	43,994

Stage 3: Study Selection

A two-phase approach was adopted using the results from the advanced search term number 6 in table 1 as this contained the most literature sources (43,994 sources found). Table 2 shows the first phase of the inclusion and exclusion criteria applied to the search. Drawing on the works of Wang et al. (2018) and Sidani et al. (2018) who carried out similar retrieval processes and literature reviews within this field. Published literature including journal articles and doctoral research were selected for inclusion, with exclusion of non-academic articles (Unuigbe et al., 2017). Due to the research topic been a current and rapidly evolving field, the search was set to identify literature published within the last 10 years. As the review aims to identify a wide scope of research all geographical locations were included however, the search excluded those not in English language. The first phase inclusion criteria also included a selection of key subjects in order to refine to the search to construction related sectors.

Table 2: Inclusion and Exclusion Criteria (phase 1)

Initial searches found from stage 2		**43,994**
Phase 1 – initial criteria		
Criteria	**Inclusion**	**Exclusion**
Time	2009 - 2019	Any study before 2009
Publication type	Academic journals and Doctorial research	Sources which are not academic journals or Doctorial research
Geography	All	None
Language	English	None-English
Subject		
Virtual reality	✓	
Research article	✓	
Computer simulation	✓	
Augmented reality	✓	
Simulation methods and models	✓	
Simulation	✓	
Education	✓	
Questionnaires	✓	
Learning	✓	
Cognition	✓	
safety	✓	
Technology	✓	
Construction	✓	
Technological innovations	✓	
Sources identified within search		**4,745**

Review of abstract	
Reviewed abstract for relevance	- 4,612
Total sources	**133**
Review for duplicates	- 12
Review for relevance	- 97
Total sources identified at phase 1	**24**

Table 2 indicates that further to assigning the inclusion and exclusion criteria, the search databases responded with 4,745 literature sources. This was then refined manually by reviewing the source titles and abstracts for relevant themes. This process reduced the number of literature sources which covered majority of the key criteria to 133. Out of the 133 that remained, 97 sources were not specifically within the field of construction and 12 were duplicates. At the end of phase one, 24 sources were identified and continued to phase two. In phase two the sources were reviewed to identify the study focus and determined which were empirical studies as opposed to review papers (Unuigbe et al., 2018). Table 3 shows the list of literature and identified that 18 of the 24 were relevant empirical studies to continue to stage 4. Figure 1 illustrates a summary of the review process.

Table 3 Study focus review of identified literature (phase 2)

Number	Citation	Title	Empirical study	literature review
1	(Ahmed, 2018)	A Review on Using Opportunities of Augmented Reality and Virtual Reality in Construction Project Management		✓
2	(Behzadi, 2016)	Using Augmented and Virtual Reality Technology in the Construction Industry		✓
3	(Bhoir & Esmaeili, 2015)	State-of-the-Art Review of Virtual Reality Environment Applications in Construction Safety	✓	
4	(Chan, 2012)	The use of virtual reality for visualizing construction safety management process	✓	
5	(Chun et al., 2012)	The use of virtual prototyping for hazard identification in the early design stage	✓	
6	(Getuli et al., 2018)	A Project Framework to Introduce Virtual Reality in Construction Health and Safety	✓	
7	(Gheisari & Esmaeili, 2019)	PARS: Using Augmented Panoramas of Reality for Construction Safety Training	✓	
8	(Goulding et al., 2012)	Construction industry offsite production: A virtual reality interactive training environment prototype	✓	
9	(Guo et al., 2012)	Using game technologies to improve the safety of construction plant operations	✓	
10	(Jeelani et al., 2017)	Development of Immersive Personalized Training Environment for Construction Workers	✓	
11	(Le et al., 2014)	A Social Virtual Reality Based Construction Safety Education System for Experiential Learning	✓	
12	(Li et al., 2012)	Multiuser Virtual Safety Training System for Tower Crane Dismantlement	✓	
13	(Li, 2017)	Virtual Reality and Construction Safety		✓

14	(Li et al., 2018)	A critical review of virtual and augmented reality (VR/AR) applications in construction safety		✓
15	(Lu & Davis, 2018)	Priming effects on safety decisions in a virtual construction simulator	✓	
16	(Park et al., 2015)	A Framework for Using Mobile Based Virtual Reality and Augmented Reality for Experiential Construction Safety Education.	✓	
17	(Pedro et al., 2015)	Framework for Integrating Safety into Construction Methods Education through Interactive Virtual Reality	✓	
18	(Perlman et al., 2014)	Hazard recognition and risk perception in construction	✓	
19	(Sacks et al., 2013)	Construction safety training using immersive virtual reality	✓	
20	(Sacks et al., 2015)	Safety by design: dialogues between designers and builders using virtual reality	✓	
21	(Shamsudin et al., 2018b)	Virtual Reality for Construction Occupational Safety and Health Training: A Review		✓
22	(Shamsudin et al., 2018a)	Utilization of Virtual Reality Technology Smartphone Application for the Enhancement of Construction Safety and Health Hazard Recognition Training in Piling Work: Pilot Study	✓	
23	(Wang et al., 2018)	A Critical Review of the Use of Virtual Reality in Construction Engineering Education and Training		✓
24	(Zhao & Lucas, 2014)	Virtual reality simulation for construction safety promotion	✓	
Total			**18**	**6**

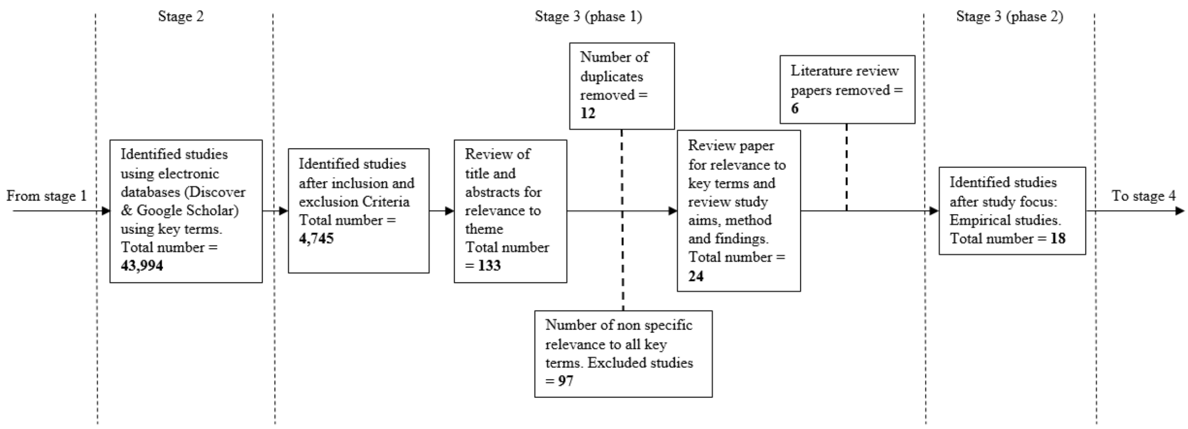

Figure 1 summary flowchart of scoping review process

Stage 4: Charting Data

Drawing from the works of Arksey and O'Malley (2005) and Unuigbe et al. (2018) standardised information was gathered from each of the 18 sources. The following was collected.

- Author / year / title

- Geographical location
- Aim of the study
- Methodology adopted
- Key findings of the study
- The extent to which the study addresses the research question

The literature was stored on Mendeley software and reviewed methodically according to alphabetical order. In most cases the data required was available within the literature source however, in some cases the information was not accessible and therefore were stated as 'unknown'. Table 4 shows an example of the extraction and review process.

Table 4 Example of Charting data

number	Author	Year	Title	Geographical Location	Emperical study	Summary of Research Aims	Methodology	Key Findings of the Research	Key Focus	The Extent to Which the Study Addresses the Research	Type of Source
14	Perlman et al	2014	Hazard recognition and risk perception in construction	Israel	Yes	To explore the extent to how supervisors perceive hazards and assess site risks. The study assesses how training and experience effects hazard perception and if hazards can be identified more effectively using virtual environments over traditional means of construction documentation	Sixty-one individuals participated in the experimental study. The individuals were grouped into one of three categories based on their role and level of experience and training (supervisors, students and safety directors). The comparison between supervisors and remaining categories assumed that the students had minimal exposure to site environments and safety training and that the safety directors had a wealth of site experience and safety training. Each of the participants partook in a hazard perception test, either using traditional documentation (such as drawings, photos etc) or using a three sided virtual CAVE. For each of the tests, a total of 48 hazards were present, the study utilised ANOVA tests to compare the results across the key groups. A range of data was collected and analysed, this included the total number of correct hazards identified, the number of instances for each hazard, the hazard type and those which related to 'high risk' hazards	The results indicated that within the supervisor group, there was no positive correlation between the number of years' experience or training and the ability to identify hazards. This could suggest that very little experience or training is needed to achieve an ability to identify hazards. Although, as the most experience group (safety directors) preformed far better than both other groups it would therefore indicate that thorough formal safety training and site experience, (as well as safety imbedded into their role) is required to achieve a high level of hazard perception and assessment skill. The data suggested that the supervisors participating in the study were not able to identify hazards to the same degree as the director group using either of the traditional or virtual methods. As anticipated, in most cases percipients were able to identify hazards more effectively using the CAVE environment in comparison with traditional methods. This was most apparent with hazards involving moving vehicles and poor PPE however the virtual environment was not more effective in all cases	educational. safety training, hazard identification	The research focuses on education uses of VR in regards to its impact on hazard identification and risk assessment when compared to traditional methods of teaching and learning. The study demonstrates the effect of VR within training and education for identifying hazards generally, as opposed to integrated within an organisation or project.	Journal

Stage 5: Results

The fifth stage of the study is designed to collate, summarize and report the results. In order to ascertain specific gaps in current literature, the sources were further analysed. Firstly, the year of publication is shown in table 5. The data demonstrates no published work between the years 2009 – 2011 followed by inconsistent pattern of publications with a wide range of peaks and troths. The years 2012 and 2015 showed the highest rate of publicised journals and although the study identified no research papers during the year 2016 there has been a gradual rise of related studies up to the date of this review.

Table 5 Year of publication

Year	Author	Total number of publications in year	Percentage
2009		0	0%
2010		0	0%
2011		0	0%
2012	(Chan, 2012; Chun et al., 2012; Goulding et al., 2012; Guo et al., 2012; Li et al., 2012)	5	27.8%
2013	(Sacks et al., 2013)	1	5.6%
2014	(Perlman et al., 2014; Zhao & Lucas, 2014)	2	11.1%
2015	(Bhoir & Esmaeili, 2015; Le et al., 2015; Park et al., 2015; Pedro et al., 2015; Sacks et al., 2015)	5	27.8%
2016		0	0%
2017	(Jeelani et al., 2017)	1	5.6%
2018	(Getuli et al., 2018; Lu & Davis, 2018; Shamsudin et al., 2018a)	3	16.7%

2019	(Gheisari & Esmaeili, 2019)	1	5.6%
Total		**18**	**100%**

The data shown in table 6 identifies the locations of the publications and highlights the eighteen research papers were predominantly sourced from the USA, China and Israel. Within the UK, one related source was found from this scoping review using the search criteria; this identifies a lack of research in this field within the UK in comparison to other aforementioned geographical locations. The data in table 7 shows the key methods included interviews (mainly qualitative) and experimental. The experimental methods often included the use of industry / students to participate in trial VR applications in order to ascertain the effectiveness over more traditional methods. Surveys and questionnaires were used in four of the studies to draw out experiences of those interacting with the immersive technology. Case studies were used within five literature sources. These predominantly aimed to capture practical insights of the effectiveness of VR in the context of safety training in project environments.

Table 6 geographical location of identified studies

Geographical Location	Total number	Percentage
Australia	1	5.6%
China	1	5.6%
Hong Kong	2	11.1%
Israel	3	16.7%
Italy	1	5.6%
Korea	2	11.1%
Unknown	3	16.7%
UK	1	5.6%
USA	4	22.2%
Total	18	100%

Table 7 adopted methodologies

Methodology	Total number
Interviews	8
Surveys / Questionnaire	4
Case study	5
Experimental	8
Subject questioning	2

The results shown in table 8 highlight that sixteen out of the eighteen studies focused on the use of VR for safety training with fourteen of these also focused on hazard perception and recognition. The studies included general site hazard identification with three of these dedicated to heavy plant. Five of the papers where specifically focused within the construction education sector, primarily assessing students perceptions of training using VR. The scoping review only identified one paper focused within the industry. This assessed designers and contractor’s collaboration for safer design solutions using VR as a tool. The data demonstrates that fifteen of the eighteen papers focused solely on the impact of VR regarding training and whilst six of the papers referred to its effects on behaviours this was not further explored. None of the resources found as a result of this scoping review presented qualitative or quantitative data regarding the impact of VR on health and safety performance.

Table 8 Study focus

Study Focus	Total number
VR for safety training	16
VR for plant / equipment training	3
VR adoption	1

Table 9 critic against research question

Hazard identification	14
Education	5
Industry based	1
Design review	1

Critic	Total number
The study solely focused on H&S training	15
The study did not link to overall H&S performance measures	18
The study did not link to the impact on personal / organisational behavioural towards H&S from using VR	13

Conclusions

This review aimed to assess the extent of the existing research pertaining the impact of virtual reality on health and safety performance. The review used framework adopted by Arksey and O'Malley (2005) in order to explore a broad field of research and identify gaps in existing literature. To conclude, the literature has begun to explore the link between VR and health and safety in the construction sector however tends to focus on its impact to singular aspects of health and safety management. The prominent link being towards safety promotion, specifically its impact in training and education. Though the impact of VR in safety training is significant there is an absence of literature that addresses this impact on other components of a safety management system. Focusing mainly on safety training may limit the potential impact of VR concerning other elements of safety promotion (such as behaviour) as well as those related to safety policy, assurance and risk management. Due to the worldwide importance of health and safety in both developed and developing countries, this review recommends further research related to the impact of VR technology to these other key components of safety management. This further knowledge can therefore broaden the understanding of the impact of VR on safety within the construction sector.

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Methodologies, strategies and interactions: how best to engage industry when researching a new health and safety tool

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Abstract

Purpose : To examine and explore optimal methods of engagement between academia and industry when researching and developing an innovative technological solution for construction project health and safety. The paper aims to inform academic practice by referencing research findings against leading models of university-industry engagement, such as the Knowledge Integration Community (KIC) model of the Cambridge-MIT Institute.

Design : The paper reflects on experiences of the research team on the University of Manchester's Discovering Safety project BIM Digital Risk Library for Health and Safety. It provides details of the developed BIM-based tool and what methods/strategies have been used to engage, secure and develop ongoing industry support with the research idea.

Findings : Specific research engagement activities (e.g. steering committees workshops; software prototype development; practitioner shadowing) are discussed and reflected against existing models of university-industry engagement (i.e. the KIC of Cambridge-MIT Institute). Findings explore how the unique characteristics of UK construction and fragmented industry health and safety expert knowledge and experience affect and influence work to develop innovative solutions for widespread adoption.

Limitations : Findings and reflections are limited to the early phase of technological innovation development: a prototype proof of concept software tool.

Originality : Originality stems from: (1) Development of a BIM-based tool linking construction risks to mitigation treatments is at forefront of research in the field; (2) the Discovering Safety project is a collaborative effort with UK regulator for health and safety, the Health and Safety Executive (HSE).

Practical Limitations : The findings present useful recommendations which construction health and safety researchers could implement when engaging with industry organisations and professionals to develop technological innovations to improve safety in construction.

Keywords: *Building information modelling, Construction industry, Design for Safety, Health & Safety, Prevention through Design, Technology Innovation.*

Introduction

This paper reports on ongoing research at University of Manchester (UoM) to design and develop a new tool to connect identifiable construction project design risks with relevant mitigations/treatments based on industry expertise, official guidance and the archive of the UK regulator Health and Safety Executive (HSE). The "BIM Digital Health and Safety Risk Library" tool ultimately aims to assist designers in their work by mobilising mitigations in a BIM environment: such an approach aligns with research work that recognises risks may be identified in design phase work, called Prevention Through Design (PtD) (Hale et al. 2007; Tymvios, 2017). Such work demands several processes: proactive use of knowledge resources of the HSE; extraction of data; industry consultations; transformation of data into useable format for BIM environment; industry review, etc.

Whilst the paper briefly reviews the stages in the development of a prototype tool, the primary focus is the relationship between academia and industry to explore what methodologies, strategies and interactions work effectively when researching, designing and delivering a new health and safety tool for industry. The paper aims to inform academic practice by referencing findings against the Knowledge Integration Community (KIC) model of the Cambridge-MIT Institute, USA (a leading model of university-industry engagement).

The applicability and utility of the KIC model will be explored in relation to health and safety technology research and development in the UK, to inform our understanding of the relationship between academia and industry, the fragmented nature of health and safety expert knowledge and how different outlooks and perspectives of practitioners (often resulting from their position in the project lifecycle and the effect of different project procurement models) can effect research work evolution.

The BIM Digital Health and Safety Risk Library project

The "BIM Digital Health and Safety Risk Library" project commenced in 2019 under the Discovering Safety programme of the Thomas Ashton Institute (TAI, 2020), a collaborative research enterprise between the UK Health and Safety Executive (HSE) and University of Manchester (UoM). The project aims to assist design and construction professionals better manage their health and safety objectives via proactive use of digital technologies and mobilization of information resources via a Prevention Through Design (PtD) approach (Yuan et al. 2019). Opportunities provided by technologies such as Building Information Modelling (BIM) as well as industry standard guidance such as PAS 1192-6: 2018 (BSI, 2018) to provide digital solutions for construction health and safety, motivated the research to explore how BIM can be applied to health and safety (Hossain et al. 2019; Mordue and Finch, 2014; Ding et al. 2016). Comprehensive and continuous industry engagement was recognised as essential from the start: phase 1 of the research (January 2019 – June 2020) aiming at the delivery of a prototype Proof of Concept tool in a BIM environment.

Before proceeding to detail the different stages of industry engagement employed, the paper will now describe the Knowledge Integration Community (KIC) model of the Cambridge-MIT Institute, a leading model of university-industry engagement. We seek to cross reference activities of the BIM Risk Library project against the KIC model, exploring the utility, appropriateness and suitability of the KIC model for creation of innovative technologies for construction health and safety. In so doing, we shine a light on the nature of academic/industry engagement and the realities, challenges and opportunities the construction industry presents for academics wanting to do impactful research.

The Cambridge-MIT Institute and the Knowledge Integration Community (KIC)

The Cambridge-MIT Institute (CMI) was established in 2000 by the UK government to develop and implement innovative approaches for knowledge exchange between academia and industry (Acworth, 2008, p.1242). The CMI aimed to replicate the success of the Massachusetts Institute of Technology (MIT) in collaborating with industry in a two-way flow of knowledge to strengthen research and development of innovative technologies. CMI launched its` own Knowledge Integration Community (KIC) model to enhance university-industry links; an objective being that the problems and market needs of industry effectively become the basis for defining research goals of universities. The CMI operates at the centre of an alliance of stakeholders from Research, Education and Industry communities (figure 1).

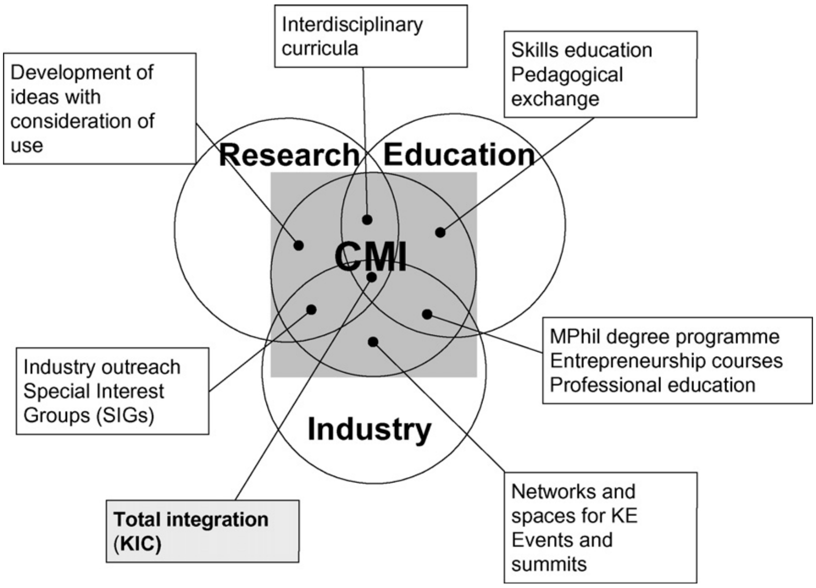

Figure 1: The Cambridge-MIT Institute model for knowledge exchange (KE) (Acworth, 2008, p.1242).

The CMI is based on the premise that positive research outputs can lead to solutions for industry that benefit society and the economy: the concept of multidirectional knowledge exchange (KE) (as opposed to unidirectional knowledge transfer) guiding its overall strategic work. For the purposes of this paper, we focus on the key components of the Knowledge Integration Community (KIC): each KIC being a "collaborative platform for development of a comprehensive and multi-faceted solution addressing technological, economics and social issues." (Acworth, 2008, p.1242).

Acworth (2008) describes the functional components, support mechanisms, organisational structure, review processes and mechanisms of a KIC, noting the importance of *intermediaries* in facilitating links between universities and potential users of knowledge, notably commercial firms. Intermediaries from industry are critical to the flow of research ideas, concepts and prototypes through intra and extra-organisational networks. They can act as gatekeepers to further contacts of importance, opening up doors for trialling, testing and refinement of research ideas and tools in real-world commercial settings.

Figure 2 visualizes the KIC model; Acworth (2008) identifying six components (four human; two concept-based):

- Human: *Research; Industry; Government; Education*
- Conceptual: *Knowledge Exchange; Study of Innovations in Knowledge Exchange (SIKE)*
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The four Human components (Government; Industry; Education; Research) are self-explanatory in meaning; each one having an important role to play in the research journey. The two conceptual elements require some explanation.

Knowledge exchange between research stakeholders is achieved via various mechanisms within the KIC (e.g. workshops; personnel exchanges; web spaces; e-newsletters; video-conferencing; professional communications; formal business development networks, etc.) (Acworth, 2008, p.1248). Such mechanisms enable interconnectedness between stakeholders, facilitating an exchange of ideas and open communication between parties. Knowledge exchange is central to the functionality of the KIC model (as indicated in figure 2).

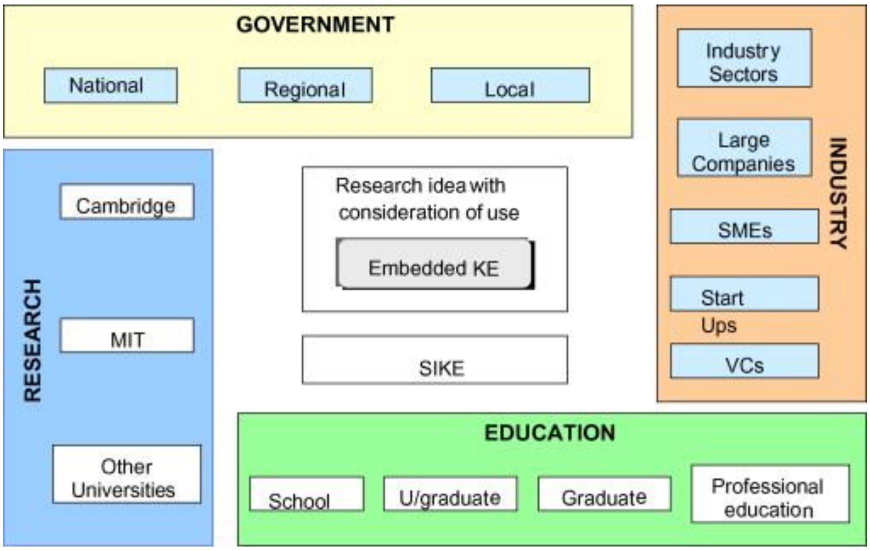

Figure 2: six-component model of a Knowledge Integration Community (KIC)(Acworth, 2008, p.1247).

Study of Innovations in Knowledge Exchange (SIKE) is effectively what facilitates reflective assessment and consideration of the knowledge exchange activities for continuous improvement. The goal here is "codification and dissemination of knowledge exchange methods within the wider community" (Ackworth, 2008, p.1248). This is important for learning and achieving more effective research work: SIKE activity clarifying how ideas/questions from industry translate into responsive research actions and continual examination of how research projects translate into practical use by industry. Again, this is a central component of the KIC.

A strength of the KIC is its` social, *non-hierarchical nature*: individuals engaging in an open forum, where individual company rank and title are set aside for the shared, common research good. Moreover, research is driven by a "consideration of use", so that future potential viability is always an important question. This latter point was identified as particularly important by UK government (2001), when noting the lack of ability in the UK to exploit the scientific results of research (DTI, 2001).

There are a number of differences between the KIC model and funded research projects commonly undertaken by university academics. For example, many academic research projects may not engage with Educational institutions or different tiers of Government, and such a difference should not be viewed as a deficiency. Each separate KIC aims to be a comprehensive model for the CMI: each KIC being a large organisational entity with its` own Manager and dedicated staff. Additionally, each KIC is not intended to be a closed-end project (unlike majority of Research Council funded grants), but is meant to develop into a long-term self-sustaining entity. So, whilst direct comparisons between the KIC model and individual funded research projects should be avoided, we aim to reflect on the KIC model itself as a useful reference for academic/industry research collaboration in construction health and safety research and to draw lessons from the model. The paper now proceeds to detail the different stages of researching and developing the prototype tool on the BIM Risk Library project together with the industry engagements employed.

BIM Risk Library research approach

Industry engagement was integral to work of the BIM Risk Library project from the start; this motivation originating in the overall project aim to:

(1) Provide industry with new tools/techniques to improve health and safety in digital BIM environment

(2) Desire of HSE to enhance and improve construction industry health and safety performance (HSE being official UK regulator or health and safety and major stakeholder and driver on the project).
Figure 3 presents the overall research approach of the BIM Risk Library project. Each of the steps in figure 3 will be briefly described prior to a closer examination of the industry engagements occurring.

1. Academic Literature Review

A review of the academic literature relating to BIM and health and safety concentrated on the design phase of projects. There is a large and growing body of work in this area (Tymvios, 2017; Gambatese et al. 2008; Yuan et al. 2019; Morrow et al. 2015); recent research highlighting the need for designers to enhance their safety knowledge and expertise via digital solutions (Hayne et al. 2017; Hare et al. 2019). Findings of the literature review were synthesised and coded using Nvivo software to produce a rich file of published work in the field. The review provided insights into the implementation of any IT tool for better safety management in construction project design. This work stream was considered an essential foundation for the research project.

2. Industry Software Review

Specific construction industry software packages were identified and reviewed by the research team. Specific workshops and webinars were subsequently attended, so the potential for hosting a pilot tool on different platforms could be explored. Following a number of further meetings, one specific software platform was selected as the most appropriate for our research work. It should be noted that the software providers were very accommodating to engage in the research discussions. Following the selection of one specific platform provider, a separate contract was set-up so that our research concepts could be integrated with and hosted on the BIM software platform. An important insight here is the need to reserve project funds for software development work (if the expertise/capability is not within the academic research team).

3. Research Centres

Several national and international research centres of excellence in the field were identified for subsequent contact in future project work.

4. BIM 4 H&S Group

University of Manchester (UoM) was invited by HSE to engage with the BIM for Health and Safety group (BIM4H&S), a body of industry experts in the field. The BIM4H&S group were instrumental in work leading to the industry standard PAS 1192-6: 2018 “Specification for collaborative sharing and use of structured health and safety information using BIM” (BSI, 2018); a working link with the BIM4H&S group therefore being important for the research project. A working link was subsequently established and several meetings attended, with ongoing work being presented at periodic intervals. This link was important for the research project, giving a direct communication link with industry figures managing construction health and safety in their organisations.

5. Industry Workshops

Two industry workshops were held at UoM to review research work done and scope out directions of the research project. Industry figures were invited and contributed positively to the research work tasks conducted. The research work was also presented at several national events (e.g. Digital Construction Week 2019; BIM for Water event 2019), with potentially useful collaborative contacts being made.

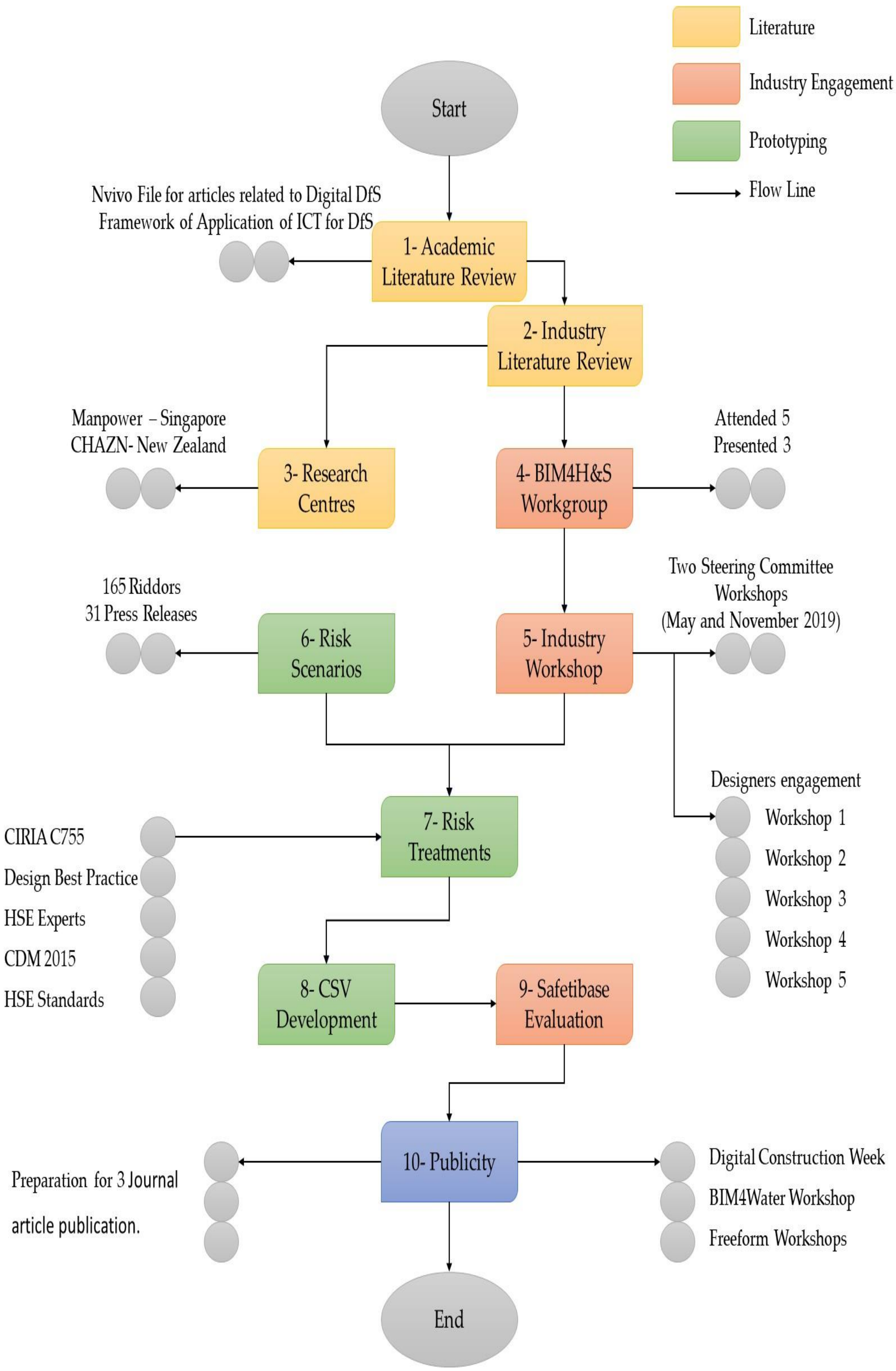

Figure 3: research approach: BIM Risk Library project

7. Treatment Actions
Treatment actions for the 9 scenarios were identified from a combination of industry workshop events (see above), official industry guidance documents (CIRIA C755; CDM 2015), HSE expert opinion and the Design for Best Practice Website (www.dbp.org.uk). Treatments were then placed into a matrix, classifying treatment actions based on treatment type and phase of implementation: Treatment Type (eliminate; reduce; control; inform); Project Phase (preliminary; detailed; preconstruction; site management).

For each scenario, several treatment actions were identified and placed in the appropriate matrix slot. These Treatments were then validated in one to one meetings with industry experts. The work led logically to the creation of a csv file showing all different combinations of seven concepts for the proof of concept risk.

8. CSV development
It was determined that a csv file could contain relations between the different concepts and several mitigation plans based on several scenarios; the csv file then being uploadable to the new software interface development work (see above).

9. Tool testing and evaluation
With the creation of the new interface on the BIM platform that could host the csv file, the scenarios and treatments tool could then be tested and refined with an industry audience. This work began at the end of phase 1, to be subsequently expanded in further work.

Discussion

The above activities are now discussed with reference to the KIC model of the CMI to inform understanding of conducting research in construction health and safety. To do this, each of the KIC components are reviewed in turn, as well as the overall KIC characteristics of *intermediary roles* and its` *non-hierarchical nature*.

Human components (Government; Research; Education; Industry)
The BIM Risk Library project has several Human component stakeholders. UoM, as appointed research partner, belongs in the *Research* category. The project sponsor (Lloyds Register Foundation), as a global charity, straddles both *Industry* and *Research* components: Lloyds Register providing funds to the HSE, which in turn, commissions research work. Whilst the BIM Risk Library project has no *Education* components, the potential of using the BIM Risk Tool in educational settings was noted by several stakeholders during project work. The HSE, as government agency, falls into both *Government* and *Research* components. Having the HSE as research partner greatly assisted the project in several ways: the HSE opening up communication links with industry more easily than an independent academic team could achieve. Several companies became involved in research work, either as software providers or construction industry companies: these falling into the *Industry* category of the KIC model.

We may conclude that having active players in each of the *Research*, *Government* and *Industry* categories definitely helped the project. Having both the HSE and Lloyds Register Foundation straddle several categories also strengthened the overall research project: industry organisations being more interested in becoming involved in our work. Therefore, it can be stated that for research teams aiming to produce innovative health and safety technical solutions, having representation in each of the human component categories is beneficial for the research project.

Knowledge Exchange

Knowledge exchange was facilitated in a number of ways on the project. Active membership of the BIM4H&S group, the setting up of a research project steering committee and regular attendance of industry events allowed opinions and thoughts of industry leaders to be obtained. This was vitally important for research project progress.

Software provider expertise and opinion was also essential for the prototype tool development. As noted, one BIM software provider enhanced their own software interface to allow integration of the UoM concepts and csv file. This followed formulation of a separate Contract between the HSE and the company to do so. The insight illustrates how it may be expedient to employ external expertise to complete a task which the internal team may not have the capacity or capability to undertake themselves. Although a financial cost was incurred, considerable time and effort was saved as result. Therefore, for research project managers, it may be expedient to budget in for possible software development work on a project, especially if the internal team lacks the expert knowledge. In terms of digital technology development, this may well be an issue of importance.

Knowledge exchange was also facilitated by the industry workshops. These were held for risk scenario completion, and were important in several respects. Not only did they facilitate the necessary knowledge exchange, but the organisation, management and running of the workshops had a cumulative effect on participants. Composition of each workshop was carefully considered beforehand (6 workshops were conducted with different companies to fill the treatment plans for the 9 identified scenarios); the meetings consisting of safety experts, design engineers and construction managers to fill the scenarios with different mitigation plans. During several workshops, a spreadsheet was uploaded onto the Cloud to allow simultaneous access and concurrent inputting of data (with shared viewing).

The workshops also facilitated knowledge exchange between industry stakeholders who commonly do not meet or communicate with each other in their professional lives. For example, in one workshop, a leading design and engineering consultancy worked closely with a Tier 1 contractor on the scenario task, obtaining a unique, holistic view of an integrated design in the process. There was thus added value for the participants in attending the workshop. No less important to the running of a successful industry workshop are its` organisation, venue, travel arrangements and food/refreshment provision, which all feed into the opinion of the academic partner by the industry practitioners. The above mechanisms were key to effective knowledge exchange on the research project.

Study of Innovation in Knowledge Exchange (SIKE)

SIKE activity was limited as the bulk of effort went into prototype tool concept and development work. However, the authors believe SIKE activity will be critical in future as SIKE is effectively what facilitates reflective assessment and consideration of the knowledge exchange activities for continuous improvement, as noted by Acworth (2008), who states,

“The goal here is “codification and dissemination of knowledge exchange methods within the wider community” (p.1248)

The research team at UoM have certainly laid the groundwork and conditions for fruitful SIKE activity in further research work.

Intermediary roles

There were several important intermediaries who provided a vital link between the academic team, construction industry companies and potential users of the tool. These were persons from the HSE and individual construction companies.

As noted by Ackworth (2008), these intermediaries are critical to the flow of research ideas and concepts, acting as gatekeepers to further contacts of importance, opening up doors for trialling, testing and refinement of research ideas and tools in real-world commercial settings. For the BIM Risk Library project, these intermediaries were very important to the eventual success of the project.

The authors conclude that a research project should try and identify such intermediaries very early in the research project lifecycle, probably at the research proposal stage. A project lacking intermediaries would experience more difficulties in making the important connections between industry, academia and government.

Non-hierarchical nature

The research was conducted in a non-hierarchical fashion from the start. Different companies were treated equally, with the BIM4H&S group meeting being non-hierarchical in nature. The workshops were open and non-hierarchical in nature, and the participants enjoyed this set-up, more readily contributing their thoughts and opinions as a result. It may be concluded that treating research participants equally is of benefit to a research project.

Obviously, context of study is a very important factor here: the BIM Risk Library being "project-neutral" in that our research work was not connected to one specific project, examining health and safety work from an objective, independent viewpoint. Conducting research work in a project setting might compromise the non-hierarchical ideal we experienced, as different companies/individuals would be sensitive to how their responses to research questions would be interpreted by other stakeholders on the project.

Conclusions

The paper reviewed the UoM BIM Risk Library project, discussing what methods, strategies and interactions were employed by the research team and referencing the CMI KIC model of research in the process. Whilst there are obvious alignments between the KIC model and the BIM Risk Library project (i.e. the Human components, importance of intermediaries), the authors believe that the characteristics of the construction industry and how health and safety expertise and knowledge is held makes conducting research in the field uniquely different.

For example, the fragmented nature of industry knowledge and expertise means industry workshops have added value for participants: workshops allowing different professional perspectives to come together in a relaxed forum to share opinion. Additionally, construction software providers are likely to be very positive towards research teams that offer them links with industry and government agencies (as the BIM Risk Library project did), whilst a research project that has a governmental entity as part of the research team brings with it distinct advantages. For research teams about to engage in health and safety research work, recognising the unique differences of construction industry and catering for them, can result in more fruitful research outputs and longer sustaining relationships.

The research project has now (Sept. 2020) proceeded to a further stage of industry engagement, with several pilot projects being planned to test and refine the tool in real construction design work settings on multiple projects with multiple design and construction organisations. These closer industry interactions will bring further issues forward and highlight more lessons regarding academia and industry engagements.

Acknowledgements

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A Case Study on the Use of SafeSim Investigation Simulation Game to Improve Incident Investigation Education

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Abstract

Effective incident investigation is an important element of a workplace safety and health (WSH) management system. However, learning incident investigation requires an authentic context, which is difficult to create in an Institute of Higher Learning (IHL). An educational digital simulation games (DSG) can provide an authentic experience to undergraduate students to learn incident investigation skills. Therefore, the aim of the study is to evaluate the difficulties, advantages and disadvantages of developing and deploying a DSG for teaching incident investigation in an IHL to improve the use of simulation games in WSH education. A prototype three-dimensional multiplayer DSG called SafeSim Investigation was developed to provide an authentic learning platform for Project and Facilities Management (PFM) students. The game is structured in two parts where in the first part, students role-play as a team of three incident investigators. Students are required to collect evidence in the virtual site which is guided by an incident analysis technique taught in lectures. By interacting with non-player characters, collecting objects and analysing documents will help students to unlock information about the incident. Students also must respond to quizzes within the game and receive immediate feedback for their responses. In the second part of the game, students are to recommend appropriate actions to improve WSH of the site based on their findings. At the end of the session, the system will calculate the students' scores and students can review their performance. Both practitioners and students provided positive feedback during the study, but they also provided numerous recommendations for improvement.

Keywords: accident causation theory, authentic learning, construction health and safety, incident investigation, safety training, simulation game, workplace safety and health

Introduction

The construction industry exhibits significant workplace safety and health (WSH) risk as it remains the top contributor for workplace accidents and fatalities around the world. The United States reported an increase in fatality cases from 971 in 2017 to 1,008 in 2018 (Bureau of Labor Statistics, 2019). In Singapore, the Ministry of Manpower (2019) reported that the construction industry is the main contributor for workplace fatalities in Singapore in the same year and accounts for a fatality rate of 1.6 per 100,000 workers. It is crucial for workers to identify and understand the root causes of an incident to prevent similar occurrences in the future. Therefore, an effective incident investigation is an important element of a WSH management system as it helps to determine the causes of an incident and facilitates improvement of the WSH management system.

The complexity of the dynamic and unpredictable conditions in the construction industry makes it difficult for inexperienced personnel to understand how to conduct investigation in the industry. Furthermore, it was suggested that the pedagogical method adopted in construction safety and health training and education were inadequate (Bell et al., 2001; Dipiro, 2009). There it is especially challenging to teach incident investigation to undergraduates with no industry experience. Furthermore, learning incident investigation requires an authentic context, which is especially difficult to create in an Institute of Higher Learning (IHL). It is not possible for undergraduates to be involved in actual incident investigations due to safety, confidentiality and logistical reasons. The author faced these challenges while teaching an undergraduate elective WSH module in the Project and Facilities Management (PFM) programme in the Department of Building, National University of Singapore.

An educational digital simulation game (DSG) can allow undergraduates to be immersed in an authentic learning environment (Galarneau, 2005), which will help to improve their competency in incident investigation. DSG-based learning provides a safe, cost-saving, and interactive virtual world where students are free to explore and thus, increase their engagement with the topic. Additionally, the simulation game allows provision for undergraduates to make mistakes – which is a form of interactive authentic learning, helping them to understand the process and how their actions affect the outcome of the investigation.

Therefore, in this paper, we will introduce an educational DSG prototype, SafeSim Investigation, that was built based on the nine principles of authentic learning to provide an authentic experience to undergraduate students learning incident investigation (Herrington & Kervin, 2007). The game requires players to collect evidence to unlock clues and recommend actions based on the evidence collected. This paper presents the prototype SafeSim Investigation as a qualitative case study of how a simulation game is designed to implement the pedagogical concept of authentic learning to improve the WSH education is IHL.

Literature Review

Issues in Construction Safety Education and Training

Most construction education is designed with the assumption that knowledge transfer will occur seamlessly though a lecture-based setting (Jonassen et al., 2006). However, this passive teaching approach limits the interaction between the learners and the educator. Furthermore, the lack of application of WSH knowledge often resulted in graduates entering the industry with inadequate safety skills (Pedro et al., 2016).

Placements or internships and site visits to construction sites can potentially be effective forms of construction safety training and education as it enables students to actively experience real-world problems (Haslam et al., 2005). However, due to its logistical, scheduling and safety issues, attachments and site visits are difficult to arrange. Furthermore, site visits are usually carried out in a controlled manner and guided by a site personnel. This would potentially limit the students' opportunity to explore the site freely and it may create a misconception that construction problems are well-defined and can only be solved in a certain way (Lee et al., 2015).

Authentic Learning and Simulation Games

Authentic learning framework provides a framework to guide the design of learning activities that allow students to conduct realistic tasks, act and make decisions like actual professionals in the field, and produce feasible solutions for specific problem statements (Jonassen et al., 2006). Herrington and Herrington (2006) Have identified the nine principles of authentic learning where educators could adopt to design their teaching and learning activities as shown in Table 10. Herrington and Kervin (2007) Suggested various ways to operationalise the authentic learning framework through different approaches and one of it is using DSGs.

Simulation games replicate reality and they incorporate common game features such as rules and competition (Sitzmann, 2011). Simulation games that are more entertaining is more likely to improve instructional effectiveness (Sitzmann, 2011). Liu et al. (2011) Adopted a simulation game as an approach to guide students' development in computational problem-solving abilities. They found that students who learned computational problem-solving with the game improved their problem-solving skills more than students who learned from traditional lectures.

Evidence of positive behavioural and cognitive changes arising from the use of simulation games have been extensively documented. Games and simulations contribute to cognitive learning outcomes, acquisition of knowledge and understanding of subject matter (Vlachopoulos & Makri, 2017). It also provide safe and interactive virtual worlds where students are free to explore (Guo et al., 2012). The ability to explore freely without any safety implications would increase students' engagement (Goedert et al., 2011). Furthermore, simulation games reward players for completing tasks with increasing difficulty (Vu, 2017), thus encouraging them to continue to learn.

There are considerable benefits for integrating simulations into investigation to facilitate learning from safety incidents. For example, Macrae (2018) used simulation games to improve incident investigation in the context of patient safety. Simulations can be used to develop key competencies in incident investigations such as identifying evidence, interviewing, systems analysis and development of a recommendation (Macrae, 2018).

Table 10: Principles of authentic learning adapted from Herrington and Herrington (2006)

Principles	Definition
Authentic Context	Providing a physical or virtual environment which replicates the way how the knowledge transmitted is used in real life
Authentic Activities	Tasks and responsibilities with real-world relevance, which is ambiguous, complex and to be completed over an extended period
Access to Expert Performance	Having experts in the domain to demonstrate a skill or concept for students to observe and learn from
Multiple Roles and Perspective	Providing opportunities to examine, explore and evaluate problems from the different point of views
Collaborative Construction of Knowledge	Emphasising on teamwork, joint problem solving and social support
Reflection	Opportunity to think about and have a meaning discussion of choices
Articulation	Avenue for learners to present ideas, argue, speak, and write above their growing understanding
Coaching and Scaffolding	Collaborative learning with more able partners to assist and support, and metacognitive help from teachers instead of didactic help
Authentic Assessment	Providing seamlessly integrated assessment within the task with changes to collaborate and produce a polished product

Research Methodology

This study focuses on the undergraduates majoring in Project and Facilities Management (PFM) in the Department of Building, National University of Singapore. The PFM degree programme offers a wide array of modules related to building and construction, and one of the elective modules offered is PF4202 Safety, Health and Environmental Management (PF4202). The testing of SafeSim Investigation game was held during PF4202 tutorial classes. Students were randomly separated into teams of three members at the start of the class. Prior to each session of the gameplay, the tutor will conduct a 10-minute briefing to familiarise the students with the objectives of the tutorial session. The tutor will explain the learning objectives and the controls of SafeSim Investigation. Teaching assistants were also available throughout the tutorial session to assist the students.

Students are also required to complete an online questionnaire at the end of the tutorial. The questionnaire is designed to collect anonymous information of the students' demographic data such as age, gender, and their experience in simulation games. The questionnaire consists of several questions pertaining to the effectiveness of SafeSim Investigation. The questionnaire also collects feedback on the game design, including issues such as user-friendliness and user experience.

The fundamental hypothesis of this study is that "an incident investigation simulation game designed based on the authentic learning framework will improve the perceived authenticity of the learning experience". The prototype SafeSim Investigation game was developed to test this hypothesis and to identify the advantages and limitations in achieving the objectives of the study. In this paper, the game design will be discussed as a reference case study for other educators and researchers intending to implement authentic learning through a DSG. An overview of the game can be viewed through this YouTube video: https://www.youtube.com/watch?v=rGVnmBzR-zA.

Case Study: SafeSim Investigation gameplay

A prototype three-dimensional multiplayer DSG called SafeSim Investigation was developed to provide an authentic learning platform for PFM students. SafeSim Investigation is structured in two parts. In the first part, students role-play as a team of three incident investigators. In the second part of the game, students are to individually recommend appropriate actions to improve WSH of the site based on their findings. The prototype SafeSim Investigation was designed based on the nine principles of authentic learning while still providing the medium for students to understand the procedure and invoke investigative skills throughout their gameplay.

Two subject-matter experts with more than 30 years of construction experience were consulted to provide an accurate representation of the incident cases on construction site. Documentation and content were based on an actual incident case and was modified based on the feedback provided by the subject-matter experts. The virtual world in SafeSim Investigation mimics the actual construction site with a building under construction and a site office. The prototype SafeSim Investigation has a gameplay of about 60 minutes, where the first 45 minutes is allocated to the first part of the game whereby the players will assume the role of incident investigators and collect the different evidence in the virtual construction site, and the remaining 15 minutes is allocated for each player to recommend appropriate actions based on the data collected.

This following discuss the SafeSim Investigation gameplay.

Briefing and Grouping

Prior to each tutorial session during which SafeSim Investigation was played, the tutor will conduct a briefing to explain the learning objectives and highlight that the game objective in SafeSim Investigation which was to investigate the underlying factors of the incident by collecting the evidence found on the virtual incident scene. Teaching assistants were available throughout the session to assist the students. The teaching assistants were required to have played SafeSim Hazards and studied the game mechanics so as to guide the students. Players were briefed on the game controls and at the same time they can access the game guide, which contains the game controls and shortcut keys, at any point in the game by pressing the F1 key. The tutor and the teaching assistants provided the coaching and scaffolding as recommended in the authentic learning framework.

SafeSim Investigation is designed to support a maximum of three players in each team, and multiple teams can be playing at the same time, but in different virtual worlds. Playing in a group also supports the principle of collaborative construction of knowledge highlighted in the authentic learning framework. Team members can communicate with one another through the in-game chat tool. Students are encouraged to use the chat tool to plan their investigation and distribute tasks among their team members. By having the in-game chat tool, it provides an avenue for the players to present their ideas and thus, allowing the operationalisation of the articulation principle of the authentic learning framework. The learning objective of the game is as follows:

1. Identify and evaluate the reliability and usefulness of different WSH evidence,
2. Analyse evidence and information collected using the Event Causation Technique (ECT) (Goh, 2018),
3. Recommend corrective actions and opportunities for continual improvement based on ECT analysis.

Event Causation Technique (ECT) is a technique developed and taught by the author in his undergraduate module (Goh, 2018). ECT is used throughout the game to provide guidance to the players. SafeSim Investigation also provided cinematic to provide the context for the game. In this case, upon logging in using the pre-allocated IDs, the players will be shown a short animation of the player receiving a phone notification about the task given to them, i.e. their game objective (Figure 2). While waiting for the game to load, the game reinforces the players with the controls of the game as shown in Figure 3.

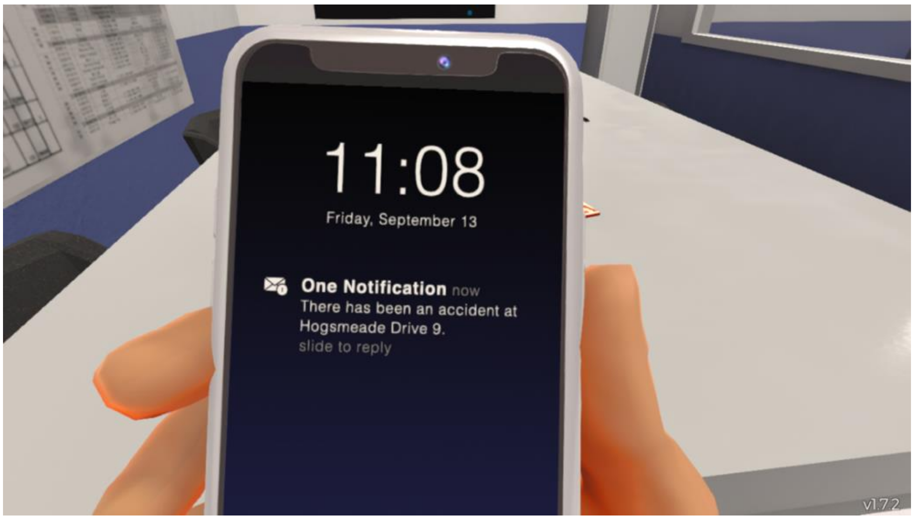

Figure 2: Cinematic to help players understand the context of the game

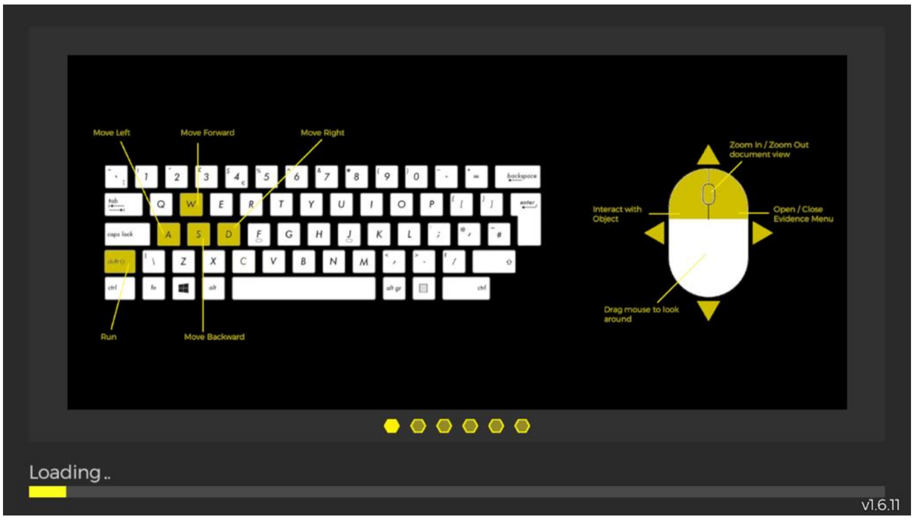

Figure 3: Controls shown on the screen while waiting for the game to load

Collection of Evidence

According to Goh (2018), there are four main types of evidence and they are part, position, people and paper, which is also known as the 4Ps. Evidence under the category of part refers to the material, equipment or parts of the environment, and it is often collected from the incident scene. Evidence in the position category refers to the physical relationship between the part(s) and people involved, and/or the place of the evidence at different point of time. Paper evidence is referred to the documentation involved and often includes close circuit television (CCTV) footage, data log sheets, log books, permits-to-work, and risk assessment. Lastly, evidence that falls under the category of people refers to the interviews gathered from the injured, witnesses and the people associated with the activity.

In SafeSim Investigation, we implemented the 4Ps to categorise the evidence on site. There are three types of evidence that the players can collect in SafeSim Investigation. They are mainly the site evidence, the document evidence and the interview evidence. Players can take up any of these roles (i.e. site investigator, interviewer, document reviewer) at any point of time during the game. Site evidence refers to the items found on the scene or evidence that can be classified as parts according to the 4Ps in incident investigation (Goh, 2018). Document evidence refers to the documentations such as permit to work, medical report, etc. that will help identify the lacking protocols which is classified as paper under the 4Ps (Goh, 2018). Lastly, interview evidence refers to the interaction with the non-playable characters (NPCs) to gather information from the people who were involved when the incident happened (Goh, 2018). Players are expected to find evidence that unlocks the ECT Clue which eventually shows the underlying factor of the accident. It is also noted that evidence collected by other teammates will be recorded into the system to prevent duplication of work.

Apart from correctly identifying the evidence, players are also required to answer the quiz attached to the evidence to obtain a point as illustrated in Figure 4. No points will be deducted for wrongly answered quiz – i.e. they will receive immediate feedback based on their choice. Marks will not be given for the subsequent tries after the answer has been revealed. SafeSim Investigation will also provide a feedback mechanism, whereby it will highlight the correct answer in instances where the player chooses the wrong option.

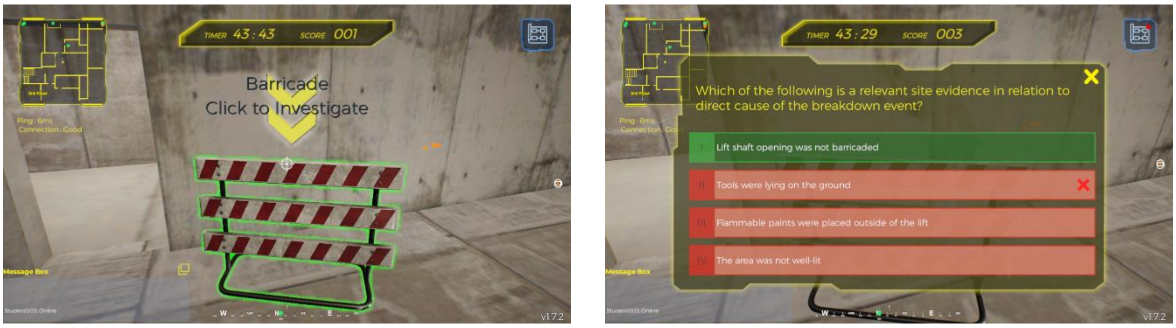

Figure 4: Players will collect site evidence (left) and an interface with a relevant question pertaining to the evidence will pops out to assess the player's rationale (right)

For document evidence, players are required to review the documents and click on the red overlay before it is collected as an evidence. Once the player has collected the document evidence, they are required to click on the 'Quiz' button at the top-right corner to answer the corresponding quiz in order to get the full score and unlock the ECT clue. This is illustrated in Figure 5.

Figure 5: Only items with red overlays are collectable and will count to the scoring system (left) and the quiz window (right)

Interaction with non-playable characters (NPCs)

In order to collect the interview evidence, players can click to interact with the NPCs. A list of questions that can be asked will be available on the right side of the screen as illustrated in Figure 6. To make the conversations authentic, the dialogues of the NPCs were crafted based on conversations found on sites in Singapore and voice actors were used to record the voices of the NPCs. For example, the players will hear the Chinese workers speak in Mandarin and see the translation on the screen.

Figure 6: Players can choose from the list of options on the right to interview the NPCs

Guidance

Proper guidance is crucial in allowing the players to understand the investigative process. Furthermore, majority of the students does not play simulation games and thus, require extra assistance in order to achieve the learning objectives. We provided an Event Causation Technique (ECT) diagram whereby the players can follow through the hints to unlock the ECT clues. ECT guides the investigative process starting with the work context, incident sequence and so on as shown in Figure 7.

The diagram in Figure 7 is easily accessible during the game by clicking on the button at the top-right corner of the game screen. The black cards contain clues to guide players on what, how or who to investigate. For example, for ECT Clue (4) in Figure 7, the player is required to review the Safety Violation List and interview one of the NPCs. Once the player has unlocked the clue, the card will turn green as shown in the ECT Clue (3) in Figure 7. It is also advisable to unlock the cards from left to right as taught by the author in his lectures.

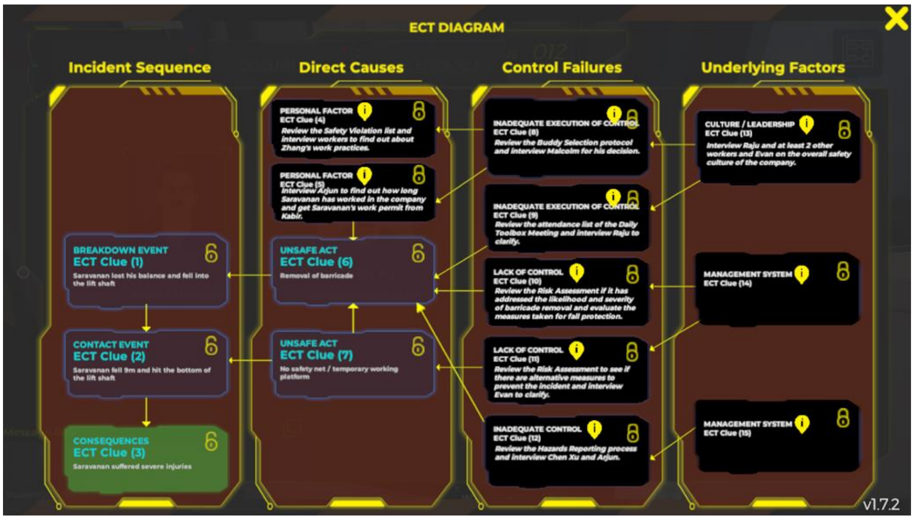

Figure 7: ECT diagram to guide the players

Recommending Actions

Once players have unlocked all the ECT clues, the players will be prompted to enter the second part of the game. A step-by-step guide is offered to the players on how to navigate the user interface. This is illustrated in Figure 8.

Figure 8: Players will be prompted to enter the second part of the game (left) and step-by-step guide provided to guide players of the user interface (right)

We have provided a list of improvement actions on the right, where the players are required to drag and drop to the appropriate ECT clue cards as shown in Figure 9. Players are also required to select the type and importance through the dropdown menu before submitting their answers for scoring.

Figure 9: List of recommended actions (left) and dropdown menu to determine the type and importance (right)

Submission and Review

Once the players have completed both part one and part two of the game, SafeSim Investigation will generate the total score of the player and their teammates as shown in Figure 10. Players can review their collected clues and quiz answers by clicking on the 'Review' button. This allow the players to assess their performance, review the items that has been collected by their teammates, and to see the model answer as shown in Figure 11.

Figure 10: Scoring screen of SafeSim Investigation

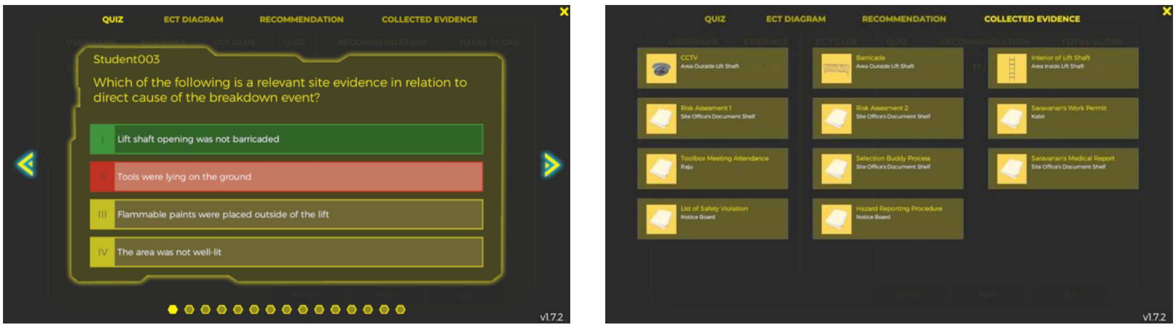

Figure 11: Review of the items collected and see model answers for the quizzes

Analysis

There is a total of 91 participants and all of them are PFM students enrolled in PF4202. Over 67% of the participants have experience in DSG, and over 59% enjoyed playing DSG in general. With a mean rating of 3.13 out of 4, students perceived that the incident investigation simulation game designed based on the authentic learning framework improves the perceived authenticity of the learning experience. Most students find the DSG-based learning realistic and interactive. Students commented that the prototype SafeSim Investigation was engaging and highly effective for their learning. Most of the comments suggested that the authentic dialogues and NPCs voices are highlights of the game.

Conclusions and Further Research

This study presented a prototype digital simulation game, SafeSim Investigation, which was used to teach investigation to undergraduate students and practitioners in adopting educational DSG in WSH education. The prototype SafeSim Investigation game tested by both practitioners and students and they provided positive feedback during the study. The data collected were analysed and based on the feedback given by the students, the prototype game was deemed to be generally effective for learning by the students.

However, there were also several recommendations for improvement. Key considerations are highlighted to improve the gameplay in terms of enhancing the game's intuitiveness and playability for non-gamers. More research and case studies need to be conducted to test the effectiveness of digital simulation games and develop guidelines to improve the effectiveness of WSH education.

Acknowledgement

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Comprehensive needs analysis for the development of construction safety education tools in immersive reality

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Abstract

Construction industry remains one of the most hazardous industries to work in, despite numerous efforts by researchers and practitioners to improve levels of Health & Safety (H&S) and reduce the number of accidents which occur on the construction sites. A potential method to reduce the number accidents is to educate construction workers in hazard identification and to raise their awareness of the risks they face at the construction site through the use of emerging technologies such as Virtual Reality (VR) and Augmented Reality (AR). This paper presents the first intellectual output of an Erasmus+ project titled Construction Safety with Education and Training using Immersive Reality (CSETIR), whose goal is to examine and apply such VR and AR tools to improve the levels of H&S. Through the literature review and discussions with relevant stakeholders, most appropriate training methods were identified for the development of safety educational tools in the following project phases. VR and AR technologies have the potential to train construction workers in H&S, especially those who have little experience in construction safety, workers with literacy limitations and workers that do not speak the local language. Visual training tools, especially immersive ones, also provide better retention of acquired knowledge and skills. An immersive reality safety education tool, therefore, has the potential to increase the levels of construction H&S and to reduce the number of accidents at construction sites.

Keywords : Construction Health & Safety, Safety training, Immersive reality, CSETIR, Needs analysis

Introduction

Construction industry for long has been and still remains one of the most dangerous industries to work in. Across the world, around 6 to 10 % of the workforce is employed in construction (Raheem and Hinze, 2014), while the industry contributes to around 20% of all work-related fatalities (EUROSTAT, 2015, U.S. Bureau of Labor Statistics, 2018). Nonfatal injuries are also very common, with construction industry taking third place in the EU by the total number of accidents and first by incidence rates (EUROSTAT, 2018). Furthermore, since Al-Aubaidy et al. (2019) estimate that as much as 50% of the injuries on the construction site are not reported, the number of accident and the significance of the issue at hand is even higher.

Since traditional accident prevention measures cannot reduce the accident levels to an acceptable degree, various tools are being developed and utilized to reduce the impact of construction work on safety and health of its workers. One of such tools will be a product of an Erasmus+ funded project, titled Construction Safety with Education and Training using Immersive Reality (CSETIR). The tool will allow the creation of virtual environments that simulate construction scenarios, allowing the identification and prevention of risks for teachers, technicians, and engineers. CSETIR aims to develop immersive and interactive VR and AR solutions in order to train construction workers and to prevent accidents.

This paper presents the results of a needs analysis conducted at all project partner institutions: Slovakia, Croatia, Portugal and Greece. Through the literature review and discussions with relevant stakeholders, most appropriate training tools for significant safety issues were identified to enable the development of safety educational tools in the following project phases. The needs analysis provided a detailed understanding of previous research in the field and has shown what are the priorities of the intended users with regards to hazard scenarios in safety training.

Project Background

Based on several literature reviews, involvement in several international conferences, involvement in H&S organizations and the construction sector, it became clear that integrating technologies such as AR/VR into safety training were considered relatively new and were not getting enough attention. After meeting with safety professionals, contractors and consultants from several countries it seemed that enterprises were isolated from academia and were not using advancements of technologies and tools that might assist workers. Although some enterprises demonstrated using some digital education and training techniques, these methods were not reaching their full potential and included a lot of limitations (Soeiro et al., 2020b).

The project was designed based on joint analysis and partners’ know-how and experience, to propose viable solutions. The specific aims for the project are (Soeiro et al., 2020a):

a) Developing, implementing, validating and tuning of interactive IR approaches to promote multidiscipline creativity, innovative thinking, and practical skills in the digital era;
b) Ensuring education and research are mutually reinforcing, and strengthening the role of institutions in their local and regional environments;
c) Exploring synergies and stimulating greater dialogue between HE, enterprises and VET schools, in the scope of community and outreach activities;
d) Supporting the civic and social responsibility of students, workers, engineers and technicians.

To address the goals, the project will develop innovative and interactive AR/VR solutions based on BIM modelling capacities to prevent accidents and train workers. The project intends to create usable tools for teachers, technicians, and engineers that could be used in any construction project. Project also aims at offering training sessions online on an online platform (project website and a wiki page) to grant learners and trainees access to interactive material and resources. These tools will range from applications to be used on smartphones to virtual reality contexts depending on the needs of training (Soeiro et al., 2020b).

Although all workers receive training and orientation meetings, they are not receiving on-the-job, hard-knocks-type training that simulates the site conditions which is necessary since every construction site is unique with different activities, schedules, approaches etc. Many training programs have shown to be effective, but however, they lack the flexibility and the ability to adapt to the current site environments, to be modifiable according to the workers' and students' needs and capabilities and are often not appropriate for people who have limitations or special educational needs, as well as foreigners or immigrants.

An additional benefit of such a "hands-on" experience and digital platforms like BIM and AR/VR simulations will be an innovative way of transmitting the diverse group roles of the construction site in a familiar language to the youth, supporting schools in their efforts to teach and to attract students to continue their education with a creative and interactive mindset (Sidani et al., 2019a). Workers and students will experience a more practical and innovative learning approach, mimicking their actual future professional careers.

Methodology

The first step of the research was to examine the available AR/VR tools on the market, in terms of both research and industrial fields. Due to a myriad of search results, and due to the fact that numerous literature review papers dealing with both application of AR/VR in particular and information technologies in general already exist (Li et al., 2018, Sidani et al., 2019b, Mihić et al., 2019, Zhou et al., 2015), this paper focuses on the most used and readily applicable tools. For each of the tool, a short description will be given, as well as their applicability for project goals in the later stages.

Following the description of the tools, the needs analysis for the project was carried out and the most important criteria were selected. Finally, the tools were graded based on the criteria and the most appropriate one was selected.

The results were validated by an industrial partner since the primary end-user of the tool is the construction industry. The industrial partner is one of the largest construction companies in Croatia with over 30 years of construction experience, with more than 500 employees and with the most developed H&S programme in the region.

Results

This section of the paper will summarize the available and most used tools on the market in terms of BIM-based AR/VR in the research and the industrial fields, as well as list the relevant uses for subsequent intellectual outputs (IO): BIM tools (IO2) and the AR/VR Tools (IO3). The goal of IO2 will be to develop a BIM model library of hazard scenarios, while IO3 will deal with designing and creating actual AR/VR scenarios for safety training.

IO2 will use the results of this paper to determine which tools to use and explore. Several strategies can be considered when addressing the use of virtual environments to improve education and training for safety in construction sites. Indeed, the targets of training initiatives are a diverse group, including site workers, engineering graduate students and safety specialists, among others. The technical skills and education levels for these groups differ considerably, as do their work environments, and functions. This diversity must be considered when defining strategies and solutions, even when the suitable available hardware and software options overlap largely for the different user groups.

Fortunately, the same VR and AR hardware and the software components have been adopted in a range of applications. This is considered as an opportunity, as solutions that target one user group might be adapted for different uses. The main current VR and AR development technologies are cross-platform, which largely reduces the importance of the choice of specific equipment within similar types of hardware such as Head Mounted Displays (HMD) or motion controllers. Naturally, different training environments demand different types of hardware, due to cost, time and other practical considerations. For instance, despite recent developments in CAVE (Computer Assisted Virtual Environment) technology, which allow for lower-cost and quicker deployment, HMDs remain a more practical solution for virtual immersion, while computers and mobile devices are ubiquitous, and provide acceptable VR experiences in many instances.

The use of BIM models as a source of information (including geometry) for the virtual models is regarded as an obvious choice. BIM models are increasingly common in practice, they support different types of information, thus providing great flexibility when deciding on technical solutions, and are compatible with other components such as game engines. Alternative solutions, such as the use of generic 3D modelling tools would require the development of models from scratch, with no relationship with the actual construction process. This means that changes in design or in construction plans would not be quickly or easily reflected in the virtual training environments. These factors greatly reduce the feasibility of a non-BIM solution. Since BIM authoring tools are interoperable, and standard open formats exist for exchanging BIM data, the choice of BIM tools is not considered to be a critical issue when designing a strategy for the development of training solutions.

Overview and analysis of potential AR/VR tools

The research of the available AR/VR tools on the market has discerned the following tools:

1. 3M - Construction Safety Virtual Reality Programs for Hands-on Learning (3M, 2020);
2. CAT Safety VR module (Caterpillar Safety Services, 2020);
3. SRI International Augmented Reality Solutions for Construction Inspection (SRI International, 2020);
4. Safety Compass - Augmented Reality Workplace Safety (Safety Compass, 2020);
5. VR Safety Training for Construction companies – LandMark VR (LandMark VR, 2020);
6. FULmax cube (FULmax, 2020);
7. Role of Visualization Technologies in Safety Planning and Management at Construction Jobsites (Azhar, 2017);
8. A framework for construction safety management and visualization system – SMVS (Park and Kim, 2013)
9. OSHA PIXO safety compliance Virtual Reality (PIXOVR, 2020);
10. Web-based Collaborative Virtual Environments (LIRKIS G-CVE, 2020).
11.

3M - Construction Safety Virtual Reality Programs for Hands-on Learning

3M (2020) has recently released a series of VR construction safety modules. 3M’s virtual reality training platforms are available online. There are several modules on the website for training. This case study is for the preparation and construction phases.

- Software: Revit, 3D Studio, EON Studio, EON Viewer with CAVE.
- Hardware: HTC VIVE, Samsung Gear VR, Oculus Go, 2 Joysticks.
- Potential for IO2: BIM was not an essential tool inside this case study although integrating BIM will help for a training module.
- Potential for IO3: Platform where VR devices may be attached to get an immersive training experience.

CAT Safety VR module

Caterpillar Safety Services (2020) started their VR safety programme with safety in road construction by simulating real-life scenarios. CAT designed the VR tools as a multiplayer environment so a group of workers could train simultaneously. Application is implemented in the preparation phase. Training module presents a wrap-up to reinforce the positive lessons learned and stress that no emergency at the jobsite is worth risking the safety of the worker or anyone else.

- Software: Revit, Game engines.
- Hardware: Gaming laptop preloaded to run the program, HTC VIVE, 2 Joysticks.
- Potential for IO2: BIM is not applied in this safety experience.
- Potential for IO3: Communication and mobile modules are possible contributions.

SRI International Augmented Reality Solutions for Construction Inspection

SRI International (2020) uses AR to simulate job site operations for construction inspectors. By utilizing drones the tool is used for inspection by comparing the footage with BIM models. SRI international AR tool is designed for site inspections. The application targets the construction phase for inspection by safety managers and engineers.

- Software: Revit, several data collection software.
- Hardware: Drones, Vehicles, AR Glasses.
- Potential for IO2: BIM is used to model and inspect possible errors or differences in the construction by comparing it with a BIM model using AR.
- Potential for IO3: AR captures images with headset and tags these with notes for sharing with other devices.

Safety Compass - Augmented Reality Workplace Safety

Safety Compass (2020) gives access to live information which is updated based on the worker’s location. The tool uses AR technology to identify potential risks at the location via mapping on a tablet or phone. This application also allows interaction and collaboration of all construction site personnel.

- Software: Location tracking system (LTS), location database (LD), user identification interface (UII), user database (UD), Revit.
- Hardware: iPhone, AP sensor, computer, GPS.
- Potential for IO2: BIM is linked to the GPS and the mobile app can give risk alerts and notifications based on the location.
- Potential for IO3: Workers will be notified of potential risks pinpointed on an interactive mapping system. The AR app is effective and easy to develop.

VR Safety Training for Construction companies – LandMark VR

In LandMark VR (2020) the participants experience risky scenarios where each one has to choose adequate precaution in order to pass a certifying test. It uses full immersion by visual, sound, and physical effects. It has a multi-scenario selection, supports trainer and trainee real-time guidance, tracks individual behaviour, and can be tailor-made for conducting practical training. The scenarios are created in a CAVE environment.

- Software: Revit, 3D Unity.
- Hardware: CAVE, HTC VIVE, high-performance computer.
- Potential for IO2: The application did not demonstrate any BIM integration.
- Potential for IO3: Training solutions and scenarios were used with low-cost equipment.

FULmax CUBE

FULmax (2020) CUBE provides possibilities to communicate, share and collaborate as a team in an immersive BIM environment. It may introduce stakeholders to the virtual asset before it is built. The system may educate and train personnel and communicate onsite, simulate operational based activities virtually before setting foot on site. The tool may provide a dedicated BIM space for virtual exploration of the built asset coupled with the associated valuable BIM data. BIM models and data are processed in minutes for the FULmax environment. It is easy to navigate and to explore the digital asset and to access BIM data, it is a compact solution and it is ideal for reviews, stakeholder engagement and collaboration.

- Software: Unity platform.
- Hardware: FULmax CUBE system with projectors and projector screens.
- Potential for IO2: BIM models are used for creating virtual environments.
- Potential for IO3: Can support more than one person training at a time.

Role of Visualization Technologies in Safety Planning and Management at Construction Jobsites

The research (Azhar, 2017) used advanced visualization technology applications for safety in building projects which was tested in three projects, on their 4D BIM models. Only commercially available tools were used and tested by designers, engineers and contractors. The application targeted preparation and construction stages and the developed tools were used to train workers.

- Software: Revit, Sketchup, 3Ds Max, Unity 3D, AutoCAD, Synchro, MS Project, Camtasia, MS Movie Maker
- Hardware: Oculus Rift
- Potential for IO2: BIM was used in 4D simulations.
- Potential for IO3: VR used common and affordable tools.

A framework for construction safety management and visualization system (SMVS)

The proposed SMVS (Park and Kim, 2013) tool is centred on a visualization engine for the integration of all information. Visualization engine is the hub of the SMVS that imports and exports external information such as BIM-based site model, safety information data, and sensor signal location data that is created in other software engines for its use in each system module. Microsoft XNA Game Studio 4.0 program environment has been employed considering the interoperability of data necessary to the system operation. All information from/to interfaces of the modules is displayed on the visualization engine browser (VEB). It is a framework for safety management and visualization system (SMVS) that integrates BIM, location tracking, AR, and game technologies. A prototype system has been developed and tested based on an illustrative accident scenario.

- Software: Microsoft XNA Game Studio 4.0, Visualization engine browser (VEB), risk identification interface (RII), location tracking system (LTS), location database (LD), user identification interface (UII), user database (UD), Revit.
- Hardware: iPhone, AP sensor, computer, GPS, mouse, keyboard, joystick.
- Potential for IO2: Integrates BIM with other tools.
- Potential for IO3: Game engine might be suitable due to interoperability.

OSHA PIXO safety compliance Virtual Reality

This training module (PIXOVR, 2020) for safety compliance tries to achieve realism in the virtual environment. Training processes explore these environments which also feature construction. For example, one mode is a safety sweep that tries to find potential OSHA violations, faulty equipment, inadequate storage of hazardous materials, and co-workers not wearing safety gear or working unsafely. It comprises of digital tests and assessments based on OSHA standards. This application focuses on the preparation and construction stages.

- Software: Unreal Engine.
- Hardware: Oculus Rift, Leap Motion, high-performance computers.
- Potential for IO2: Environments do not seem to be modelled in BIM.
- Potential for IO3: Training is based on OSHA standards, assessment is digital, randomized scenarios, several training methods and detailed in terms of graphics, sound and scenarios making it fully immersive.

Web-based Collaborative Virtual Environments (LIRKIS G-CVE)

Collaborative virtual environments mediate interaction in virtual space among more participants that may be spread over large distances. Globally, multi-user groups can participate together in one completely immersive virtual environment to achieve goals. Distributed virtual environments can be purposely used as training tools for real-time 3D simulations or scenarios. Benefits of G-CVE are (LIRKIS G-CVE, 2020): multi-user, no expensive software or hardware needed, web-based (only web browser needed), without installation of any software, works on any operating system and any device (also with Oculus, HTC, MS Hololens products), switch to VR mode (with VR headset), open-source.

- Software: Web-based system, built on top of the Networked-Aframe framework.
- Hardware: Any online device/any operation system, any headset - Oculus, HTC, Microsoft Hololens, etc.
- Potential for IO2: BIM models can be imported into the tool
- Potential for IO3: Training solutions and scenarios executable on any device.

Needs analysis

The aforementioned cases were all studied to see which one or which ones would be best fitted to the goals of the project. Needs of the project were analysed and through a session with all project partner institutions and industry partners. The following needs of the project and consequently the deciding criteria were identified:

- Is the tool available for use
- Is the tool proprietary or freely available, and if proprietary is it affordable
- What are the hardware requirements (for computing power)
- Is any additional special hardware needed (i.e. special hardware elements, not including Head Mounted Displays (HMD))
- Does the tool have a desktop version in addition to a full virtual environment
- Does the tool have a smartphone version (i.e. for Samsung Gear) in addition to a full virtual environment
- Does the tool support multiple platforms (supports more HMD's such as HTC Vive, Oculus Rift…)
- Does the tool require additional supporting software, and if yes, is it available to use
- How detailed and realistic can the virtual environment be
- How simple is the tool to install and to use
- Does the tool support multiple users in VR at the same time
- How simple would it be to replicate the research results outside the project partners' institutions
- Is the tool appropriate to teach Health and Safety related topics
- What hazards/scenarios are available in the tool
- Does the tool support the import of user generated BIM models
- Does the tool support creating additional scenarios
- Does the tool have open source, enabling modifications to suit the user's needs

Initial brainstorm yielded 17 of the possible criteria for selecting the most appropriate tool. This number of criteria is too large to model a solution for the problem at hand, so in a further session, the criteria were prioritized and 8 of them were used in the decision making process.

The first and most important (and eliminatory) criterium was the availability of the solution. If the tool is not available for use, then all other characteristics are irrelevant. The second eliminatory criterium would be whether the tool is suitable to teach Health & Safety (H&S) topics. Other 6 criteria serve to differentiate and prioritize remaining tools to determine which would be more appropriate. Those were the ability to create and customize scenarios, the possibility to have multiple users, having open source, being able to support various HMD's and to have mobile and desktop versions. Furthermore, the tool needs to be fairly simple to use and to replicate in outside the project partners' institutions. The tools and their characteristics with regards to the criteria are shown in Table 11.

Table 11. Comparison of the identified tools based on the selection criteria

	The tool is available	The tool is suitable to teach H&S topics	Ability to create and customize scenarios	Possibility to have multiple users in VR	Has open source	Supports various HMD's	Has mobile and desktop versions	Possible to use and to replicate in outside the project partners' institutions
1. 3M	YES	YES	NO	NO[1]	NO	YES	NO	YES[2]
2. CAT	YES	YES	NO	NO[1]	NO	NO	NO	YES[2]
3. SRI	YES	NO	NO	NO[1]	NO	NO	NO	YES[2]
4. Safety Compass	YES	NO	NO	YES	NO	NO	YES	YES[2]
5. LandMark VR	YES	YES	NO	YES	NO	YES	NO	YES[2]
6. FULmax cube	YES	YES	YES	YES	NO	N/A	NO	YES[2]
7. Visualization Technologies in Safety Planning and Management	YES	YES	YES	NO[1]	NO	YES	NO	YES[2]
8. SMVS	YES	YES	YES	NO[1]	NO	YES	NO	YES[2]
9. OSHA PIXO	YES	YES	NO	NO[1]	NO	YES	NO	YES[2]
10. LIRKIS G-CVE	YES	YES	YES	YES	YES	YES	YES	YES

[1] Only one user in VR, however others can watch on a separate screen

[2] Possible, but the intended user needs to buy the software and/or special hardware

After careful consideration of all identified technologies and having these requirements and criteria in mind, the tool "Web-based Collaborative Virtual Environments (LIRKIS G-CVE)" was chosen as the most suitable to use the BIM models and advantages of immersive reality tools for construction safety education. Final selection of the tool will however be carried out after all hazard scenarios are defined.

Discussion

This research identified 10 potential AR/VR tools to be used for safety training in the project. The tools each have a different goal and some were not initially intended for H&S training. For each of the tools, a short description was given, followed by information on what hardware and software is needed, as well as what is the tool's potential for use in the following project stages.

There were several BIM programs used by the tools, but major and most used was Autodesk Revit with the combination of BIM 360 for tracking, collaboration and document management. Along with Revit, other 3D and visualization software were used like 3Dmax, Blender, AutoCAD, ArchiCAD, Bentley and SketchUp. Visualization methods of the tools were structured as a gamified structure for training and risk predictions of accidents. Other methods based on BIM models rely on tracking devices to obtain an onsite visualization of the models, safety information data and sensor signal location data.

For gamification, most tools use Unity and Unreal Engine, and some use specialised or proprietary software for virtual scenario generation. On the hardware side, tools use either HMD's or CAVE systems, while some also feature a desktop or mobile version. Cost-effectiveness, availability of both hardware and software, and multiplatform support are important factors since the final safety training tool should be as widely available as possible. Some other selection criteria will be the ability to model custom scenarios, simplicity to use, multi-user support, etc.

The identified tools were presented to the industry partner and discussion was held on the possibilities to use each of them for safety training purposes. The partner validated the tools as having indeed the potential for safety training, with LIRKIS G-CVE having slight lead due to adaptability and multi-user support. Final selection will, however, only be carried out after precisely defining which hazard scenarios will be modelled for the safety training tool.

Conclusion

Construction safety training programmes exist in various forms, but mostly they are lecture driven, with no hands-on experience. This is not surprising since putting novice workers and students in potentially harmful situations is not possible and not feasible. For this reason, using immersive reality in safety training has gained some interest from the practitioners. Immersive reality can overcome the effectiveness issue of non-practical lectures and the ethical limitations of purposely putting people in harm's way. However, software solutions are not yet mature enough to offer complete safety training programmes.

The project described in this paper aims to aid in the effort of providing safety training in immersive reality. It plans to do so by developing a methodology for hazard scenario generation, as well as a few hazard scenarios. The first step of the project is described in this paper. It consisted of identifying what tools already exist in the market and checking for their suitability for the project goals.

One of the greatest limitations of the research is it not being a complete and comprehensive review of all AR/VR tools available for the construction industry and construction safety. However, such a comprehensive review was not the goal of the paper since literature review papers have already covered the topic. Furthermore, for a more comprehensive validation of the chosen tool, other contractors should be included, since each of them has their own specific safety issues and view of the topic at hand.

Future research steps are defined in the project documents and research on the next intellectual output regarding the use of BIM models in the AR/VR environment is already underway.

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Continuous Automation of Jobs in the Construction Industry and the threat of increased unemployment in the 4th Industrial Revolution: Are there Mitigation Strategies?

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Abstract

The world is currently in the age of the Fourth Industrial Revolution (4iR) defined by genetic developments, artificial intelligence (AI), robotics, autonomous consumer goods, 3D printing, and biotechnology. While this Revolution appears to make life more efficient than ever, jobs that once needed are easily being replaced by automated technologies that can do the job faster and more efficiently. As such, the most important impact of the 4iR appears to be its effect on the workforce. In construction, Automation is fast displacing workers, and as the 4iR era advances, it will progressively impact more heavy inertia on conservative industries like construction. This study identifies the skill levels and occupations that are at risk in the construction industry and recommended solutions to mitigate the impacts of the 4iR. Through a review of available literature, a general outlook of the impact of the 4iR in the South African job market is outlined. After that, the kind of jobs at risk in the construction environment is outlined, followed by an overview of the implication of the findings for South African construction. Based on this, solutions are suggested as implications for the future of work in construction and conclusions are drawn.

Keywords: 4iR, Automation, Mitigation strategies, Skills development, South Africa

Introduction

The Fourth Industrial Revolution (4iR), is characterised by the fusion of technologies, which blurs the lines between the physical, digital, and biological spheres (Schwab, 2016). In terms of the world of work, Oosthuzien (2017) considered that workforce transformation is inevitable due to 4iR. This Revolution, with its potentials, is making life more efficient, as people can now access information easily through smartphones and make financial transactions through FinTech (Bray, Frankenfeld, & Lincoln, 2019). The main focus of this study will be Automation, specifically. While there are several benefits, the potential impact of the Automation on the construction workforce, particularly in the South African context has not been researched.

The World Economic Forum (2016) suggested that in less than five years, over one-third of skills that are considered important in today's workforce will have changed. While Automation has played a significant role in displacing manufacturing workers, Manzo *et al* (2018) note that as technology advances, it will progressively impact more industries including heavy inertia and conservative industries like construction. As Gaspar *et al* (2018) concluded, the ability to correctly interpret and perceive changes due to increased penetration of Automation in the workplace will allow the current and future workforce to gain a higher level of awareness that will help prepare for and adapt to the work paradigm change. Hence, this paper identifies the occupations that are at risk in the construction industry and suggested solutions to mitigate the impacts of Automation on the construction workforce. Therefore, the paper first, presents an overview of Automation and the current workplace, followed by the implications of the findings, mitigation strategies for South African Construction and conclusions.

Research Methods

A systematic review of the scholarly literature was adopted for the study. 4iR and Automation are broad concepts that include a large number of related constructs and themes. Therefore, the following search terms were used to match the focus of the study to the literature search: 4iR/Automation/Skills Development/Unemployment in North America, Europe, South America, Asia, Australia, Oceania and Africa. Concepts, theories and themes such as 'Automation adoption', 'Skills Development', and 'Unemployment' were used to extract information from the selected articles.

The literature search conducted on Google Scholar, Primo and University of Cape Town's electronic library (https://www.lib.uct.ac.za/&usg=AOvVaw2GdHaMTdj-w9NKfJLgwJpA) mainly retrieved 'grey literature' such as non-peer-reviewed articles, reports, theses, dissertations, and books. This suggests the newness of the study area, especially in the context of the construction industry and South Africa. Furthermore, as a supplementary search, all articles that have cited articles that are relevant to the study were reviewed in other to ensure that the search is comprehensive.

The Automation and Current Workplace

The Organisation for Economic Cooperation and Development (OECD) conducted a study based on jobs data provided by the organisation's 32-member countries to estimate the risk of Automation for specific jobs for adult skills (Nedelkoska & Quintini, 2018). According to this study, the functional loss due to Automation has a bias towards the level of education required for that occupation, except for some relatively low-skilled jobs – notably, personal care workers. While South Africa was not included in this study, the data is relevant since the member countries vary from high skill service-based economies like Norway and UK, manufacturing-based economies like Germany to low skilled economies like Slovakia. These findings suggest a rather monotonic decrease in the risk of Automation as a function of skill level (Nedelkoska & Quintini, 2018). As indicated in Figure 1, professional occupations (higher education) have a 45% to 28% chance of being unemployed while technicians, assistants and workers have a much higher chance ranging from 64% - 42% of being unemployed.

These finding of a monotonic decrease in the risk of Automation as a function of skill level is aligned to studies undertaken in the construction industry by Jones (2016 and 2018) in the United States of America. According to Jones (2016), 77% of jobs in construction (in the USA) are at risk because most of the current robots are good at simple and repetitive tasks such as bricklaying and rebar tying while operating engineers have an 88% chance of job loss to Automation. This is due to the technology for autonomous heavy equipment already at play like self-driving vehicles, roofers at 31%, construction labourers at 35% and sheet metal workers at 39% while other occupations have a smaller potential for Automation (Jones, 2018). Jones (2018) cites the dynamic and unpredictable nature of construction sites as the main reason for this level of potential job loss in the sector.

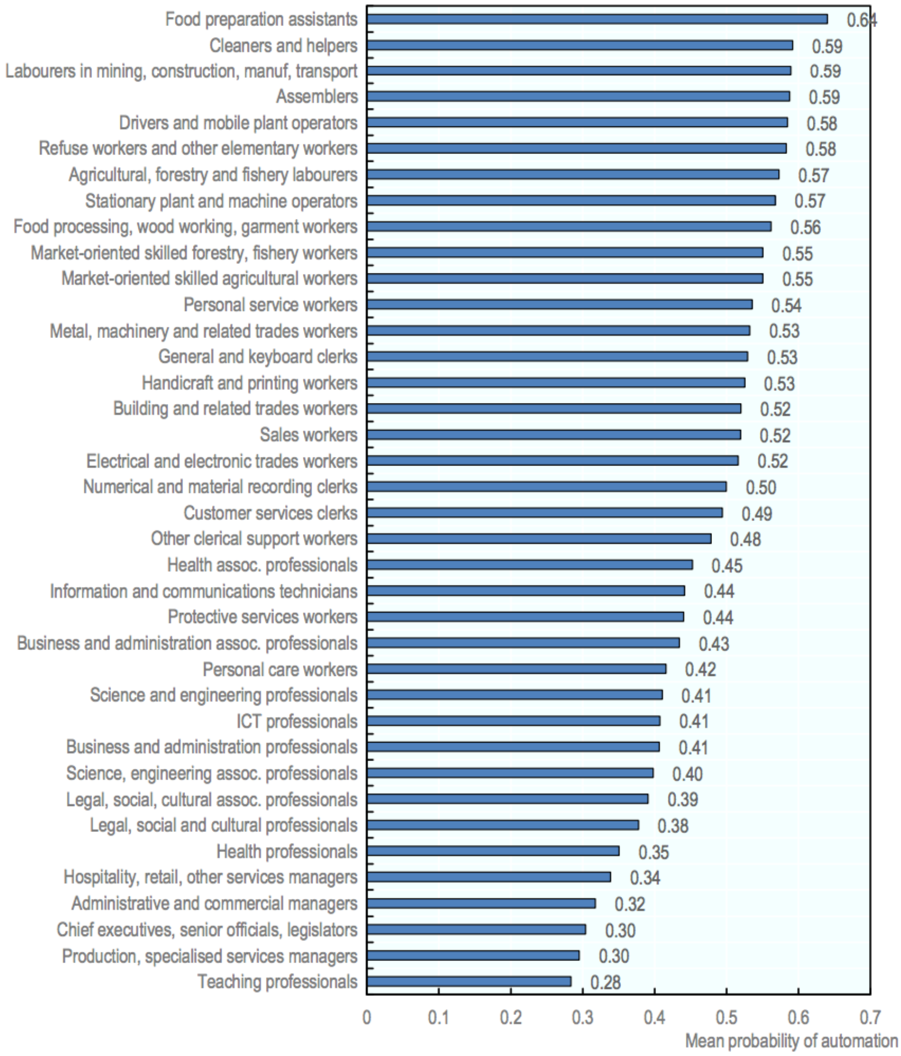

Figure 12: Mean Probability of Automation by occupation (Nedelkoska & Quintini, 2018)

The literature suggests that likelihood of the loss of jobs due to automation declines with the level of education, with the level of measured skills, the unpredictability of the task (an example would be a low skilled occupation like roofing) and with the wage level across almost all countries, suggests that this wave of Automation is skill-biased. However, the study undertaken by Nedelkoska and Quintini (2018) did not support the hypothesis that Artificial Intelligence (AI) already has a measurable impact on the job security of occupations characterised by high levels of education and skills and high degrees of non-routine cognitive job tasks. On the other hand, AI appears to affect low-skilled repetitive jobs more significantly than previous waves of Automation.

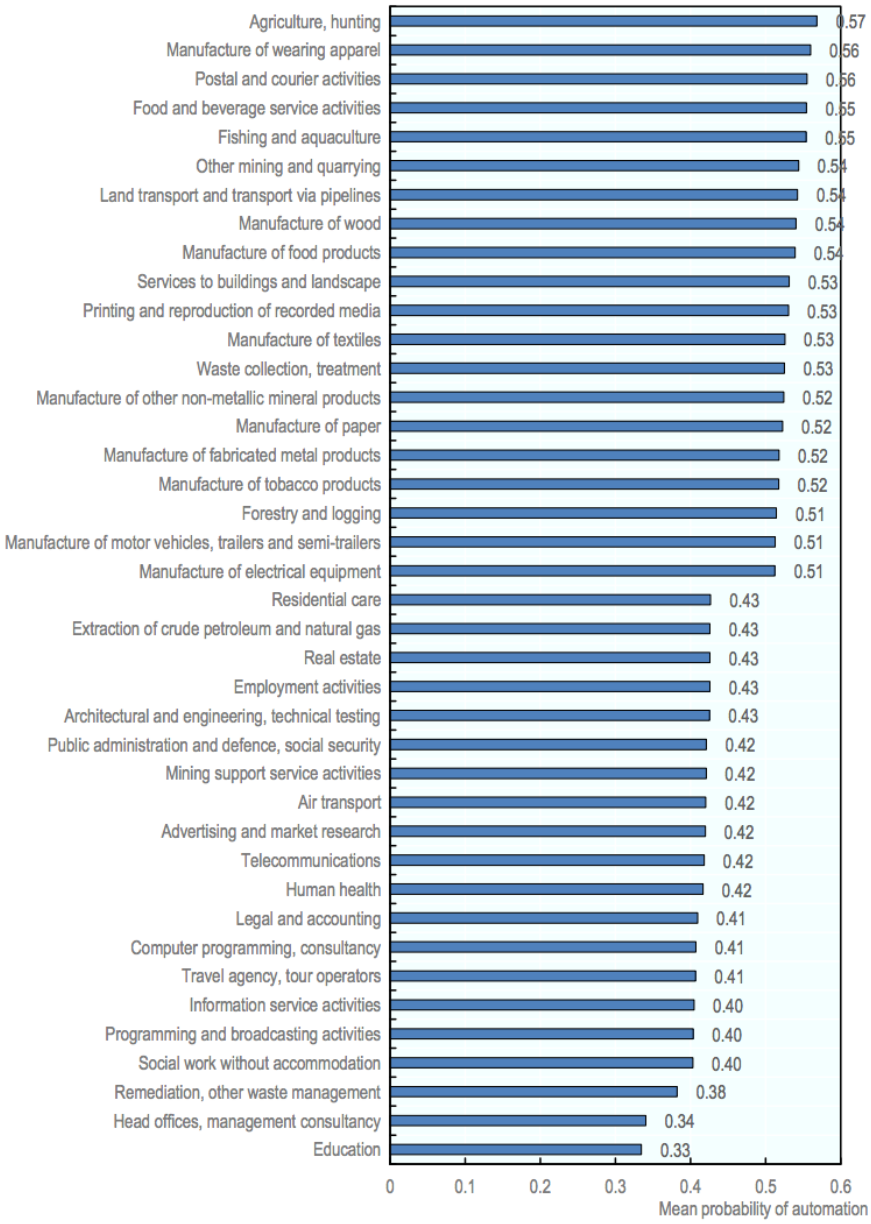

Figure 13:Mean probability of Automation by industry (Nedelkoska & Quintini, 2018)

Studies in the South African context also suggests that many construction jobs are at risk. According to a report published by a global consultancy company - Accenture (2018), 35% of all jobs in South Africa are currently at risk of total Automation. This means that machines can perform 75% of the activities that make up these jobs (Business Tech, 2018). Just like the OECD report, both indicate low skill blue-collar and white-collar jobs are at risk. With many of them being low skilled and repetitive work, see Figure 3). The job types in South Africa that will be affected would include those of general workers/labourers (tasks which require no particular skills), repetitive tasks such as bricklaying, roofing, plastering and rebar tying.

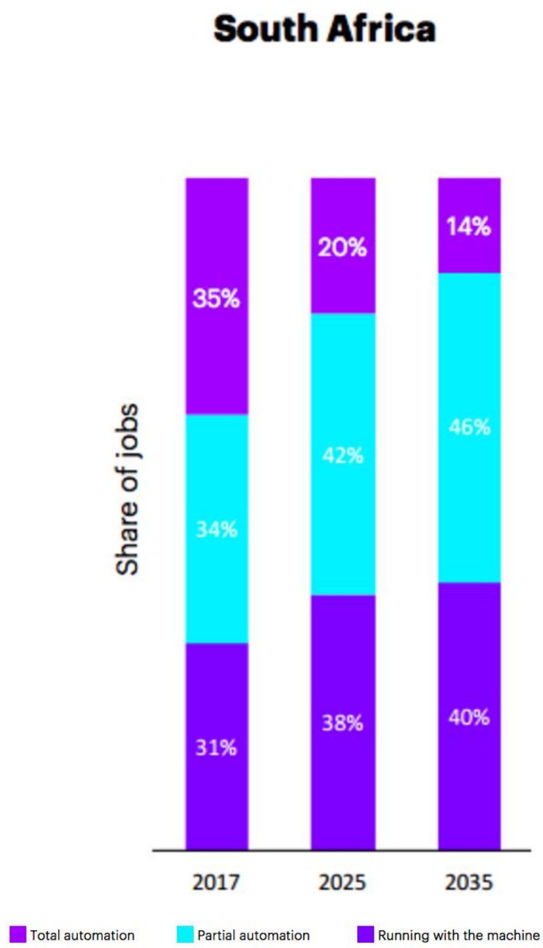

Figure 14: Jobs at risk of Automation (Accenture Consulting, 2018)

However, even though Automation of repetitive tasks is the highest, humans are still needed to set up the robots to perform the work and monitor the quality of work. As Gaspar, Juliao and Cruz (2018) acknowledged, the major challenge of current industry leaders is not on the technology and its fast-pace evolution, but the people, that is co-workers. The more likely scenario is that a small number of jobs and occupations may be eliminated or replaced by robot workers. Gaspar et al. (2018) posited that most jobs would remain with humans working in conjunction with robots performing more of the repetitive and laborious tasks, allowing workers to be more productive and efficient by focusing on the highly skilled tasks of their job.

Implications of the finding

This exploratory study found that the risks of jobs to be lost to Automation are those that involve repetitive tasks, skills level, and level of education. This finding implies that Capital's (big money) share of the construction industry will increase, while the amount of money that goes to workers will reduce, which can reduce the quality of life for the workers, their ability to pay for essential services, which can hurt the economy on the long run due to reduced consumption by workers. These findings also imply that new job opportunities and occupations will be created as robots make their way to the construction site, the machines will need to be repaired and maintained just like any other machine.

Despite the relatively limited impact on workers (mass unemployment not being a threat but a reduced share of the industry while Capital gets an increased share of the industry due to paying lower wages) and the benefits due to the adoption of these new technologies, the construction industry is still going to be slow to adopt the new technology. Mainly because the construction industry is conservative based on old traditions and standards of operation; therefore, the impact of Automation will take some time to be embedded in the sector. As a result of this long lead time, there is ample time to come up with robust solutions to mitigate the risks that Automation will have on the workers, jobs and the economy. It is important to note that Automation could cause far more damage to nations like South Africa, with a young population and large labour pool/unemployment (29.1%) of mostly an unskilled population (Stats SA, 2020), than it would be for first-world nations, ageing population and dwindling labour pool, that is advancing Automation as an alternative.

Mitigation Strategies for South African Construction

To successfully embrace Automation and the 4iR paradigm and deal with the potential for job loss, political and economic consequences of the era in the South African construction industry, multiple solutions will have to be implemented. This will involve different stakeholders considering that all parties stand to either lose or gain from the use of Automation in the construction industry. Hence, the following recommendations are made to deal with labours' reduced share in the industry:

1. Capital must develop a 4iR Leadership effectiveness framework. More often than not, when dealing with the impacts of 4iR (a recent example would be the planned layoffs of South African bank employees), there is always an emphasis on the workforce “upskilling” themselves after the fact rather than company’s who benefit from these upskilling paying for the development of the requisite skills. The 4IR Leadership effectiveness framework (Alade and Windapo, 2020) for construction organisations shown in Figure 15, advances that leadership, especially in moments of uncertainty and change is beyond a position or title. Instead, it is a process of influencing others to understand and agree on what needs to be done, how it should be done, whilst facilitating individual and collective efforts to accomplish shared objectives.

2. Knowledge and understanding of the 4IR landscape will be essential for leaders, and strategic positioning will facilitate effectiveness. At the personal level, construction executives should be change intelligent, and be conversant with their change leadership style to adopt the 4IR strategies for effectiveness.

3. Public policymakers should collaborate with educational institutions to foster a trained workforce prepared for the jobs of the future. So long as machines cannot perform the varied tasks that humans can complete, they remain imperfect substitutes. Hence, workers will experience a rise in demand for complementary roles, which can lead to higher wages as such workers displaced by Automation must be provided with the education and complementary skills to design, produce, operate, and work alongside robots, drones, and other artificial intelligence technologies. As such, states and local communities should invest in vocational training and worker retraining to ensure that displaced construction workers become employed in new sectors and benefit from the potential gains of the automated construction industry.

These investments would require funding and grants to make post-secondary education more affordable but would make career transitions easier for displaced construction workers and improve sectoral mobility in the labour market. Additionally, states also need to boost investments in science, technology, engineering, and math (STEM) programs at public elementary and secondary schools (Manzo, Manzo, & Bruno, 2018).

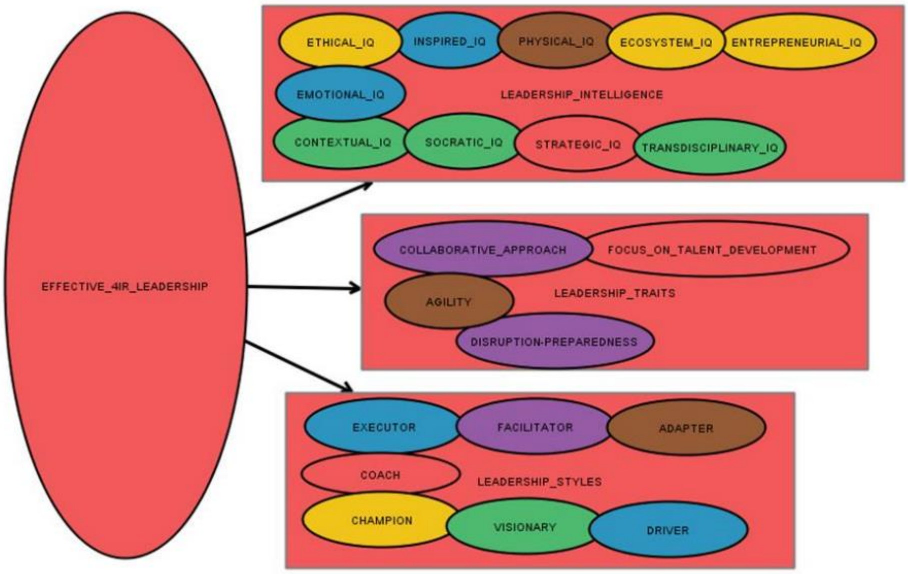

Figure 15: 4IR Leadership effectiveness in Construction business organisations (Alade & Windapo, 2020)

4. Construction workers should be prepared for the evolving workplace and life-long learning. As the world of work is changing, it is essential to re-orientate the construction workforce to align them with 4iR realities. Sensitisation and creating awareness will help the workers to upskill for digital skills and position them for continued relevance.

5. Public Policymakers can tax manipulate the behaviour of Capital. Since Automation is going to improve the productivity and result in capitals increased share of the constructive industry, Capital should play its part in mitigating the effects of 4iR on its employees and the broader economy. This can be done by increasing the taxes of companies that adopt 4iR to redistribute some of the wealth to its workers while offering to reduce it if the companies are willing to provide training to workers to increase their skills and make them more prepared for a changing work environment.

Conclusions

The Fourth Industrial Revolution is upon the world and the COVID-19 global pandemic which disrupted the world in recent times has further created the path for digital realities. Studies have shown that 4iR will make life and work more efficient and safer than ever before in human history. This will elevate the daily tasks consumers and workers do but consequently resulting in massive unemployment or reduced labour share of the industrial sector, including construction, which can result in economic contraction. The paper established that the lower the skill level, the lower the level of education required and the more repetitive the occupation, the more likely that the task performed will be taken over by Automation or robots. These include tasks such as bricklaying, roofing, plastering and rebar tying. However, the increased likelihood of Automation will not lead to significant unemployment in construction, but reduced labour share.

The contribution of this study to knowledge is to highlight the impending future since industries are embracing Automation. The paper is intended to draw the attention of developing economies to the need to start looking into how the upcoming youths, unemployed and low skilled construction workers can be trained/retrained with skills that will enable them to participate in the new era. Skills such as complex problem solving, creativity, decision making, critical thinking. Skills development programmes should be less routine in nature. This study suggested strategies to mitigate the effects of Automation, particularly in the South African context. Although there are theoretical justifications for the concept advanced in this paper, these have not been tested. This is an emerging area that requires more studies to establish the idea empirically.

Acknowledgements

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Measurements for sustainable infrastructure development: A review on sustainable development goal 9

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Abstract

Plans to develop infrastructure in any developing economy is crucial for the wellbeing of the public and the productiveness of the country, however the existing plans fall short in completely addressing measurements of sustainable infrastructure development. In support of the United Nation's Sustainable Development Goal 9, on the need for building resilient and sustainable infrastructure this study further assesses measurements for sustainable infrastructure development. The desk study used secondary data to determine key measurements for sustainable infrastructure development. The research paper is part of a broader ongoing study on sustainable infrastructure development thus the need to collect primary data for this research paper at this stage was not necessary, additional literature still needs to be reviewed before undertaking any field work. The reviewed literature revealed that economic, social, environment, project administration/management, stakeholder engagement, technology and innovation, health and safety and service performance were crucial measurements of sustainable infrastructure development. The study further identified policy as a significant measurement that assists in carefully planning and recognising how infrastructure facilities and services meet the needs of the end user. Every nation should prioritise the development of its own indexes similar to the ones by World Bank (Logistics Performance Index) and World Economic Forum (Global Competitiveness Index), to carefully measure and improve infrastructure development, more so, measures to prioritise and prepare for risks of the existing infrastructure should be pursued, this should clearly show consequences and probabilities of the expected risk. The study is limited to secondary data, no primary data was collected. The study is relevant to the ongoing project on sustainable development and can also be of support to researchers and institutions that are tasked with conceptualising the delivery and monitoring of sustainable infrastructure facilities and services.

Keywords: Infrastructure development, Sustainable development goals, Logistics Performance Index, Global Competitiveness Index, Gross domestic product

Introduction

Sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and development, 1987). Current existing infrastructure fails to live up to the expectations of the definition. Even with the performance benchmarks for infrastructure development established by both the Global Competitiveness Index (GCI) and the World Bank (Logistics Performance Index (LPI)) (Ugwu and Haupt, 2005). World Economic Forum (2015) shares that there is still a great need for infrastructure development in developing economies. Achieving sustainable development and ensuring environmental sustainability are key goals for infrastructure development, as means to ensure the socio-economic well-being of different communities. This study addresses sustainable infrastructure development measurements that have not yet been considered collectively in the current literature. Sustainable development encompasses advancing infrastructure development through economical, societal and environmental pillars. Hong Kong and South Africa have taken extra steps to promote sustainable development, programmes and initiatives have been put in place to ensure that the objectives stipulated in Rio Declarations on Environment and Agenda 21, as well as the South African summit held in 2002 will be met (Ugwu and Haupt, 2005).

With the rapid growth of socio-economic demands in urban cities, developing economies desperately need to accelerate infrastructure investment, to ensure the operation, maintenance and restoration of the existing infrastructure assets. Sharp *et al.* (2015) enunciates that developing countries greatly depend on infrastructure development for the sustainability of their economies, which includes effective communication systems, safe roads and sustainable power infrastructure. Development Bank of Southern Africa (1998) posits that infrastructure must be divided into economic and social infrastructure. Social infrastructure is defined as built assets that provide social services for the well-being of the people, while economic infrastructure refers to assets that supports business activities in the country (Fedderke and Garlick, 2008).

The need for building infrastructure that is sustainable and resilient is emphasised in the United Nation's Sustainable Development Goals (SDGs). Goal 9 of the SDGs posits on "building resilient infrastructure, promoting inclusive and sustainable industrialization and foster innovation" (Statistics South Africa, 2019). For the purpose of this study only the first part (building resilient and sustainable infrastructure) of goal 9 was addressed. The study further moves further from emphasing undisputed grounds of knowledge on building infrastructure that is sustainable and resilient to elucidating on measurements of the then built sustainable and resilient infrastructure.

Measurements of Sustainable Infrastructure Development

The study discusses measurements for sustainable infrastructure development. Ugwu and Haupt (2005) articulates that South Africa has contributed a mouthful to the existing body of knowledge with sustainable research in socio-economic issues (Talukhaba *et al*., 2005), health and safety improvement, and most importantly the sustainability of the environment in affordable housing (Dalgleish *et al*., 1997). Fedderke and Garlick (2008) have emphasised the pivotal role of sustainable infrastructure development, especially in South Africa's economic growth. Bogetic and Fedderke (2006) acknowledged that an increase in the capital expenditure of infrastructure development has a direct impact on the output of the economy, since infrastructure is regarded as a direct input for economic growth (Development Bank of Southern Africa, 1998). Inadequate or deteriorated infrastructure negatively affects commercial businesses from maintaining or increasing productivity, thus firms now need to establish contingency plans against the malfunction of the existing infrastructure, which negatively affects the efficiency of micro and macro enterprises. Sustainability is essential for continuous and persistent infrastructure development.

Saeima (2010) defines infrastructure as "components of the territorial structure of the national economy, which transport systems, water infrastructure, power and communication systems play a pivotal role towards sustainable development". There are two forms of infrastructure, soft and hard infrastructure. Soft infrastructure is more of a framework developed to maintain and monitor different institutions, this include both physical and non-physical infrastructure (Kularatne, 2006; Spacey, 2017). Infrastructure development involves the growth or expansion of infrastructure projects. This is guided by government policy, which represents the public at large (Shen *et al*., 2011), and these policies need to show how the constructed and restored infrastructure is going to benefit the people economically and socially. Infrastructure development further means the growth or expansion of telecommunication systems, water and power supply systems, roads, dams, railways and transport systems (World Bank, 1994).

Performance indicators of sustainable infrastructure development

Sustainable infrastructure development performance indicators are required for accountability, to ensure that existing infrastructure is performing according to the pre-determined standards. Sharp *et al.* (2015) as well as the Department of Public Works and CIDB (2017) discuss the importance of infrastructure performance. They highlight how it assists in identifying needs and careful prioritising of the infrastructure needs. Service performance is one of the measures used to recognise how the infrastructure meets the needs of the end user. Sharp *et al*. (2015) continues to affirm that amongst other indicators service performance is the most significant, as this assists parastatals to prioritise investment, and this can only be executed properly if an understanding of how the outcomes of that investment is valued by the end user. Quality of the service provided by specific infrastructure as one of the measurement for outcome metrics can be further categorised into reliability, stability, safety and resilience of the infrastructure facility (Sharp *et al.,* 2015).

Other indicators include the environmental impact of infrastructure development on key local, regional, provincial, national and international stakeholders, and its influence on societal development. The performance of infrastructure development will thus be determined by infrastructure outcomes, impact on the economic growth (Coetzee and Le Roux, 1998) and ecological systems. Determining current performance can identify how to improve the performance of the existing infrastructure for present and future generations.

Additionally, The World Economic Forum (2015) previously established the Global Competitiveness Index (GCI) to measure the competitiveness of an economy, which includes infrastructure development as a key component to a competitive economy. The World Bank, as stated by Ojala and Celebi (2015) and Skorobogatova and Merlino (2017) established the Logistics Performance Index (LPI), which measures the quality of infrastructure, amongst other things, to determine the performance of infrastructure development. Table 1 represents key indicators of sustainable infrastructure projects determined by existing literature, these indicators are extracted from different sectors, such as water, building and construction as well as the energy sector.

Table 1. Measurements for sustainable infrastructure development from previous studies

Related literature	Selected sustainability indicators in previous studies	Perspectives
Timmermans and Beroggi (2000)	Economic sustainability, social sustainability, technological safety, attractiveness for living, attractiveness for businesses	Planning of infrastructure projects
Lundin and Morrison (2002)	Annual freshwater withdrawal/annual available volume, water use per capita per day, water treatment projects' performance, chemical use for drinking and waste water treatment	Urban water infrastructure projects
Balkema *et al*. (2002)	Minimal technical requirements of the solution projects; costs of investment, operation, and maintenance; optimal resource utilization; institutional requirements and acceptance	Wastewater infrastructure projects

Sahely *et al*. (2005)	Construction materials usage; energy and water usage; capital, operation, and maintenance costs; expenditures in research and development change; performance in building function; accessibility; health and safety acceptability	Buildings, transportation, and water supply infrastructure projects
Ugwu and Haupt (2007)	Initial cost, life-cycle cost, extent of land acquisition, extent of loss of habitat or feeding grounds, extent of encroachment on concerned areas, complaints from local parties/villages	Civil engineering infrastructure projects
Klevas *et al*. (2009)	Growth in GDP; effect on environment expressed in external costs; effect on job market, equity, technological innovation, and security of energy supply	Energy infrastructure projects

Source: Shen *et al*. (2011)

Environmental aspect: Impact on the existing ecosystems

Sustainable infrastructure development also speaks to the wellbeing of the environment, Venter (2009) alludes that the constitution of South Africa refers to the quality of our environment as having an impact on our daily lives, that environmental contamination such as air, water and noise pollution have a negative impact on the existing ecosystems, and this can be as a result of the existing infrastructure facilities. As a result the study envisioned to understand and determine the impact of infrastructure development to the surrounding ecosystems in South Africa.

Economic aspect: Infrastructure investment

In developing economies, such as South Africa, the central government is the sole custodian of infrastructure investment, with limited involvement from the private sector. To supplement government funding public institutions (Eskom and Transnet) are established in each sector of the country to fund, construct, operate, maintain and restore infrastructure facilities. The central government from the national revenue fund in the year 2006 set aside 40% of R372 billion for both Eskom and Transnet (Venter, 2009) for infrastructure development R84 billion and R47 billion was allocated to Eskom and Transnet respectively (Venter, 2009). While R5.2 billion and R19.7 billion was allocated for airport improvement and water infrastructure respectively (Venter, 2009). In specific situations the expertise of foreign companies is brought in to build, operate and maintain these facilities, for a fee. It is clear that the macro-economy of the country matters for sustainable infrastructure development. There have been discussions over the years on the importance of public, private and international funding for infrastructure development (Perkins *et al*., 2005) funding decisions taken by either party depends immensely on detrimental macroeconomic effects. When funds are borrowed from international agencies interest and capital repayments in foreign currencies affect countries that are borrowing the most.

Project administration/management aspect

Existing literature has continuously relegated sustainable infrastructure development to solely project performance. The Dutch Committee Elverding (2008) asserts that sustainable infrastructure development has over the years been negatively affected by the continuous outcome of projects showing deficiencies in cost and time overruns. Additionally, quality has also emerged as a key indicator for the advancement of sustainable infrastructure development. Projects are measured according to different stages of the project, namely; conceptualisation of design, construction, operation and decommissioning (Blomquist *et al.,* 2010) Utilising project performance as a sole indicator means encouraging collaborative partnerships in various projects, inclusive of local, consortia of private parties, even international agencies (Lenferink *et al.,* 2013). In such instances, contracts procurement systems such as Design-Build-Finance-Maintain (DBFM) are employed where a private consortium is responsible for all the phases of the project. Such systems are similar to Build-Operate-Transfer (BOT) and Build-Own-Operate (BOOT) (Pietroforte and Miller, 2002). A team that is employed to carry out the works is invited through open, negotiated, nominated, qualified or quotation tendering (Venter, 2009).

Stakeholder involvement

There has been hesitation shown in the existing literature towards introducing citizen participation as a key performance metric for sustainable infrastructure development, Ugwu and Haupt (2005) opine that, even though much progress has been made towards sustainable development, policies and strategies continue to sideline micro-level (citizen participation) decision making (Anex and Focht, 2002). Existing research continues to isolate stakeholder from the key performance metrics, Ugwu and Haupt (2005) agree that the initial condition for the sustainability of the any project is for the stakeholders to develop the performance metrics. The study encompassed both stakeholders and project management as part of the performance metrics for sustainable infrastructure development.

Lessons Learnt on Measurements for Sustainable Infrastructure Development

Sustainable development refers to the urgent need to protect the existing resources for future generations, this includes investing in the existing infrastructure and using water and electricity more efficiently, minimising pollution, investing in green building, and ultimately raising awareness on sustainable living. The above is addressed in the United Nation’s 17 Sustainable Development Goals (SDGs), which have the potential to transform the world to be a better place (Klapper, El-Zoghbi and Hess, 2016). Morton and Pencheon and Squires (2017:81) asserts that the objective of the United Nations on the development of SDGs is to to end poverty, protect the environment and ensure people live prosperous lives. The focus of the study however was on Sustainable Development Goal 9, on “building resilient infrastructure, promoting inclusive and sustainable industrialization and foster innovation”. SDG 9 focuses on infrastructure, industrialization and innovation, but for the purpose of this study the aspect of infrastructure was the main focus.

Building infrastructure that is sustainable and resilient include enhancing and extending financial, technological and technical support to countries with deteriorating infrastructure, and investing in regional and trans-border infrastructure for the purpose of improving the global economy and the wellbeing of the people (Statistics South Africa, 2019). In addition to plans of building resilient infrastructure the study completed the circle of infrastructure development by discussing critical measures of monitoring the performance of sustainable infrastructure development. Almost every nation through national, regional, continental or global agendas have plans for sustainable infrastructure development, but not every nation has invested in monitoring, measuring and comparing standards of sustainable infrastructure development. The study thus placed its focus on critical measurements for sustainable infrastructure development.

From the reviewed literature it is evident that sustainable infrastructure development has an impact on the performance of developing economies. The performance of the developing economies is thus dependent on the construction, maintenance and performance of built infrastructure facilities and services, ranging from transport systems, water and power infrastructure to telecommunication facilities and services. Infrastructure is differentiated between social and economic. Both the activities of social and economic infrastructure contribute to the performance of the Gross Domestic Product (GDP), poor performance of the GDP increases possibilities of high unemployment rate, increased petrol prices and higher government borrowing thus relegating the country into recession. Amongst key indicators of a poor performing economy is rapid deterioration and decay of infrastructure systems and lack of limited budget to maintain and upgrade the facilities. Another indicator is lack of a comprehensive measurement metrics that is representative of different infrastructure systems. The main criteria for sustainability is the ability of assets to currently and in future operate in a manner that considers and is accommodative of the needs of the people. Currently with the existing infrastructure and with the existing measurement tools the public sector is unable to determine and plan for the maintenance and expansion of the current and future infrastructure facilities and services.

Measurements for sustainable infrastructure development exist to ensure and monitor the performance of infrastructure systems, without monitoring measurements systems cannot be compared to their predetermined standards set either by government or regulatory bodies. In South Africa the Department of Public Works (DPW) and Construction Industry Development Board (CIDB) are tasked with the duty of monitoring the construction, commissioning, operation, maintenance and replacement of infrastructure systems. According to the DPW and CIDB (2017) the most commonly used measurement apart from social, economic and environmental metrics is service performance. The importance of service performance for sustainable infrastructure development cannot be over emphasised, the metric clearly interrogates and confirms the current performance of the systems with the developed performance standards and further recognizes how the infrastructure system meets the needs of the end user.

The importance of social, economic and environmental elements as measurements of sustainability even in this study remains undisputed (Coetzee and Le Roux, 1998; Venter, 2009; Sharp *et al.* 2015). Social sustainability in the development of infrastructure acknowledges the welfare and empowerment of the people. There is indeed no development without the development of people, this also includes community engagement. In the three underpinnings of sustainability social sustainability is the least discussed and prioritised. It is of utmost importance that in the plans of developing communities through improved infrastructure and services that social responsibility is incorporated in the decision-making. The economic aspect of sustainability in the development of infrastructure indicates the need for funding for the life cycle of the facilities or services, alternative means of funding in the form of public-private partnerships, through local financial institutions, development banks and the World Bank have played an important role in financing the construction of many infrastructure facilities and services (Coetzee and Le Roux, 1998; Perkins *et al.,* 2005; Bogetic and Fedderke, 2006). But the conditions of borrowing including lending rates by institutions such as the World Bank are structured in a way that affects the policy decision-making or sovereignty of the country. As a result caution must be applied before any attempts of approaching such institutions.

In addition to the three well-known measurements of sustainability project management, stakeholder engagement, technology and innovation, service performance, health and safety and policy were rated as critical measurements for sustainable infrastructure development (Dalgleish *et al*., 1997; Timmermans, 2000; Sahely *et al*. 2005; Klevas *et al*., 2009). Policy for sustainable infrastructure development is the study's contribution to the existing conceptualisation of sustainable infrastructure development measurements. Ugwu and Haupt (2005), The Dutch Committee Elverding (2008), Venter

(2009) and Lenferink *et al.* (2013) have shown the importance of project management (the management and controlling of time, cost and quality) and stakeholder participation. Stakeholder participation referred to in this study by Ugwu and Haupt (2005) is the micro-level decision making in the communities. Communities are not consulted on any infrastructure development plans, and this in turn negatively affects the relationship of the communities within the municipalities. Ugwu and Haupt (2005) and Anex and Focht (2002) postulate that stakeholder participation is key for infrastructure development and must be prioritised.

Conclusion and Recommendations

This desk study used secondary data to determine key performance indicators for sustainable infrastructure development. The research paper is part of a broader ongoing study on sustainable infrastructure development thus the need to collect primary data for this research paper at this stage was not essential, additional literature still needs to be reviewed before undertaking any field work. The primary focus of this study is thus to identify gaps in literature and provide a foundation of knowledge on the subject of sustainability for the envisaged stage of primary research.

From reviewing literature, this study has identified economic, social, environment, project administration, stakeholder engagement, technology and innovation, service performance, health and safety and policy as critical measurements of sustainable infrastructure development. Policy on sustainable infrastructure development is the study's contribution to knowledge, policy completes the framework of the already established measurements. With clear policies on sustainable infrastructure development stakeholders are able to engage better and fulfil their mandates. More so, lack of models to guide sustainable infrastructure development in developing economies is amongst many factors delaying sustainable development. The identified measurements complement each other for a sustainable environment, and addresses key issues of service performance encountered post occupancy. It is recommended that nations develop their own measurement metrics like the Logistics Performance Index (LPI) and Global Competitiveness Index (GCI) by the World Bank and World Economic Forum respectively, to monitor the performance of the infrastructure facilities and services. LPI and GCI allow nations to measure and improve their own infrastructure development against the world's standards. Nations developing their own indices has the benefits of locally determining areas of concern and solutions to better improve the sustainability of infrastructure development and improve the growth of the economy. These indexes should further be categorised according to different business sectors. Criteria to prioritise investment, maintenance and risk should clearly be defined. Lastly, measures should be taken to prioritise and minimise poor quality, unsafe facilities, water, air, and noise pollution that show a negative impact on sustainable infrastructure development, so as to ensure the safety and quality of the environment. The findings of this study are relevant to the ongoing project on sustainable development and can also be of assistance to researchers and institutions that are tasked with the delivery and monitoring of sustainable infrastructure facilities and services.

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Implementing Safety Leading Indicators in Construction: Insights on Relative Importance of Indicators

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Abstract

Lagging indicators have been widely used in the construction industry to measure and improve safety performance for decades; however, they are criticised for providing insufficient information to generate continuous improvement because they only indicate safety outputs. Against this backdrop, industry and academia have investigated safety leading indicators in addition to traditionally used lagging indicators. Leading indicators are proactive in nature because they measure safety initiatives that provide an early indication of impending adverse events, which in turn allows management to initiate corrective steps. Although leading indicators are an emergent area of research, there is limited knowledge to guide their implementation in terms of their selection and use. Having insight regarding their relative importance could thus be useful. To address the knowledge gap, this study conducted a systematic literature review on safety leading indicators in construction which resulted in the identification of 16 safety leading indicators. A subsequent two-round Delphi technique involving industry experts was used to determine the relative importance. The results show that organisational commitment, client engagement, main contractor engagement, supply chain engagement, and designer engagement are perceived by the industry experts as being among the topmost important indicators for safety management performance. The findings would enhance the construction industry's understanding of safety leading indicators and help organisations prioritise efforts to enhance their safety performance.

Keywords: Construction safety; Delphi technique; Safety leading indicators; Safety performance measurement

Introduction

Safety performance in construction has been found to have plateaued in many developed countries. Traditionally, lagging indicators, such as lost time injury frequency rates (LTIFRs) and total recordable injury frequency rates (TRIFRs), have been widely used to manage safety performance in construction. The effectiveness of using lagging indicators to improve safety performance, however, often does not meet the needs on making long-term and continuous improvement because they are retrospective and reactive in nature and can trigger only short-term actions in a case-by-case way. Recent studies look beyond lagging indicators to shed light on leading indicators that measure safety initiatives (e.g. Hinze et al., 2013).

Safety leading indicators feature a proactive approach to managing safety because they can provide an early indication of impending adverse events and drive preventive actions. Furthermore, the process of implementing and measuring proactive management activities provides knowledge beyond individual incidents, allowing for continuous learning and an adaptive safety system. Despite the various leading indicators that have been proposed in construction management research, the industry lacks empirical insights to guide the implementation of indicators in practices. Consequently, questions have been raised regarding the 'ideal' indicators or 'ideal set of indicators' when using leading indicators as part of a health and safety management system (Hinze et al., 2013). Under the circumstances, this paper sought to: 1) identify safety leading indicators used to manage safety performance in construction; and 2) identify their relative importance.

Literature Review: Safety Leading Indicators in Construction

To achieve the above aims the research team conducted a systematic literature review and found that safety leading indicators were commonly recognised as measures of the safety management system, which consists of safety rules and resources as well as actors with the aim of creating and sustaining the safety of a workplace (Guo et al., 2017). In construction, safety leading indicators measure safety management processes and practices of firms and projects. The measurements precede the occurrence of adverse safety outcomes (e.g. Kjellén, 2009). They provide early signals of situations that might increase levels of risk or lead to adverse safety outcomes (e.g. Leveson, 2015). Therefore, leading indicators can prompt proactive measures in response to the current state in order to address the deficiencies or further develop the safety management system (Hallowell et al., 2013; Hinze et al., 2013).

To conduct the systematic literature review, 226 peer-reviewed journal papers in Scopus and Web of Science that contain key words "safety", "leading indicator", "safety", "lead indicator", "upstream indicator", "predictive indicator", "positive indicator" and "heading indicator" were first reviewed. In addition, five industry reports regarded as highly relevant (i.e., Autralian Constructors Association 2015; Campbell Institute 2015; Center for Chemical Process Safety 2019; eCompliance 2016; Health and Safety Executive 2006) were added to the review pool. After three rounds of reviews and filtering, 30 articles and one report were finally selected for detailed analysis because they are directly related to the safety of people working in construction.

The analysis of the 30 articles was facilitated by MAXQDA 2018, a software for qualitative data analysis. Indicators and their descriptions were manually coded by the terms used in the original articles. Initial codes were then extracted across all articles to conduct in-depth analysis and make sense of the indicators in terms of what they were revealing about safety management and the level of measurement. This process refined the initial findings by collating codes referring to the same safety management measures. In addition, the robustness of the research methods was also taken into consideration. Table 1 summarised the 16 safety leading indicators in construction identified from the literature. They were grouped under firm, project, and group and individual level.

Table 12: List of 16 construction safety leading indicators

Safety leading indicator	Description	Examples of measures (in a specific time frame)	Examples of literature sources
Firm level			
1. Organisation commitment	Client, designer, principal contractor and subcontractor commitment to safety	- Total safety expenditures/total expenditures	Guo et al. (2017)

2. Safety auditing	The process of collecting independent information on the efficiency, effectiveness and reliability of the safety management system and drawing up plans for preventive actions.	- Frequency of completed audits completed according to schedule	Mitchell (2000)
3. Training and orientation	Improving skills, knowledge, attitudes and experiences of employees to effectively manage safety	- Hours of training received	Alruqi and Hallowell (2019)
Project level			
4. Client engagement	Client is engaged in construction safety throughout a project.	- Frequency of meetings between client's safety professional and designer teams	Alruqi and Hallowell (2019)
5. Designer engagement	Principal designer and other designers are engaged in construction safety throughout a project.	- Number of meetings with main contractors per role	Mitchell (2000)
6. Principal contractor engagement	Principal contractor is engaged in construction safety throughout a project.	- Frequency of a safety professional's onsite safety inspection	Rajendran (2013)
7. Supply chain and workforce engagement	Subcontractors, suppliers and self-employed workers are engaged in construction safety throughout a project.	- Number of safety inspection conducted by a subcontractor/supplier/self-employed worker	Guo et al. (2016)
8. Safety design	Preventing accidents during construction is considered as one of the objectives of design.	- Number of hazards/risks highlighted and addressed in the design	Mitchell (2000)
9. Plan for safety	Safety in construction is considered in the planning process	- Number of hazards and risks highlighted and addressed in site logistics and layout plans	Agumba and Haupt (2012)
10. Hazard identification and control	The process and outcome of identifying and controlling hazards and risks in workplace.	- Percentage of high-risk items identified	Alruqi and Hallowell (2019)
11. Safety learning	Learning from accidents, incidents and relevant experiences.	- Number of safety reports with actions implemented	Biggs and Biggs (2013)
12. Recognition and reward	Mechanisms to motivate workforce to comply with safety rules and actively	- Percentage of individuals or groups recognised	Guo et al. (2017)

	participate in safety improvement activities		
13. Site communication	Familiarising operatives with a job, informing risks and improving task-specific competence to prevent accidents	- Percentage of operatives who receive induction prior to commencement of work	Versteeg et al. (2019) Lingard et al. (2017)
Group and individual level			
14. Safety climate	Employees' perception of the priority an organisation and workgroup placed on safety-related policies, procedures and practices.	- Use of quantitative scales e.g. a five-point scale for measuring perceived management commitment and supervisor safety responses on safety matters	Chen et al. (2018);
15. Worker involvement	Workers' level of involvement in establishing, operating, evaluating, and improving safety practices.	- Percentage of attendance of workers at safety events, e.g., training and induction/toolbox meeting	Aksorn and Hadikusumo (2008)
16. Competence	Ensuring that employees have the skills, knowledge, attitudes and experience to safely carry out assigned tasks.	- Number of certification cards	Hinze et al. (2013)

Delphi Technique

Based on a systematic literature review, the study identified the 16 key safety leading indicators. To determine the relative priority/importance of the safety leading indicators to safety performance management, a two-round Delphi technique used to collate expert opinion. The Delphi technique is an iterative process used to collect experts' opinions/responses regarding an issue through the use of several rounds of questionnaires which are interspersed with feedback (Skulmoski et al., 2007). The round of questionnaire administration stops when consensus among the experts is attained or saturation (i.e. point where sufficient information has been exchanged) is attained. Consensus was determined by the use of Kendall's concordance (*W*).

For this study, the 16 safety leading indicators were incorporated in a questionnaire distributed to nine industry experts who joined an industry committee workshop in September, 2019. All the experts have over 20 years of work experience in construction and their profiles are summarised in Table 2. In the first round, the questionnaire requested the participants to rank the 16 leading indicators based on their level of importance to safety management performance. In the second round, the median ranks for the 16 indicators were presented to the experts who were then asked to reflect on the information (i.e. their responses and the median ranks) and then rank the indicators again. After using two rounds of Delphi method, consensus was reached. The median ranks of the 16 indicators at the end of the second round were then used as the basis to rank the indicators in the order of their importance to safety management performance.

Table 2 Participant information

Organisation Type	Position
Client 1	Health, Safety Environment Business Partner

Client 2	Principal Estates and Facilities Health and Safety Manager
Client 2	Performance and Systems Manager
Contractor 1	Head of Health and Safety
Contractor 2	Head of Health and Safety
Contractor 3	Safety, Health, Environment and Quality Director
Project Management Consultancy	Principal Consultant and CDM Principal Designer Manager
H&S Professional Membership Organisation	Chairman
Government Agency	Health and Safety Inspector

Results and Discussion

Table 3 shows the results of the ranking of the 16 indicators as well as the Kendall's concordance (*W*). From the perspective of the experts, the top five leading indicators in sequence are: organisational commitment, client engagement, main contractor engagement, supply chain engagement, and designer engagement. Organisation commitment was the most important indicator for safety management and is an indicator at the firm level. Organisation commitment has been argued to be the foundation for effective safety management (e.g. Hallowell et al., 2013) because it enables the creation and maintenance of safety culture within the organisation that can affect employees' attitudes and behaviour toward safety (Choudhry et al., 2007). The level of commitment is reflected in the organisation's strategies and policies, which specify the safety-related goals and imply the relevant importance of safety compared with other functional priorities such as production (Mahmoudi et al., 2014).

The second to fifth most important indicators were related to key stakeholders' engagement in construction safety at the project level. Specifically, clients' engagement with designers can mitigate safety risks early in design. Selection and early involvement of competent contractors can ensure risks recognised in design are addressed in execution and sufficient preventive measures have been put in place (Suraji et al., 2006). Establishing a project safety committee consisting of designers, contractors and supply chain partners and regular site walkthroughs by the client can align divergent interests and build a mutual understanding of safety issues among various stakeholders (Evans, 2008). Last but not least, clients' proactive involvement communicates the message that safety is valued in daily operations, hence promoting a safety culture within projects (Hallowell et al., 2013).

Table 3: Ranking of safety leading indicators

Indicators	Round 1 (N=9)				Round 2 (N=9)			
	Median rank	Overall rank (based on median)	Kendall's W	Sig.	Median rank	Overall rank (based on median)	Kendall's W	Sig.
Organisation Commitment	1	1	0.241	0.005	1	1	0.470	0.000
Safety Auditing	13	16			13	13		
Training and Orientation	9	11			10	10		
Client Engagement	3	2			3	2		
Designer Engagement	3	2			3	2		
Main Contractor Engagement	4	4			3	2		
Supply Chain Engagement	5	5			5	5		
Design and Planning	7	6			5	5		
Hazard Identification and Control	7	6			7	7		
Incident Reporting and Investigation	11	14			13	13		
Reward and Enforcement	8	10			13	13		
Site Induction	12	15			13	13		
Safety Climate	9	11			10	10		
Workforce Involvement	7	6			8	8		
Competence	7	6			8	8		
Wellbeing	10	13			10	10		

The designer's level of engagement determines the level of risk before construction and the level of prevention to address residual design risks during construction (Hallowell et al., 2013). The designer's knowledge and skills affect the client's and contractors' ability to manage safety (e.g. Suraji et al., 2006), which in turn are enriched by the experience of learning with other parties, particularly about the underlying accident causes that include the effects of design and the design process (e.g. Suraji et al., 2006).

Principal contractor engagement influences the level of prevention and control in construction. Through early involvement in projects, principal contractors can help identify safety risks in design so that potential incidents can be mitigated through changing unsafe structures, layout or materials at the early stage of a project (Saurin, 2016). Formal and informal control of subcontractors and suppliers, such as auditing subcontractors' management systems and rewarding safety behaviour, can help improve the performance during execution (e.g. Hallowell et al., 2013).

Conclusions

Although lagging indicators, such as fatal injury rates, have been widely used in the construction industry to measure safety performance of projects and companies for decades because of their easy-to-measure nature, they are criticised as insufficient indicators to generate continuous improvement as they only indicate how bad or good the performance is. Against this backdrop, industry and academia have investigated safety leading indicators in addition to traditionally used lagging indicators. Leading indicators are proactive in nature because they measure safety initiatives that provide an early indication of impending adverse events, which in turn allows management to initiate corrective steps in a short period of time.

Leading indicators are an emergent area in both research and practice with a wide range of indicators being suggested. However, there is insufficient guidance to the industry on what and how indicators should be used in different levels of organisation and different stage of construction projects. To address this knowledge gap, this study conducted a systematic literature review to identify safety leading indicators in construction, and then applied a two-round Delphi technique to determine their relative importance. The findings reveal that safety indicators relating to organisation commitment and stakeholders' engagement are among the most important that need to be prioritised in the implementation of a safety leading indicator programme. The findings would enhance the construction industry's understanding of safety leading indicators and help organisations prioritise efforts to enhance their safety performance.

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Occupational Health in Construction: Can Industry 4.0 Contribute to Performance Improvement?

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Abstract

Historical occupational health (OH) challenges, in terms of a range of issues, continue to be experienced, namely not following procedures, unsafe acts, unsafe conditions, non-compliance, sprains and strains, fatigue, and heat stress among workers, materials containing hazardous chemical substances, untrained workers undertaking work, commencement of activities without conducting hazard identification and risk assessment (HIRA), data gathering and recording, and monitoring.

Given the abovementioned, and the advent of Industry 4.0, an exploratory quantitative study, which entailed a self-administered questionnaire, was conducted among registered Construction Health and Safety (H&S) practitioners to determine the perceived importance of project parameters, OH challenges experienced, the degree of awareness of / exposure to eleven Industry 4.0 technologies, and the perceived potential of Industry 4.0 technologies to enhance OH-related interventions / outputs / processes.

The findings indicate that a range of historical challenges, which negatively impact OH performance, continue to be experienced in construction; H&S practitioners rate themselves below average in terms of awareness of / exposure to most Industry 4.0 technologies, and that Industry 4.0 technologies can contribute to resolving the OH challenges experienced in construction.

Conclusions include: a different approach is necessary to mitigate the persistent OH challenges; current technology is not capable of resolving the OH challenges; an integrated digital effort is required to resolve the OH challenges, and artificial intelligence, blockchain technology, digitalisation in general, drones, the internet of things, robots, and virtual reality have the potential to contribute to resolving the H&S challenges experienced in construction.

Recommendations include: employer associations, professional associations, and statutory councils should raise the level of awareness relative to the potential implementation of Industry 4.0 relative to OH in construction; case studies should be documented and shared; tertiary construction management education programmes should integrate Industry 4.0 into all possible modules, especially H&S and OH-related modules, and continuing professional development (CPD) OH should address Industry 4.0.

Keywords: Construction, Industry 4.0, Occupational Health, Performance.

Introduction

The World Health Organization (WHO) (2001) presents an extended definition of OH and refers to it as a multidisciplinary activity aimed at:

- Protecting and promoting workers' health by preventing and controlling occupational disease and accidents, and by eliminating occupational factors and conditions hazardous to H&S at work;
- Developing and promoting healthy and safe work, work environments, and work organisations;
- Enhancing the physical, mental, and social well-being of workers and support for the development and maintenance of their working capacity, as well as professional and social development at work, and
- Enabling of workers to conduct socially and economically productive lives and to contribute positively to sustainable development.

Perkins refers to workplace health as the 'Cinderella' to safety, and asks what this rather mysterious, seemingly complex, scientific-clinical, multi-disciplinary area is all about? (Institute of Occupational Safety & Health, 2016). Furthermore, Ponting (2008) states that to date, most site-level H&S initiatives have focused on improving safety, despite construction losing twice as many working days a year to work-related ill health as it does to workplace injuries.

A study conducted among twelve organisations in the United Kingdom (Pilkington, Donaldson, Groat & Cowie, 2002) entailed the observation of thirty-five tasks: painting using rollers, brushes and spraying; cutting or grinding tiles, or concrete slabs; cutting hardwood or medium density fibre board, and laying or sanding floors. Likely health hazards were identified, and respiratory and skin hazards predominated, followed by musculoskeletal and ocular, with hand-arm and whole-body vibration hazards, and some noise. The most relevant potential health outcomes were dermatitis or skin irritation, asthmatic or bronchial symptoms and irritation of nose and throat, followed by eye irritation, neck / shoulder, back or upper limb disorders, vibration white finger, and hearing loss. Furthermore, dust and paint were the most frequent hazardous substances, and physical hazards included manual handling and noise, vibration, and ocular foreign bodies.

Other authors summarise construction in terms of OH. Seo et al. (2015) state that due to the nature of construction work, workers are frequently faced with hazards and risks throughout the entire construction process. Furthermore, construction work is physically demanding, and workers can exceed their physical capacity (Nath et al., 2017), the challenge being to mitigate same.

The Council for Scientific and Industrial Research (CSIR) (2018) refers to Industry 4.0 as a collective term for technologies and value chain organisation, which draw together cyber-physical systems, the Internet of Things (IoT) and the Internet of Services (IoS), together with other emerging technologies such as cloud technology, big data, predictive analysis, artificial intelligence, augmented reality, agile and collaborative robots, and additive manufacturing.

Given the continuing poor OH and H&S performance in South African construction, the limited OH in construction-related research that has been conducted, and the cited benefits of implementing Industry 4.0 technologies, an exploratory study was conducted to determine the:

- Importance of seven parameters to the construction industry;
- Frequency at which nineteen OH-related phenomena are experienced on projects;
- Respondents' awareness of / exposure to eleven Industry 4.0 technologies, and
- Perceived potential of Industry 4.0 technologies to enhance forty-nine interventions / outputs / processes.

Given that the paper reports on an exploratory study, in-depth interrogation of the issues in terms of the empirical component of the study was not possible. Furthermore, due to paper length constraints, not all the empirical findings could be included.

Review of Literature

Legislation

A range of legislation and regulations impact on OH.

The Occupational Health and Safety Act (OH&SA) (Republic of South Africa, 1993) schedules generic requirements. Employers are required to provide such information, instructions, training, and supervision as may be necessary to ensure, as far as is reasonably practicable, the H&S at work of their employees.

The Construction Regulations (Republic of South Africa (RSA), 2014) require multi-stakeholder contributions to OH. Clients are required to conduct a baseline risk assessment (BRA), and compile a project specific H&S Specification based thereon, which is first provided to the designers, and later included in the tender documentation to be provided to the principal contractors (PCs) tendering for the project concerned. However, designers are required to respond to the H&S Specification in the form of a report to the client before tender stage. The report must, inter alia, include: all relevant H&S information about the design that may affect the pricing of the work; inform the client of any known or anticipated dangers or hazards relating to the construction work; make available all relevant information required for the safe execution of the work upon being designed or when the design is changed, and modify the design or make use of substitute materials where the design necessitates the use of dangerous procedures or materials hazardous to H&S. Therefore, hazard identification and risk assessment (HIRA) is necessary to identify the use of dangerous procedures or materials hazardous to H&S. Furthermore, the report that is submitted to the client should schedule the residual hazards remaining after the response to the HIRA, which in turn should be included in the H&S specification provided to the PCs tendering. PCs in turn must provide the client with an H&S Plan in response to the H&S Specification, which H&S Plan must be discussed with and approved by the client.

PCs and subcontractors are required to: establish hazards and precautionary measures; eliminate hazards; ensure safe systems of work, plant, and equipment; provide training, information, and trained supervision; conduct inspections, and take all necessary measures to ensure compliance (RSA, 1993).

Occupational health problems

Ponting (2008) records the key OH problems in construction as: hand-arm vibration syndrome; musculoskeletal disorders, including lower back pain, joint injuries and repetitive strain injuries; noise-induced hearing loss; respiratory diseases, including silicosis and mesothelioma, and occupational asthma; skin disorders such as work-related dermatitis, and work-related stress. The HSE adds that medical surveillance data suggests that the industry suffers from well-above-average incidence rates for mesothelioma, vibration white finger, and upper limb disorders.

The role of Industry 4.0 technologies

Traditionally, monitoring and measuring H&S-related issues has primarily been manual in nature, which has been limiting, and therefore, automated H&S monitoring is considered one of the most promising methods for accurate and continuous monitoring of H&S performance on construction sites (Awolusi et al., 2018). According to Autodesk & the Chartered Institute of Building (CIOB) (2019), digital technologies are transforming every industry, and construction is no exception. Infinite computing, robotics, machine learning, drones, the Internet of Things (IoT), augmented reality, gaming engines, and reality capture, to name just a few, are innovating the design, build, and operation of buildings and infrastructure.

Pereraa et al. (2020) state that current construction project management processes suffer numerous challenges related to, *inter alia*, information sharing and process management, however, the introduction of a smart contract enabled blockchain system will ensure that the latest information is updated and made available for the respective stakeholders. This is of relevance to H&S as the latest related information can be 'H&S' flagged.

A study conducted by Martinez et al. (2019) determined that the adoption of unmanned aerial vehicle (UAV) technology as a tool for H&S planning and monitoring enables better identification and evaluation of hazards compared with the traditional method, especially in the outdoor environment. The common hazards the H&S managers could identify using UAV technology was relative to hazards associated with unsafe conditions, such as missing guardrails or safety nets around unprotected edges or openings, loose, or unsecured material at height, and lack of proper PPE or safety harnesses.

Balfour Beatty, United Kingdom, is using drones for inspections as well as Building Information Modelling (BIM) to create models and mock-ups of its works locations at various stages of the construction process. This enables the use of BIM models to identify where work at height risks exist. Furthermore, drones are a substitute for people inspecting at height, preventing exposure, and potential injuries (Bimplus, 2019).

According to Lescohier (2020), Hilti North America's new EXO-O1 wearable exoskeleton is a human augmentation device to reduce peak loads on shoulders by transferring weight on the arms to the hips. This is in response to the heavy physical work workers in the construction and industrial manufacturing industries are required to perform, and the resultant musculoskeletal disorders (MSDs).

The HSE (2019) states that there is growing evidence that wearable devices can significantly benefit H&S in the workplace through positioning and sensor technologies. Consequently, a pending HSE sponsored research project will monitor occupational personal exposure to hazardous substances and physical hazards on construction sites, and musculoskeletal disorders (MSDs) in workers identified at greater risk. Cousins (2018) in turn highlights that wearable devices can detect fatigue risk, high heart rates, and stress. A study conducted by Nath et al. (2017) determined that wearable technology was able to prevent work related injuries and fatalities by ergonomically designing the work environment based on previous data collected, which led to the identification and elimination of the ergonomic risks at the source.

Virtual Reality (VR) is rapidly gaining traction as a training tool in occupational H&S, as VR technology provides a virtual environment that allows users to immerse themselves in a virtual world that uses sight, sound, and sometimes motion to provide a realistic experience (Silliker, 2018). A study conducted by Sacks et al. (2013) determined that workers had better recall in identifying and assessing construction H&S risks using VR-based training, than they would have using traditional conventional methods using classrooms and slide presentations.

Ethical considerations

Schwab (2018) stresses the importance of developing a mindset that considers system-level effects, the impact on individuals, which remains future oriented and is aligned with common values across diverse stakeholder groups. Furthermore, Schwab (2018) advocates that the following four principles should be kept in mind when considering how technologies can create impact: systems not technologies; empowering, not determining; by design, not by default, and values as a feature, not a bug. Cousins (2018) echoes a similar sentiment and states if staff are not onboard with the journey, it's possible that 'Big Brother syndrome' could result in distrust towards management, and create an additional source of workplace stress and low morale.

Research

Research method and sample stratum

A 14-question questionnaire was circulated per e-mail to 92 Professional (Pr) Construction Health and Safety Agents (CHSAs), 139 Candidate (Can) CHSAs, and 562 Construction Health and Safety Managers (CHSMs) registered with the South African Council for the Project and Construction Management Professions (SACPCMP). 39 CHSM e-mails could not be delivered, which resulted in a net sample of 754. Seven of the questions were demographic related, six were closed-ended and Likert Scale type questions, and one was open-ended. 58 Responses, courtesy of 16 Pr CHSAs, 16 Can CHSAs, and 26 CHSMs, which equates to a response rate of 7.7%. The analysis of the data entailed the computation of frequencies, and a measure of central tendency in the form of a mean score (MS).

Research findings

21.1% of respondents were female and 78.9% were male. The mean age of respondents was 53.1 years, the youngest being 26.1 years and the oldest being 71.6. years. Respondents had worked in / been involved with the built environment / construction for 26.3 years on average, the shortest period being 7.5 years and the longest being 39 years. Respondents have worked for their current employer for 16.4 years on average, the shortest period of service being 0.5 years, and the longest period being 37 years. The mean percentage in terms of the types of construction respondents or their organisations were involved with in 2019, is as follows: commercial (25.0%), industrial (60.0%), infrastructure (10.0%), residential (0.0%), and other (5.0%).

Table 1 indicates the importance of seven project parameters to the construction industry on a scale of 1 (not important) to 5 (very important), and a MS ranging between 1.00 and 5.00. It is notable that all the MSs are above the midpoint score of 3.00, which indicates that in general the respondents can be deemed to perceive the parameters as important to the construction industry.

However, a review of the MS ranges provides enhanced insight. 5 / 7 (71.4%) MSs are > 4.20 ≤ 5.00, which indicates the respondents can be deemed to perceive that the parameters are between more than important to very important / very important to the construction industry - cost, time, productivity, quality, and safety (occupational). The remaining 2 / 7 (28.6%) MSs are > 3.40 ≤ 4.20, which indicates the respondents can be deemed to perceive that the parameters are between important to more than important / more than important to the construction industry - health (occupational), and environment.

Furthermore, it is notable that the three traditional project parameters of cost, quality, and time are ranked within the top four, and secondly, that safety (occupational), ranked fifth, achieved a MS of 4.40, as opposed to 4.00 achieved by health (occupational), ranked sixth. This finding relates to previous South African findings arising from studies where health and safety have been delinked, namely that safety is perceived to be more important than health.

Table 1: Importance of seven project parameters to the construction industry

Parameter	Response (%)						MS	Rank
	Un-	Not……………………………………………Very						
	sure	1	2	3	4	5		
Cost	0.0	0.0	1.8	0.0	26.3	71.9	4.68	1
Time	0.0	0.0	3.6	1.8	19.6	75.0	4.66	2
Productivity	0.0	0.0	3.6	3.6	21.4	71.4	4.61	3
Quality	0.0	0.0	1.8	12.3	26.3	59.6	4.44	4
Safety (Occupational)	0.0	0.0	1.8	19.3	15.8	63.2	4.40	5
Health (Occupational)	0.0	3.5	12.3	15.8	17.5	50.9	4.00	6
Environment	0.0	1.8	15.8	24.6	14.0	43.9	3.82	7

Table 2 indicates the frequency at which nineteen OH-related phenomena are experienced on projects in terms of percentage responses to a scale of never to constantly, and MSs ranging between 1.00 and 5.00.

It is notable that 16 / 19 (84.2%) of the MSs are above the midpoint of 3.00, which indicates that in general the respondents can be deemed to perceive the phenomena to be experienced on projects.

Only 2 / 19 (10.5%) of the phenomena have MSs > 4.20 ≤ 5.00, which indicates the frequency is between often to constantly / constantly - under-pricing, and late information.

11 / 19 (57.9%) of the MSs are > 3.40 ≤ 4.20, which indicates the frequency is between sometimes to often / often. 5 / 11 (45.5%) MSs of similar or alike errors are repeated, information anomalies / ambiguities, inadequate coordination of subcontractors, data / statistics is / are not available, and management information is not available are > 3.80 ≤ 4.20 – the upper part of the range. The remaining 6 / 11 (54.6%) MSs are > 3.40 ≤ 3.80 - non-compliance, unauthorised people fulfil functions, unhealthy / unsafe plant and equipment, materials containing hazardous chemical substances, injuries, and fatigue among workers.

5 / 19 (26.3%) MSs are > 2.60 ≤ 3.40, which indicates the frequency is between rarely to sometimes / sometimes – sprains and strains among workers, difficulty monitoring the process and activities of construction (in terms of OH), accidents, and heat stress among workers.

The MSs of the last ranked phenomena, namely fatalities, and occupational disease, are > 1.80 ≤ 2.60, which indicates they are experienced between never to rarely / rarely. However, it should be noted that both MSs are within 0.07 of the upper point of the range.

Many of these phenomena are frequently referred to in the literature (HSE, 2017; Autodesk & CIOB, 2019; HSE, 2019a; HSE, 2019b), and furthermore, Industry 4.0 technologies have been identified as being able to reduce the occurrence of phenomena as per the literature (Autodesk & CIOB, 2019).

Table 2: Frequency at which nineteen OH-related phenomena are experienced on projects

Phenomenon	Response (%)							
	Unsure	Never	Rarely	Some-times	Often	Con-stantly	MS	Rank
Under-pricing	0.0	0.0	1.8	8.8	42.1	47.4	4.35	1
Late information	0.0	0.0	0.0	21.4	35.7	42.9	4.21	2
Similar or alike errors are repeated	0.0	0.0	3.5	17.5	50.9	28.1	4.04	3
Information anomalies / ambiguities	0.0	0.0	1.8	21.1	52.6	24.6	4.00	4
Inadequate coordination of subcontractors	0.0	0.0	7.0	21.1	38.6	33.3	3.98	5
Data / Statistics is / are not available	0.0	0.0	7.0	21.1	42.1	29.8	3.95	6
Management information is not available	1.8	0.0	7.1	26.8	39.3	25.0	3.84	7
Non-compliance	0.0	0.0	5.3	31.6	50.9	12.3	3.70	8
Unauthorised people fulfil functions	1.8	1.8	8.8	28.1	43.9	15.8	3.64	9
Unhealthy / Unsafe plant and equipment	0.0	0.0	14.0	26.3	47.4	12.3	3.58	10
Materials containing hazardous chemical substances	0.0	0.0	15.8	31.6	36.8	15.8	3.53	11
Injuries	0.0	1.8	17.9	26.8	37.5	16.1	3.48	12
Fatigue among workers	1.8	0.0	16.4	34.5	36.4	10.9	3.43	13
Sprains and strains among workers	0.0	1.8	12.3	43.9	33.3	8.8	3.35	14
Difficulty monitoring the process and activities of construction (in terms of OH)	1.8	1.8	17.9	35.7	33.9	8.9	3.31	15
Accidents	0.0	0.0	17.5	42.1	35.1	5.3	3.28	16
Heat stress among workers	0.0	7.1	25.0	41.1	21.4	5.4	2.93	17
Fatalities	1.8	7.0	43.9	35.1	12.3	0.0	2.54	18
Occupational disease	8.9	14.3	28.6	35.7	10.7	1.8	2.53	19

Table 3 indicates the respondents' self-rating of their awareness of / exposure to eleven Industry 4.0 technologies in terms of percentage responses to a scale of 1 (limited) to 5 (extensive), and a MS ranging between 1.00 and 5.00. It is notable that only 3 / 11 (27.3%) of the MSs are above the midpoint of 3.00, which indicates that in general the respondents can be deemed to rate themselves as above average, as opposed to below average relative thereto - Internet of Things, drones, and digitalisation of information. With respect to the other 8 / 11 (72.7%) technologies, the respondents can be deemed to rate themselves below average. However, it should be noted that smart sensors has a MS of 2.96, which is marginally below the midpoint.

It is notable that the respondents do not rate themselves above average to extensive / extensive (MSs > 4.20 ≤ 5.00) relative to a technology. Only 1 / 11 (9.1%) MS is > 3.40 ≤ 4.20, which indicates a rating of average to above average / above average relative to Internet of Things. However, it should be noted that drones has a MS of 3.40, which is the upper point of the next lower range.

6 / 11 (54.5%) MSs are > 2.60 ≤ 3.40, which indicates a rating of below average to average / average relative to drones, digitalisation of information, smart sensors, 3-D printing, blockchain, and Artificial Intelligence (AI) / Machine Learning.

The remaining 4 / 11 MSs are > 1.80 ≤ 2.60, which indicates a rating of limited to below average / below average relative to the technologies. Virtual Reality, robotics / exoskeletons, and Augmented Reality fall within the upper half of this MS range (> 2.20 ≤ 2.60), whereas nanotechnology falls within the lower half (> 1.80 ≤ 2.20).

Table 3: Respondents' awareness of / exposure to eleven Industry 4.0 technologies

Technology	Response (%)						MS	Rank
	Un-sure	Limited…………………………Extensive						
		1	2	3	4	5		
Internet of Things	1.8	10.9	7.3	18.2	29.1	32.7	3.67	1
Drones	3.6	9.1	16.4	18.2	32.7	20.0	3.40	2
Digitalisation of information	3.6	10.9	12.7	27.3	30.9	14.5	3.26	3
Smart sensors	7.3	16.4	20.0	23.6	16.4	16.4	2.96	4
3-D printing	1.8	21.8	21.8	29.1	18.2	7.3	2.67	5
Blockchain	20.4	16.7	20.4	22.2	14.8	5.6	2.65	6
Artificial Intelligence (AI) / Machine Learning	3.8	18.9	30.2	22.6	18.9	5.7	2.61	7
Virtual Reality	5.5	32.7	16.4	20.0	18.2	7.3	2.48	8
Robotics / Exoskeletons	9.1	29.1	27.3	16.4	9.1	9.1	2.36	9
Augmented Reality	12.7	40.0	14.5	14.5	9.1	9.1	2.23	10
Nanotechnology	10.9	32.7	27.3	16.4	7.3	5.5	2.16	11

Table 4 indicates the perceived potential of Industry 4.0 technologies referred to in Table 3 to enhance forty-nine interventions / outputs / processes in terms of percentage responses to a scale of 1 (minor) to 5 (major), and MSs ranging between 1.00 and 5.00. It is notable that all the MSs are above the midpoint of 3.00, which indicates that in general the respondents can be deemed to perceive the potential to be above average.

During the discussion below, the stakeholder that undertakes the intervention or process, or who produces the output, is recorded in parentheses thereafter as follows: client (CT); construction project manager (CPM); designer (D); quantity surveyor (QS), and contractor (C).

It is notable that 9 / 49 (18.4%) MSs are > 4.20 ≤ 5.00, which indicates between near major to major / major potential - 'design and construction' method statements (D), designer reports in response to 'designer' H&S specifications (D), 'designer' H&S specifications (CT), designing for construction H&S (process) (D), design hazard identification and risk assessment (HIRA) (D), OH statistics (C), 'contractor' H&S specifications (CT), construction HIRA (C), and H&S management systems (H&SMSs) (C). In summary: 2 client; 4 designer, and 3 contractor.

The remaining 37 / 49 (75.5%) MSs are > 3.40 ≤ 4.20, which indicates between potential to near major / near major potential. 34 / 37 MSs fall within the upper half of this range, namely > 3.80 ≤ 4.20. There is a MS difference of 0.06 between the fifteen interventions / outputs / processes ranked 10th and 24th. These include: determining OH requirements from programmes / schedules (C); appropriate H&S appointments (competent) (C); integration of design, procurement, and construction (in terms of OH) (CPM); temporary works design (C); financial provision for OH (QS & C); H&S plans (C); H&S audits (not inspections) (CT); client baseline risk assessments (CT); OH measurement (C); safe operating procedures (SoPs) (C); security (C); OH induction (C); site entrance control (C); H&S research and development, and OH training (C). In summary: 2 client; 1 CPM; 1 client / QS / contractor, and 11 contractor.

The twenty-two interventions / outputs / processes ranked 25th to 46th are: H&S method statements (C); safe work procedures (SWPs) (C); H&S inspections (C); H&S investigations (C); fire protection and prevention (C); consideration for OH during pre-tender planning (C); emergency planning (C); H&S feedback (C); environmental measurement e.g. dust, noise (C); determining the cost of H&S (prevention) (QS / C); management of materials (C); management of plant and equipment (C); OH administration (C); consideration for OH during site layout planning (C); OH compliance (C); close out reports (in terms of H&S) (CT / CPM / D / QS / C); management of personal protective equipment (PPE) (C); OH awareness and promotion (C); determining the cost of accidents (C); method statements (generic) (C); workplace organisation (C), and H&S files (CT / CPM / D / QS / C). In summary: 2 client / CPM / designer / QS / contractor, 1 QS / contractor, and 19 contractor.

The three interventions / outputs / processes whose MSs are > 3.40 ≤ 3.80, include stacking and storage (C), H&S disciplinary procedure (C), and housekeeping (C).

Despite the respondents' generally low self-rating of their awareness of / exposure to the eleven Industry 4.0 technologies, they perceive the potential of Industry 4.0 technologies to reduce the occurrence of the phenomena as per the literature (Autodesk & CIOB, 2019).

Table 4: Perceived potential of Industry 4.0 technologies to enhance forty-nine interventions / outputs / processes

Intervention / Output / Process	Response (%)						MS	Rank
	Un-sure	Minor... Major						
		1	2	3	4	5		
'Design and construction' method statements	0.0	0.0	3.6	9.1	38.2	49.1	4.33	1
Designer reports in response to 'designer' H&S specifications	0.0	0.0	5.5	9.1	32.7	52.7	4.33	2
'Designer' H&S specifications	1.8	0.0	7.3	9.1	27.3	54.5	4.31	3
Designing for construction H&S (process)	0.0	0.0	3.6	12.7	32.7	50.9	4.31	4
Design hazard identification and risk assessment	0.0	1.8	1.8	9.1	38.2	49.1	4.31	5
OH statistics	1.8	3.5	3.5	8.8	29.8	52.6	4.27	6
'Contractor' H&S specifications	0.0	0.0	3.6	14.5	34.5	47.3	4.25	7
Construction hazard identification and risk assessment	0.0	1.8	1.8	9.1	45.5	41.8	4.24	8
H&S management systems (H&SMSs)	0.0	0.0	5.6	13.0	35.2	46.3	4.22	9
Determining OH requirements from programmes / schedules	1.9	1.9	1.9	13.2	39.6	41.5	4.19	10
Appropriate H&S appointments (competent)	1.8	0.0	5.5	12.7	38.2	41.8	4.19	11
Integration of design, procurement, and construction (in terms of OH)	0.0	1.8	5.5	12.7	32.7	47.3	4.18	12
Temporary works design	1.8	0.0	9.1	9.1	36.4	43.6	4.17	13
Financial provision for OH	0.0	1.9	3.7	11.1	42.6	40.7	4.17	14
H&S plans	1.8	0.0	9.1	12.7	29.1	47.3	4.17	15
H&S audits (not inspections)	1.8	1.8	3.5	14.0	36.8	42.1	4.16	16
Client baseline risk assessments	0.0	1.8	5.5	16.4	29.1	47.3	4.15	17
OH measurement	1.8	3.6	5.4	10.7	32.1	46.4	4.15	18
Safe operating procedures (SoPs)	1.8	0.0	3.6	16.4	41.8	36.4	4.13	19
Security	1.8	1.8	5.5	9.1	43.6	38.2	4.13	20
OH induction	1.8	1.8	5.5	9.1	43.6	38.2	4.13	21
Site entrance control	1.9	1.9	3.7	11.1	44.4	37.0	4.13	22
H&S research and development	3.5	1.8	7.0	15.8	24.6	47.4	4.13	23

OH training	1.8	1.8	5.5	12.7	36.4	41.8	4.13	24
H&S method statements	1.8	0.0	5.5	14.5	43.6	34.5	4.09	25
Safe work procedures (SWPs)	1.8	0.0	7.3	12.7	41.8	36.4	4.09	26
H&S inspections	1.8	1.8	7.0	8.8	43.9	36.8	4.09	27
H&S investigations	1.8	1.8	7.0	12.3	36.8	40.4	4.09	28
Fire protection and prevention	1.8	0.0	5.5	18.2	38.2	36.4	4.07	29
Consideration for OH during pre-tender planning	0.0	3.6	9.1	3.6	43.6	40.0	4.07	30
Emergency planning	1.8	0.0	3.6	25.5	30.9	38.2	4.06	31
H&S feedback	3.5	1.8	3.5	19.3	35.1	36.8	4.05	32
Environmental measurement eg. dust, noise	0.0	0.0	9.1	12.7	41.8	36.4	4.05	33
Determining the cost of H&S (prevention)	1.8	1.8	8.8	15.8	29.8	42.1	4.04	34
Management of materials	0.0	0.0	8.8	12.3	45.6	33.3	4.04	35
Management of plant and equipment	0.0	0.0	10.5	14.0	36.8	38.6	4.04	36
OH administration	1.8	0.0	10.9	10.9	41.8	34.5	4.02	37
Consideration for OH during site layout planning	0.0	3.6	9.1	9.1	38.2	40.0	4.02	38
OH compliance	0.0	0.0	12.5	10.7	39.3	37.5	4.02	39
Close out reports (in terms of H&S)	3.5	3.5	3.5	19.3	33.3	36.8	4.00	40
Management of personal protective equipment	1.8	3.5	7.0	14.0	35.1	38.6	4.00	41
OH awareness and promotion	1.8	1.8	3.5	26.3	29.8	36.8	3.98	42
Determining the cost of accidents	1.8	3.5	7.0	14.0	36.8	36.8	3.98	43
Method statements (generic)	0.0	3.7	5.6	16.7	42.6	31.5	3.93	44
Workplace organisation	0.0	0.0	3.5	28.1	42.1	26.3	3.91	45
H&S files	1.8	3.5	3.5	24.6	33.3	33.3	3.91	46
Stacking and storage	0.0	0.0	12.5	30.4	30.4	26.8	3.71	47
H&S disciplinary procedure	0.0	1.8	8.8	35.1	28.1	26.3	3.68	48
Housekeeping	1.8	5.3	14.0	22.8	31.6	24.6	3.57	49

Conclusions

Given the perceived importance of seven project parameters to the construction industry, it can be concluded that the traditional project parameters of cost, quality, and time drive the project ‘performance agenda’. Furthermore, given that safety is perceived to be more important than health, it is likely that the industry is more familiar with safety than health, and that safety receives more attention than health.

Given the frequency that nineteen OH-related phenomena are experienced on projects, it can be concluded that the respondents' OH perceptions reflect the general research findings relative to OH performance in South African construction, and that there is a need for improvement, potential to improve, and a perceived need for the implementation of Industry 4.0 technologies.

Given the respondents' below average self-rating of their awareness of / exposure to eleven Industry 4.0 technologies, it can be concluded that there is a need for interventions to raise the level of awareness, and to integrate such technologies into built environment / construction / construction OH / H&S and education and training.

Given the perceived potential of eleven Industry 4.0 technologies to enhance forty-nine interventions / outputs / processes relative to OH and H&S, the need for the implementation of Industry 4.0 in construction is amplified. Furthermore, the disciplines related to the interventions / outputs / processes lead to the conclusion that it is perceived that all project stakeholders will benefit from such implementation and that the stakeholders will be better able to contribute to construction OH as a result thereof.

Recommendations

Built environment, and construction H&S-related tertiary education, and construction OH / H&S-related training must include, or rather embed Industry 4.0 in their programmes.

Construction employer associations, and built environment associations and statutory councils must promote, and preferably provide Industry 4.0-related OH / H&S continuing professional development (CPD) and evolve related guidelines and practice notes.

The Construction Industry Development Board (cidb) should evolve a position paper relative to Industry 4.0 in construction and deliberate the development of a related industry standard in collaboration with South African National Standards (SANS).

The research reported on is perception based, although some perceptions may have been based upon interventions, which amplifies the need for 'experimental' case study research, which entails the quantification of the impact of Industry 4.0 interventions, and comparison thereof with 'traditional' interventions on projects.

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Design for Occupational Safety and Health: AN Integrated Model for Designers' Knowledge Assessment

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Abstract

One of the approaches to mitigate occupational safety and health (OSH) risk on construction projects is the design for occupational safety and health (DfOSH) initiative. The DfOSH initiative places a duty on designers to originate designs that are inherently safe for construction, maintenance, occupation and demolition. To achieve this goal, designers must possess appropriate knowledge of OSH risks as they relate to construction products. However, what constitutes DfOSH knowledge of designers is still not clear in the extant literature as well as in practice. Hence, this study systematically reviews literature of prior conceptualisations of the knowledge construct, undertakes contents analyses and provides a robust conceptualisation as a basis for its meaningful operationalisation with regards to DfOSH. The robust conceptualisation of the knowledge construct underpinned the development of a nomological network to operationalise the DfOSH knowledge of designers. The study presents knowledge regarding DfOSH as a multi-dimensional construct that can be measured at various levels of specificity. The integrated model can serve as a guide for clients to clarify the DfOSH knowledge of prospective designers in the procurement process. Respectively, designers intending to improve on their DfOSH knowledge can similarly be guided by this model to identify their DfOSH knowledge gaps and subsequently take steps to overcome such knowledge deficiencies. Additionally, the model invokes further studies, both theoretically and empirically, into how designers' DfOSH knowledge can be effectively harnessed and enhanced for managing OSH risk.

Keywords: Design for Occupational Safety and Health, Prevention through design, Designers' knowledge, Integrated model, Construction.

Introduction

The varied views and uncoordinated efforts of stakeholders along the construction supply chain partly explain the poor OSH risks management on projects (Willumsen et al., 2019). Previously, contractors mainly bore the responsibility of OSH risks management on construction projects (Hare et al., 2006). However, a deeper analysis of the root causes of sub-optimal OSH performance on construction projects is implicating project stakeholders (i.e. clients and designers) upstream of the construction supply chain. Their procurement and design decisions most often have impacts on OSH risk performance downstream of the supply chain. Hence, for effective project OSH risks management, a focus is now placed on stakeholders at the upstream of the supply chain in a philosophy termed as "prevention through design (DfOSH)" (Szymberski, 1997; Gambatese et al. 2005; Lingard et al., 2015). This philosophy places a moral, as well as in some jurisdictions a legal, duty on designers to originate designs or construction products that are inherently safe for construction, occupation, maintenance and demolition. Some researchers (for example, Gambatese et al., 2005; Goh and Chua, 2016) have advocated for awareness creation and capacity building among designers to enhance their contributions to project health and safety management, particularly at the pre-construction stage.

The nexus between procurement as well as design decisions and OSH risks downstream of the construction supply chain came to the attention of the European Union (EU) and its European Council EC) responded by adopting Council Directive 1992/57/EEC on the implementation of minimum safety and health requirements at temporary or mobile construction sites. In 1994 the UK, which had been a full member of the EU until recently, transposed the Directive into UK legislation as part of the Construction (Design and Management) Regulations 1994 (CDM 1994). These Regulations imposed statutory safety and health duties on the traditional members (i.e. clients, designers, and contractors) of construction project supply chains. Since 1994, the UK's Health and Safety Executive (HSE), the national regulatory authority for health and safety, has had to revise these Regulations twice – in 2007 (CDM 2007) and in 2015 (CDM 2015). One of the key changes made in CDM 2015 is the replacement of the requirement for *competences* of dutyholders with *skills, knowledge and experience (SKE)* of individual dutyholders and *organisational capability* where a dutyholder is an organisation.

Regulation 8(3) of the CDM 2015 puts on anyone appointing an individual CDM dutyholder, including a designer, a duty to take reasonable steps to satisfy itself that the appointee has the SKE and organizational capability (where the dutyholder is an organisation) to carry out the work in a way that secures health and safety. Respectively, a designer must not accept an appointment unless it has the SKE to carry out the assignment in way that secures health and safety. Failure to fulfil these duties is a criminal offence for which the appointer and the appointee may be prosecuted. Further, in the replacement of the CDM 2007 with CDM 2015, the HSE has indicated that the health and safety *competence* should be dealt with by way of professional bodies and the industry rather than by a regulatory requirement (HSE, 2014). However, there is a paucity of knowledge in the extant literature as well as a considerable amount of confusion in the construction industry as to what specifically constitutes DfOSH skills, knowledge, experience and organisational capability (for individual and corporate designers respectively) and more importantly how to measure these constructs. This study, thus, particularly aims at the explication and operationalisation of DfOSH knowledge of designers. It is expected that further studies investigate same for, skills, experience and organisational capability as they relate to individual and corporate designers respectively.

The study is structured in five sections. The first section provides an introduction and motivation for this study. The method or approach to the study is provided in the second section. The third section focuses on the meaning and theoretical model for measuring and assessing the DfOSH knowledge of designers. The fourth section offers some discussions on the model, points to areas for further research and indicates some practical applications of the study. In the last section, the conclusions of the study are presented.

Methods

This study initially conceptualises the DfOSH knowledge construct of designers, and subsequently develops an integrated model for the operationalisation of the construct. To fulfil the first part, a systematic review of literature of how prior studies have sought to conceptualise knowledge of a worker was undertaken. This was to provide a basis for conceptual content analysis, synthesis and provision of a broad conceptualisation of the knowledge construct. Scopus was used as the main database for the literature search with additional information from Google Scholar. In comparison with other databases (e.g. PubMed, Web of Science and Google Scholar), Scopus has an extensive coverage in all fields including science, technology, social sciences, arts and humanities (Chadegani et al., 2013; Mongeon and Paul-Hus, 2016). The key search word or phrase was “Definition of knowledge”. The search word or phrase in Scopus returned 372 results. The search results covered over 10 subject categories such as construction; engineering; social science; economics and finance; medicine; education; psychology; arts and humanities; computer science; medicine; business, management and accounting, etc. The year range was 1964 to April 2020 as supplied by Scopus.

The identified publications were screened, preliminarily, by checking the abstracts to establish their usefulness to the review. 95 publications passed the eligibility stage. The screened publications were subsequently assessed for eligibility. The main criterion for eligibility was that the publication must clearly indicate a definition for the construct knowledge. 13 publications were subsequently included in the conceptual analysis and synthesis for the constructs knowledge. As not many publications specifically provided definitions for the constructs in the first search, the reference sections of the publications that provided specific definitions of the constructs were specifically analysed to locate additional relevant publications from Google Scholar in a second search. This second search added 10 more publications making a total of 23 publications that were finally considered for the conceptual analysis and synthesis of the construct knowledge. Figure 1 indicates the publication selection process adapted from Moher et al. (2009) PRISMA systematic literature review process.

The conceptualisation of the knowledge construct in the first part of the research approach provided a basis for identifying the common components that explicate the construct, at least from the perspective of previous studies. The common components identified also provided theoretical underpinnings in establishing specific domains or modes of measurement for the construct. Combined with Quinones et al. (1995) and Tesluk and Jacobs (1998)’s postulation of levels of specificity of construct measurement, a nomological network was developed to operationalise the knowledge construct as they relate to the designers’ ability to ensure DfOSh. A nomological network establishes a linkage between the theoretical construct and its observable attributes in an attempt to operationalise the construct (Cronbach and Meehl, 1955).

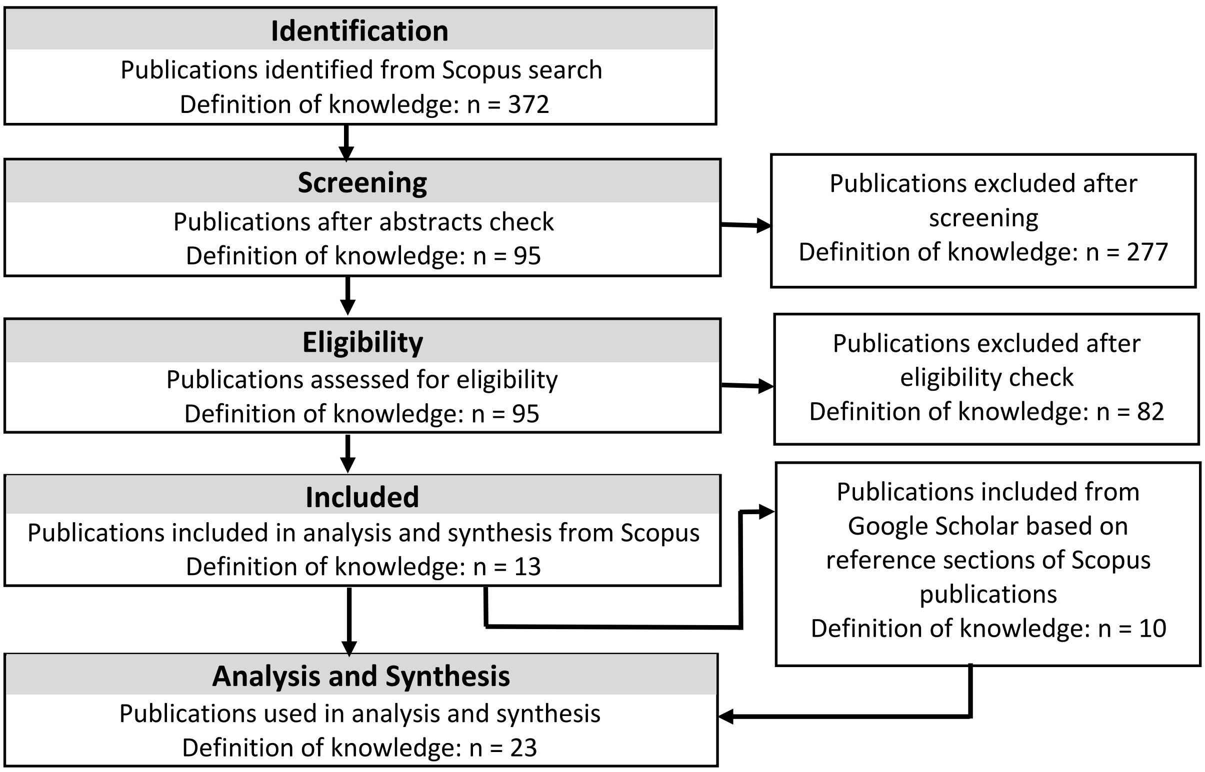

Figure 1: Publication selection process adapted from Moher et al. (2009)

Meaning and Theoretical Model for Measuring and Assessing the DfoSH Knowledge of Designers

Meaning of knowledge construct

Viewing from a cognitive psychology perspective, different kinds of knowledge can be distinguished, and the distinction between declarative and procedural knowledge is the most widely discussed (Baartman and de Bruijn 2011). Declarative knowledge is the factual information that a person knows and can be reported on (Anderson and Schunn, 2000). This is often termed as “know what” (Miller, 1990; Baartman and de Bruijn 2011; Śliwa and Kosicka, 2017). On the other hand, procedural knowledge is the connection or use of pieces of declarative knowledge and are usually knowledge that cannot be easily communicated (Baartman and de Bruijn 2011) and often considered as “know how” (Miller, 1990; Baartman and de Bruijn 2011; Śliwa and Kosicka, 2017). Tacit knowledge (Polanyi, 1958) is a critical part of this knowledge type. A third dimension of knowledge has emerged, referred to as strategic or metacognitive knowledge which pertains to knowledge about the task, context, problem-solving processes as well as oneself (Krathwahl, 2002; Pathuddin et al., 2018).

To elicit the understanding of the construct knowledge, a consideration is made to how researchers in the past have attempted to construe knowledge as indicated in Table 1. This approach provides a basis for a general understanding of the knowledge construct in order to ensure its objective and systematic measurement, particularly as it relates to designers’ ability to ensure DfOSH. As indicated in Table 1, the knowledge construct – at least from the perspective of researchers – deconstructs into three main components – information, experience and capability or ability.

Some researchers (for example, James, 1907; Plato, 1953; Sveiby and Lloyd, 1987; Mansfield, 1990; Engestrom, 1994; Blacker, 1995; Myers, 1996; Davenport et al., 1998; Nickols, 2000; Albino et al., 2001; David and Foray, 2003; Kakabadse et al., 2003; Gorelick and Tantawy-Monsou, 2005; ASME, 2010; Liu, 2015; Unger and Hopkins, 2016, Manu et al., 2019) understand or suggest knowledge from the perspective of a collection of *information* as indicated in Table 1. However, in the context of work (where performance is desired), information or a collection of it in itself is not useful unless it is situated in context (Aune, 1970) and targeted at a particular task (Kakabadse, et al., 2003; ASME, 2010). For instance, an individual can have information or a collection of it about farming practices. However, in the context of medical practice, that information or a collection of it is not useful and may not constitute knowledge. Context (Aune, 1970) justifies the worth of information and adds value to it (Sveiby and Lloyd, 1987) in our understanding of knowledge from the perspective of work.

Further, in understanding the knowledge construct, how the knowledge comes about is one element that explicates the construct. Some researchers (for example, James, 1907; Blacker, 1995; Alle, 1997; Davenport et al., 1998; Gorelick and Tantawy-Monsou, 2005; Liu, 2015; Unger and Hopkins, 2016; Manu et al., 2019), as indicated in Table 1, indicate or suggest that *experience* is the bedrock regarding the acquisition of information about a phenomenon or task which constitutes knowledge. In addition to experience, education or study (for example, Unger and Hopkins, 2016; Manu et al., 2019), as indicated in Table 1, is one avenue through which individuals can obtain relevant information, about a phenomenon, which constitutes knowledge. Generally, information obtained about a phenomenon which are recorded and passed on to others through education or study are based on other persons' experiences and views. The underlying conditions and environments that support the validity of the information about a phenomenon may change and thus discredit or invalidate the information. Hence, information through education or study which constitutes knowledge may not be adequate in itself in establishing true knowledge. On the hand, experience as an avenue for information about a phenomenon provides an opportunity for the information to be proven and validated by the individual in certain contexts. This corroborates Plato (1953)'s conceptualisation of knowledge as "justified true belief". Experience in this sense engenders a "moment of truth" in respect of information held about a phenomenon which constitutes knowledge.

Table 1: Literature definitions of knowledge

Definition	Source
Collection of information and experience an individual possesses.	International Project Management Association (IPMA) (2015)
A body of information applied directly to the performance of a task.	American Society of Mechanical Engineers (ASME) (2010)
Understanding gained through experience or study.	Unger and Hopkins (2016)
A collection of immovable, ready-made facts.	Engestrom (1994)
Facts, information or data.	Mansfield (1990)
Information, facts or familiarity gained by experience or education; the practical or theoretical understanding of a subject etc.	Manu et al. (2019)
Consists of cognitive states needed to interpret and otherwise process information.	David and Foray (2003)
Justified true belief.	Plato (1953)
Information put to productive use.	Kakabadse, et al. (2003)
Meaningful and organised accumulation of information through experience, communication or inference.	Blacker (1995)
Value added information.	Sveiby and Lloyd (1987)
Information in context.	Aune (1970)
Understanding based on experience.	James (1907)
Experience or information that can be communicated or shared.	Allee (1997)
Data and information that inform an understanding of a situation, relationships, causal phenomena, and the theories and rules (both explicit and implicit) that underlie a given domain or problem.	Bennet and Bennet (2000)
A capacity to act.	Sveiby (1997)
Knowing about something, knowing how to do something, or accumulated facts or records.	Nickols (2000)
Processed information.	Myers (1996)
Information combined with experience, context, interpretation and reflection, a high-value form of information.	Davenport et al. (1998)
The capacity (potential or actual) to take effective action in varied and uncertain situations.	Bennet and Bennet (2008)
The know-how, experience, insight, and capabilities that assist teams and individuals in making correct and rapid decisions, taking action and creating new capabilities.	Gorelick and Tantawy-Monsou (2005)
The information possessed by an entity that enables the entity to carry out a task.	Albino et al. (2001)

Memory of experience of decision making by consciousness, from cognition, rational thinking to hypothesis and belief that leads to a solution to a problem.	Liu (2015)

There are some researchers (for example, Sveiby, 1997; Albino et al., 2001; Gorelick and Tantawy-Monsou, 2005; Bennet and Bennet, 2008; Liu, 2015), as suggested in Table 1, who construe knowledge from the perspective of *capability* or *ability*. These researchers take the view that the existence of knowledge should make the individual functional or able to carry out a desirable task. This means true knowledge is not about an individual possessing a collection or body of information about a phenomenon but rather the ability of the individual to leverage the collection or body of information to perform a task. In that sense, what kind of information an individual, particularly the designer, must possess in order to be functional establishes a foundation for effective measurement of the individual's knowledge.

An agreement does not exist in literature on the specific conceptualisation of the construct knowledge as indicated in Table 1. None of the prior conceptualisations of the construct knowledge considers all the critical components or elements that explicate the construct. Hence, a more robust conceptualization, which encapsulates all the critical elements that explicate the construct knowledge, will be necessary. Thus, from the perspective of work and what knowledge is required for, this study proceeds to define knowledge as the collection of information about a phenomenon in a given context obtained through study and experience that enables an individual to perform a task.

Measurement of knowledge

The development of a framework for the measurement of designers' knowledge is based on Quinones et al. (1995)'s framework which was later extended by Tesluk and Jacobs (1998). See Quinones et al. (1995) and Tesluk and Jacobs (1998) for more details. Quinones et al. (1995) and Tesluk and Jacobs (1998) adopted a levels approach in the development of a framework for the measurement of worker experience. A levels perspective demands an appropriate definition of constructs and the domain of interest (dimensions of construct) as well as the level of measurement specificity (Klein et al., 1994). A levels perspective, in this case, forces the investigator to think conceptually about the individual, team, organisational and occupational issues as well as possible cross-level effects or domains (Quinones et al., 1995; Tesluk and Jacobs, 1998). The approach contrasts the domains or mode of measurement of the knowledge construct with the specific level where performance is required. In that sense, an opportunity is provided to ensure congruence and effective operationalisation of the knowledge construct in a nomological network. The nomological network has two main dimensions as *measurement mode* and *level of specificity.* There is a paucity of research on the measurement of the knowledge construct across occupations. Attempts have been made at measuring knowledge in the educational field (Phelps and Schilling, 2004; Hill et al., 2004) but those measurement approaches do so without providing congruence and operationalisation of knowledge across different levels of performance requirements. Emphasis of the researchers (Phelps and Schilling, 2004; Hill et al, 2004) have been on the domains of knowledge measures. For instance, Shulman (1986) in assessing and measuring a subject-matter knowledge for teaching by teachers proposed three dimensions as content knowledge; subject matter knowledge for teaching and curriculum knowledge. The first dimension, content knowledge, according to Shulman includes facts and concepts in the domain as well as why those facts and concepts are true. This dimension of teachers' knowledge corroborated by other researchers (Ball, 1990; Hill et al.,

2004) can be considered as declarative knowledge (Anderson and Schunn, 2000; Baartman and de Bruijn 2011).

The second dimension, subject matter knowledge for teaching, considers what makes a topic under a subject difficult or easy and most importantly how to teach it to the understanding of students. This is an insight beyond the declarative knowledge and focuses on stringing the declarative knowledge to achieve a goal. In essence, this dimension is considered as a procedural knowledge (Baartman and de Bruijn 2011).

The third dimension, curriculum knowledge, Shulman indicates involves how topics under a subject are both arranged within a school year and over longer periods of time as well as using curriculum resources, such as textbooks, to organise a programme of study for students. Insight in this domain requires a better appreciation of the environment and context and can be considered as a metacognitive knowledge (Krathwahl, 2002). The measurement of knowledge of an individual required to carry out a task can therefore be considered in the mode or domains of content, procedural and metacognitive information on the phenomenon. This naturally taxonomises the knowledge required by an individual to perform a task, particularly the designer – as indicated in Figure 2 – as content, procedural and metacognitive. Again, relating the domains of knowledge to some levels of performance specificity engenders some congruence and provides, somewhat, comprehensive framework for measuring the knowledge of an individual required to undertake a task, as shown in Figure 2. Each of the modes of the knowledge construct can be operationalised at five levels of specificity (task, job, work group, organisational and occupational) creating a 5 X 3 nomological network for measuring the DfOSH knowledge of a designer. Illustrations of measures or attributes of DfOSH knowledge, represented in each cell, are subsequently discussed. Designers can vary on their task content information with regard to DfOSH. While some designers may possess more task content information in respect of DfOSH, others may not. For instance, what a specific DfOSH task entails. Second, designers can vary on their task procedural information. Some designers may possess more tacit information than others regarding how a specific DfOSH task ought to be performed. Third, metacognitive information about tasks with regard to DfOSH is one dimension that can distinguish designers. Some designers may have more information about when a task required to ensure DfOSH ought to be performed in the design process as opposed to others.

At the level of a job, designers can differ in respect of DfOSH job content information. While some designers may have more content information about a DfOSH job (a collection of different DfOSH tasks), others may not. Second, designers can vary on their procedural information possession about a DfOSH job. For example, some designers may possess more tacit information about how multiple or different DfOSH tasks can be performed during the design stage as opposed to others. Third, designers can vary on their job metacognitive information in respect of DfOSH. While some designers may have more information about when a DfOSH job has to be carried out and how it affects other jobs also aimed at DfOSH, others may not.

At the level of work group, designers can differ in respect of DfOSH work group content information. Most likely in a design, designers must work in or with groups. Possession of specific information about what work groups ought to do to ensure DfOSH on a project is one area that can distinguish designers. Second, work group procedural information is another dimension that can distinguish designers. While some designers may possess more information about the process or how groups work to ensure DfOSH during project designs, others may not. Third, designers can vary on work group metacognitive information. Possession of information about what other work groups are working on or have to work on, regarding the design, to achieve the goal of DfOSH can set designers apart.

Level of Specificity	Content Knowledge	Procedural Knowledge	Metacognitive Knowledge
Occupational	Occupational content information (e.g. Architecture, Engineering, etc)	Occupational procedural information	Occupational metacognitive information
Organisational	Organisational content information	Organisational procedural information	Organisational metacognitive information
Work Group	Work group content information	Work group procedural information	Work group metacognitive information
Job	Job content information	Job procedural information	Job metacognitive information
Task	Task content information	Task procedural information	Task metacognitive information
Measurement Mode	Content	Procedural	Metacognitive

Figure 2: A conceptual framework of knowledge measures

At the level of organisation, designers can vary on organisational content information. Construction projects that require DfOSH initiative most likely will be delivered through organisations. Hence, specific information about organisational systems and structures required to deliver DfOSH on projects will be necessary. Possession of such information can vary among designers. Second, designers can vary on organisational procedural information. Some designers may have information about the processes and procedures required at the organisational level to ensure DfOSH on projects, while others may not. Third, designers can vary on organisational metacognitive information in respect of DfOSH. Some designers may possess information about different organisations and how each can make a contribution to DfOSH. Again, they may possess information about the effect of each organisation's decision in respect of DfOSH on the other so as to ensure optimal decision making. Information in this respect as possessed by designers can vary.

At the level of occupation, designers can vary on occupational content information. That will depend on the type of designer's occupation, whether an architect, civil engineer or services engineer. For example, in a building project design, an architect may have more involvement and possess more OSH risks information about the design as opposed to a services engineer who only focuses on a section of the entire design. Second, designers can vary on occupational procedural information. For example, some designers may be more familiar with standards and protocols adopted by some professional bodies in respect of DfOSH than others. Third, designers can vary on occupational metacognitive information. Information about which occupations or professions may be required on designs to make effective contributions to DfOSH may not be possessed or obvious to all designers and hence distinguish designers.

Discussion and Pointers for Future Directions for Designers' SKE Research

The construct knowledge as it relates to the designer, particularly for optimal OSH risk management, is considered as multi-dimensional in its measurements. Construing the knowledge of a designer from a single or narrow perspective can potentially undermine a useful measurement of it. Further, such a narrow view of it will not only undermine a useful measurement but can also impair the judgements and decisions of project clients who have to assess and select designers based on their knowledge. Additionally, the knowledge constructs, with regard to the designer, must be considered as multi-level. The DfOSH knowledge of designers cannot be assumed to exist at all levels (from a task to an occupational level). The knowledge that is required at the task level may not be the same as required at the occupational level.

Further, the knowledge construct, as they relate to the designer must be considered as dynamic (Teece, 2012). Knowledge, as they reside in designers, can be considered as assets (Andreu and Ciborra, 1996; Adaku et al., 2018). In that regard, it can increase through deliberate and conscious efforts by individuals or deteriorate as a result of lack of individuals' self-efficacy and neglect. Over time, the knowledge of designers can increase or deteriorate along the mode of measurement or the level of specificity. Hence, an industry framework that seeks to capture the dynamics of designers' knowledge will be a useful one. Such frameworks could be in the form of knowledge maturity models.

Future studies on designers' knowledge should focus on testing the measures (particularly within the cells) of the knowledge construct empirically to distill the most relevant ones having regard to the current practice. Again, in such an empirical test, attention should be paid to what constitutes each measure as well as the evidence or indicator that must be adduced to assess that measure, in practice. As earlier indicated, the knowledge of designers, with responsibility for effective OSH risks management, can increase or deteriorate. Thus, future studies on designers' knowledge should investigate the enablers or constraints of designers' knowledge development. This proposed models or nomological network to measure the knowledge of designers with responsibility for DfOSH cannot be deemed to be complete. Hence, further studies are invited to extend the network to deepen our understanding and measurement of the designer's DfOSH knowledge.

Practical application of the model

The suggested model for the measurement and assessment of the designer's DfOSH knowledge can support project clients to clarify the required knowledge of designers in the procurement process. In this case, the attributes of DfOSH knowledge as indicated by the model can inform pre-tender interview questions or pre-qualification questionnaires of project clients in the selection of designers. Respectively, the model can also serve as a guide for designers intending to develop their DfOSH knowledge by providing domains and levels of specificity relevant for such attainment. In other words, designers can look to the attributes of DfOSH knowledge specified by the model, identify gaps in their DfOSH knowledge and take appropriate steps to overcome such knowledge deficiencies. Some countries have public specifications that assist clients in assessing and selecting designers. For example, in the UK, the publicly available specification (PAS) 91 is one such instrument for construction-related procurement and this model can inform it. The core criteria of safety schemes in procurement (SSIP), a private sector initiative in the UK to assist project clients in the procurement of health and safety services, can benefit from this model.

Conclusions

In some parts of the world, such as the UK, Regulations (e.g., CDM 2015) have been developed to place a duty on designers to originate designs that are inherently safe for construction, occupation, maintenance and demolition. However, there is a paucity of knowledge and misunderstanding as to what specifically constitutes DfOSH knowledge of designers and more importantly how to measure it, in the literature and practice. This study has, thus, sought to investigate and deepen knowledge in this regard in a number of ways. First, it explicates or conceptualises the constructs knowledge as a basis for its meaningful operationalisation. Second, it provides a comprehensive model or framework for an effective operationalisation of the designer's DfOSH knowledge. It presents knowledge, in respect of design for occupational safety and health (DfOSH), as a multi-dimensional construct that can be operationalised at various levels of specificity.

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Design for Safety Review in Early Stages of Mandatory Implementation

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Abstract

Purpose: Prevention through design has been identified as a possible measure to prevent construction-related accidents. To operationalize this, Design for Safety (DfS) was introduced in Singapore as a legislatively mandated set of design review meeting with safety being the main focus. This study aims to investigate how DfS is practiced in the early stages of compulsory implementation.

Design: A case study approach was undertaken for this research with observations of two design stage DfS review meetings in one project. Thematic analysis was carried out.

Findings: Team members in the projects with newly established review processes were more reliant on external prompting by the team's leadership to carry out their due diligence. Relative priority placed on the review was higher in the team with an established process.

Limitations: Observations were made only during the projects' design stage. Thus, current work does not reflect lessons learnt and applied by project teams after carrying out the different stages of a project.

Originality: The impact of mandating a new safety review in construction projects is investigated. This contributes to the understanding of the competencies of project teams at different maturity levels of performing DfS review. This study provides insight to their conduct during the review meetings and provides insight to the coordination and cooperation requirements. Possible factors influencing the effectiveness of the DfS review process are identified.

Practical implications: This study is of significant use to those looking to implement or revise a DfS review process to prevent construction-related accidents. It provides insights on what to expect during early DfS adoption, allowing them to be cognizant of potential pitfalls.

Keywords: Prevention through Design, Design for Safety, Design for safety project team, Team processes.

Introduction

The construction industry is historically known to be a dangerous industry with disproportionately high contributions to recorded accidents worldwide, which results in dire social consequences impacting families, communities, and personal mental health of construction workers (Schulte et al., 2008). Therefore, controlling and minimizing hazards that lead to accidents is of paramount importance. Design for Safety (DfS) offers a promising way to address this problem, as it deals with designing out potential hazards and design risks of a facility (Goh and Chua, 2016; Toh et al., 2017). This aligns with Schulte et al. (2008), who notes that the approach to preventing hazards through design is the most effective means of preventing construction accidents. Due to its effectiveness, countries now require DfS or prevention through design (PtD) on construction projects (Larsen and Whyte, 2013). The European Union has mandated the implementation of prevention through design (PtD) through the Directive 92/57/EEC. Countries which adopted this directive earlier generally had lower accident rates as opposed to countries which implemented them later (Martínez Aires et al., 2010). The United Kingdom is one such early adopter, requiring PtD since 1995, which was subsequently updated in 2015 (HSE, 2015). Similar legislation is observed in Ireland (Health and Safety Authority, 2006), Australia (Australian Department of Consumer and Employment Protection, 2005), South Africa (South African Department of Labor, 2014), United States (Gambatese et al., 1997; NIOSH, 2013) and Singapore (Workplace Safety and Health Council, 2011, 2016).

However, implementation of DfS has not been completely smooth sailing and project stakeholders have faced difficulties in practicing DfS. In the UK, it has been reported that some designers feel that DfS has turned into a paperwork generation exercise; where designers fill out forms without meeting the purpose of the review process (Gambatese et al., 2009; Larsen and Whyte, 2013). Some reportedly perceive the problem of health and safety to be a problem of contractors to handle, even though the DfS regulations have been in place for a long time (Morrow et al., 2015, 2016). In Australia, even though attitude towards DfS is positive, it is reported that designers from small firms are less able to execute DfS (Behm and Culvenor, 2011). Even with policies for DfS in place, effectiveness is also dependent on the maturity of a particular countries' construction industry. Some developing countries have poor implementation of DfS as a result of low engagement in DfS by construction trade practitioners in those countries (Abueisheh et al., 2020; Manu et al., 2018, 2019).

In the context of Singapore, DfS was first introduced to the construction industry in 2008 as a voluntary initiative and subsequently mandated in 2015 as a regulation which has been operative since 2016 (Workplace Safety and Health Council, 2016). However, work on the effectiveness of this compulsory implementation is sparse. Therefore, the current study aims to investigate how DfS is practiced in the early stages of its compulsory implementation in Singapore. To this end, the objectives of this paper involves exploring how DfS review is practiced in the early stages of compulsory implementation through an exemplary case study; identifying areas of similarity and differences between DfS code of practice and the actual practice; and to identify potential underlying reasons for the observed differences.

Literature Review

Implementation of Design for Safety

According to the hierarchy of control, it would be most effective, reliable, and cheaper to make changes to the design to address hazards at the source (Lingard et al., 2014; Manuele, 2008). The project team's ability to influence safety in a construction project and subsequently the completed building is the highest at the start (Weinstein et al., 2005). It is found that, to operationalize and implement DfS effectively, an explicit process is required (Toole et al., 2017). By involving designers for DfS right at the start of the project through such a process; it gives them the ability to make decisions which will reduce or eliminate identifiable risks before such risks occurs (Behm, 2005).

Otherwise, as a project advances, it is subjected to greater resistance to change as the cost of changes to the project steadily increases, making it unfavourable for the developer (Szymberski, 1997).

Support from the developer is also of utmost importance to the success of the DfS implementation and in is most cases embedded into the regulatory requirements. For example, in the UK, developers are required to ensure there is no unreasonable safety and health risk to any person by hiring competent contractors and designers. The developers must also ensure relevant health and safety information is properly disseminated among project team members and sufficient resources are provided to fulfill their health and safety duties (HSE, 2015). Concurrently, Toole et al. (2017) empirically showed that high owner expectations and proactive leadership catalyses effective participation of project stakeholders in the DfS review process and subsequent successful implementation of DfS. Similarly, with the compulsory implementations of DfS, each project stakeholder, the designers and contractors, is given specific duties to ensure safer designs.

While adhering to the regulatory frameworks, actions undertaken at the design stage are able to influence how the building is constructed. Hence, risks can be eliminated or mitigated through proper analysis and assessment during this stage (Zou et al., 2008). During the pre-design phase, safety and risk management requirements are established. Roles and responsibilities of the involved parties are also assigned. Hazard identification is carried out at the conceptual and schematic design stage. When the design has developed with greater details and specifications, control measures of the hazards can be implemented. The hierarchy of control is adopted to control the hazards. Behm and Culvenor (2011) suggested that the use of hierarchy of control prompts the formation of more reliable solutions. In this process, subsequent redesign incorporating the control measures can be done when necessary.

Opportunities and challenges for Design for Safety implementation

Toole and Gambatese (2008) identify three distinct advantages of utilizing DfS to reduce construction hazards. Firstly, proactive identification and elimination of a risk is safer and cheaper than a reactive approach to managing risks. Secondly, building professionals with the most knowledge and experience with regard to common and critical hazards will consider site safety as a result of considering DfS. Thirdly, there is intrinsic symbolic value of project stakeholders being concerned with worker safety even from early design stages. This indicates a good safety culture within the construction organization. Further to this, removal of hazards have a direct relationship with reducing the total cost of a project (Toole and Gambatese, 2008). On top of this, Behm and Culvenor (2011) notes that a safer design increases workers’ safety and productivity, thereby enhancing project quality.

On the other hand, a perceived increase in design duration, cost and requirements for additional resources arising from the DfS process is observed from countries where DfS has been implemented (Behm and Culvenor, 2011; Gambatese et al., 2009). On top of that, barriers such as design professionals lacking sufficient expertise on construction safety (Gambatese et al., 1997; Hallowell and Hansen, 2016; Toole et al., 2017) and designers' concerns over legal liability have been shown to be detrimental to the effective implementation of DfS review to improve construction safety (Toole, 2005; Toole and Gambatese, 2008). This is in agreement with the findings of Gambatese et al. (2005) who found designer’s knowledge in DfS to be crucial for its effective implementation in practice. Yet, this is hindered by a lack of available and accessible knowledge compilations on DfS as identified by

Goh and Chua (2016). Furthermore, as Schulte et al. (2008) note, for a compulsory national DfS implementation to be successful, it must be more than a mere improvement of designer's competencies. There should be buy-in from commercial decision makers such as developers and clients, who have the power to insist on backing projects and professionals with a good safety track record, thus increasing demand for safer designs to protect workers. Further research into the current state of practice is therefore crucial to understanding the shortfalls. This can aid in the development of policy and legislative reforms to compulsory implementations of DfS in the construction industry.

Method

A case study approach was undertaken for this research. As the regulations were new and practice hence different from current practice, it would be difficult to anticipate how practice would carried out. The choice of the case study method gave the researchers a full and broad picture of the DfS practice without prior constraints applied to the observations.

One project was observed in detail. The project observed was a new 26 storey residential building, built on empty land. Residential buildings represented typical buildings built in Singapore. Observations were carried out twice, once in the conceptual design stage, and the second time during the detailed design stage. At early stages in the design, it would be difficult to visualize the unique features of the design, as items have not been designed yet. Later in the design, many items in the design would already have been finalized and changes difficult to make. It was anticipated that observations of this project that were still in the early stages of the DfS review process would be most productive.

Notes were taken during the meetings of the items presented, behaviours displayed, and the general flow of the meeting. The two observations were analysed using thematic analysis. Common themes that were observed between the two meetings were compiled.

Results

Background on DfS guidelines

The DfS regulations implemented in Singapore imposes statutory duties on the developer, contractor, designer, registered proprietor, and Design for Safety Professional (DfSP). The DfSP serves as the facilitator of the DfS review process. Other mandatory obligations include the developer convening the DfS review meeting and maintaining the DfS risk register. These tasks may be delegated to the DfSP. The DfS risk register is a compilation of the design risks identified in the project and the mitigation measures that should be undertaken to address them. Prescribed statutory duties are explained in the DfS guidelines. The enforcement and prescription of penalties for any lapses in implementation are based on the regulations *Workplace Safety and Health (Design for Safety) Regulations* (2015).

Published as an accompaniment to the regulations by the Workplace Safety and Health Council (2016), the DfS guidelines are a non-mandatory code of practice for DfS, suggesting a specific structure for the review process to take. They are not legally binding, and hence, projects do not have to follow the prescribed structure. However, most projects try to adhere to the structure. In event of enforcement, they may use their compliance with the guidelines as a form of protection against penalties. The suggested structure is known as the GUIDE process. During a GUIDE process, the stakeholders are to be gathered, understand the design concept, identify the risks, design around them, and to record all relevant information. It is also suggested that meetings take place at three distinct stages: concept design, detailed design, and pre-construction. These are known respectively as GUIDE-1, GUIDE-2, and GUIDE-3.

Other recommendations given in the DfS guidelines help to scaffold the design review process. A list of common design considerations that may pose risk are given. Suggestions are also given for: the design changes that are under a designer's control, the use of annotations in the designs to further convey the risk to the appropriate recipients, and the production of a maintenance strategy report to bring maintenance concerns into focus for the project team.

Results in the following sections are reported in the order of observed proceedings of the review meeting, comparing with the DfS guidelines, and finally, the elicited underlying themes.

Project observations

Attendance

Two meetings were observed. In the first meeting, the attendees comprised of; the developer's representative, the architect, the civil and structural engineer, the mechanical and electrical engineer, and the project coordinator. The architect also served as the DfSP of the project. In the second meeting, the civil and structural engineer was unable to attend. This practice is in contrast to what is provided in the DfS guidelines, which states that the developer should ensure that all the relevant parties, designers and contractors (if on-board the project) should attend the meeting.

Focus of meeting

In the first meeting observed, the stated intent of the meeting was to aid the project team in understanding how to carry out the GUIDE processes. The representative of the developer conducted this meeting as the DfSP was not considered to be satisfactorily conducting review meetings. Each item on the DfS risk register was discussed among the project team, the DfSP, and the designers. While going through each item, the developer's representative guided the team and provided opinions and advice on how to carry out GUIDE-1. During the meeting, the designers discussed the items on the risk assessment using the site map and the DfSP recorded all the amendments. The items discussed were more general as the emphasis was on familarising the project team members with the conceptual thinking of performing the DfS review, rather than specifically tackling the project's design risks. The DfS guidelines do not mention any introductory briefings, or trainings to be given to the team members. However, these are useful to clarify expectations for the team members.

For the second meeting observed, this took the form of a typical DfS review meeting, where specific design items were discussed to identify hazards and mitigate them. This meeting was considered to be part of the GUIDE-2 stage in the design review process. The timing of the meeting as appropriate as it was conducted before the design was close to finalization. This can help the designer to review the structure progressively as it develops.

Hazard identification and mitigation

One of the main processes in the DfS review is hazard identification. For the review process to be effective, it is critical that hazards are specifically identified. This allows for appropriate mitigation measures to be taken. During the first meeting, the developer's representative set out to clarify what the appropriate hazards to be identified and documented were. There must be considerations of the hazards and risks in the long term perspective, i.e. during the maintenance stage. Possible hazards and risks that may affect the site and/or surrounding environment must be brainstormed during the meeting.

Hazards identified should be recorded in the DfS risk register. Completing the DfS risk register was challenging for the project team. There were items in the DfS risk register that were similar to each other. The DfS risk register included risks that were resolved prior to the first meeting, even though the intent of the DfS risk register was to record residual risk at that specific point in the project. The contents in the DfS risk register were recorded with abbreviations instead of being spelled out in full.

The first meeting observed was aimed at introducing the project team to the ideas behind DfS and how to perform the review procedure. For the second review meeting, the focus was less on the specifics of recording items in the DfS risk register and more towards identifying hazards. The project team was prompted by the developer's representative to think about the hazards posed in all stages of the project's life cycle including maintenance. The team was also prompted by the developer's representative to consult the main contractor for expertise on construction related issues like deep excavation. Other hazards discussed included the potential traffic flow around the construction site, and the measures needed to account for that. One mitigation measure that was implemented was moving a generator away from residential areas, thereby eliminating the hazard.

Recording the hazards was still an area of confusion in the second design review meeting. There was confusion over among the team whether there would still be residual risk if the stated mitigation measures were applied. For items where there were residual risks, the designers would make a note of it in the drawings. Despite the instruction from the previous meeting, risk recorded in the DfS risk register were still inadequate. For example, items recorded did not have a stated hazard and the proposed control measure did not address the problem.

In the DfS guidelines, hazard identification should take place at each stage of the design process. The team implemented the DfS review process at each stage of the project, as necessary, to review the design while it is ongoing. It is also critical in the DfS review process to identify hazards posed in the construction and maintenance stages, which the project team did upon prompting from the developer's representative. A checklist of common design considerations is provided in the DfS guidelines, which the team used to scaffold their thinking. These were used to identify potential and specific areas of the project that needed further improvement. Brainstorming, as mentioned by the developer's representative, is also a suggested method for identifying design risk.

The DfS guidelines state that the DfS risk register is to be used to record the risks, mitigation measures chosen, and subsequent residual risk. The completed document is to be handed over to future management of the building. The team adopted a measure suggested in the annexes, which was to mark out residual risks in the drawings. Overall, the developer's representative's identification of the issues of the DfS risk register aligned with the intent of the DfS guidelines. One common issue faced herein was the lack of specificity with the identified hazards. There is no direct statement in the guidelines of how specifically a hazard should be identified. However, when keeping in mind the intent of being able to mitigate design risk hazards, the necessity of the clear identification of the design hazards becomes apparent. Other examples include adjusting for the intent of being able to keep the DfS risk register as a live document, which could be handed down to future building managers. The use of full names for items rather than abbreviations would help to make the register comprehensible to future readers of the manual.

Tender preparation

During the first meeting, the developer's representative highlighted to the project team members that the information they were creating was key to the preparing the tender documents. The information currently available was judged to be insufficient. It was highlighted to the DfSP that they would have to gather as much information as possible to place into the tender so that the contractor can appropriately price for the residual risk that they would have to address. Questions about future tender preparation were also present in the second review meeting. For example, if hoarding at the site was needed, the quantity and specific locations were all necessary so that the contractor would be able to price in the control measure.

There is no explicit mention of the link between the tender process and the DfS review in the DfS guidelines. However, there exists a duty for the developer to manage the project such that all designers and contractors have sufficient project resources to perform their duties. Placing the project specifications in the tender helps to define the necessary resources to be used for each mitigation measure.

Developer role

In both meetings, the developer's representative was observed to be a key player. They provided specific guidance to the project team, continually prompting them where necessary to better align their work with the spirit of the DfS guidelines. For example, the project team members were repeatedly asked to be more specific with identifying the hazard. By leading the meeting, the developer would be keeping to their duties of ensuring that all 'foreseeable design risks are eliminated' or 'reduced to as low as reasonably practicable'. The developer's representative in this study took a hands-on approach towards this duty by directly overseeing and getting involved in the process. The developer also helped to ensure that necessary resources were provided, by asking for them to be listed in the tender.

DfSP role

In the meetings, it was observed that the DfSP took a majority of their direction from the developer's representative in the project. While they tried to facilitate the meeting by asking probing questions of the designers, this role was mostly carried out by the developer's representative. Although they improved between the first and second meeting. Even so, the second meeting was still largely run by the developer's representative. From the DfS guidelines, it is stated that the developer may delegate the task of convening the DfS review meeting to the DfSP. Hence, the DfSP role is to serve as the facilitator of the meeting. Yet in practice, for this specific project, the meeting was facilitated by the developer's representative.

Designers

Consultants were observed to contribute actively to the meeting by providing details and information on the design features when prompted. They were knowledgeable and ready to provide information on their areas of expertise. For areas that may not be under their responsibilities, they would also offer their opinions and feedback. In the second review meeting, the mechanical and electrical consultant was clear on his work, so they were able to provide information readily whenever asked. The DfS guidelines ask that the designers provide the relevant information, and to prepare design plans that eliminate or reduce as far as reasonably practicable design risks. By participating in the meeting, identifying the risks, they are partially fulfilling their duties to do so.

Discussion

During the implementation of new regulations, knowledge about the newly imposed statutory duties must be transferred to the practitioners whom it affects. A method of doing so is through the publication of the code of practice. This serves as a formal statement of the regulator's interpretation of the guidelines, even if the enforcement would be based strictly on the text of the regulations. It is not known how many of the participants at the observed meetings had read the guidelines. However, formalized methods of training for the DfS review process will derive their information from the DfS guidelines.

Training and leadership

While the DfS guidelines providing information to the designers on their duties were published before the observed meetings, designers and the DfSP did not refer to the published guidelines. Rather, they received training in how to act from the meeting. This was done by the developer's representative as they pointed out what they felt was correct or incorrect, such as the appropriate way to identify risks, implement mitigation measures, and subsequently record this process. By doing so, the developer had fulfilled their statutory duties to 'ensure that all foreseeable design risks were eliminated or reduced to as low as reasonably practicable'. The developer's representative's advice closely matched that which was given or could be implied from the advice of the given in the guide. However, this calls into question the utility of the DfSP. Of all the positions in the DfS review, only the DfSP is required to have a minimum qualification and receive mandatory training in DfSP. It is not expected that this would make the DfSP the most familiar with the procedures. However, it was observed that the DfSP was inexperienced, and had to be guided by the developer's representative instead. This calls into question the efficacy of the mandatory training undergone by the DfSP.

The designers and team were receptive to this informal training, as they were all cooperative and actively contributed to reviews of the design. This could have been because the training was undertaken by the developer's representative. The developer's representative serves as the leader of the team. They control the resources and payment in the project, which gives them power over the other members. This power could make the team more receptive to their suggestions and instruction. The findings are in line with previous research on the importance of developer support for implementation of DfS (Toole et al., 2017).

Hazard identification

It was observed that the project team faced great difficulty with the process of hazard identification. Knowledge of DfS by the designers is both crucial and not currently sufficiently widespread for implementation to be effective (Gambatese et al., 2005; Goh and Chua, 2016). Items listed in the DfS risk register were not specific enough to truly understand what the hazard was; and what subsequent mitigation measures were needed. The DfS risk register lists common design considerations that might result in hazards. However, for the process to be truly effective, there is a need to consider the unique risks arising from the site and to clearly state the risk. The mitigation measure would be easy to derive from there. The team members also had difficulties understanding what should be included in the DfS risk register. It is not made explicit in the DfS guidelines as to what risks should be recorded. For example, if they have already considered the problem and addressed it in the design. The DfS guidelines focused on instructions for the process, and less so on the documentation required.

Implications of findings

In the early stages of implementation of a DfS review process, it is expected that project team members will be uncertain of how to carry out the process. Instruction is needed. This study shows that non-mandatory codes of practices may not be followed. Nevertheless, guidelines should still be published as it gives people an understanding of how the DfS regulations can be implemented in practice. The practical implication of the results show that this cannot be the only method in which information is spread about newly introduced guidelines. In particular, the observations made in this study suggest that a critical method in which project team members learn about newly implemented procedures is through lived experience. One or more of the senior team members serves as a guide for the team. This suggests that it is critical to have widespread DfS training targeted at all major roles in the DfS review process. Redundancies in the expertise of the review process can help to ensure that all project teams can receive guidance for a newly implemented review process.

This study also calls into question the position of the DfSP. If guidance for DfS review in the project team can come from the core team, which existed before the implementation of the regulations that created the position of the DfSP, there may not be a need for a DfSP. When the process is more familiar to practitioners, the utility of the DfSP role should be reconsidered. This would be in line with removal of a similarly designated facilitation role in the UK regulations (Carr, 2014).

To address the problem of the difficulty in identifying hazards, it would be useful to compile a sample of a potential DfS risk register. This would assist project team members in performing DfS review.

Conclusions

The objective of this study was to investigate how DfS is practiced in the early stages of compulsory implementation. In this study, observed behavior of participants in the DfS review process was compared to what was written in the DfS guidelines and regulations that implemented the DfS review process. The impact of mandating a new safety review in construction projects is investigated. This study provides insight to project team members' conduct during the review meetings. The differing roles of each project team member was also studied. This provided insight as to the importance of factors such as leadership for the project team. Possible factors influencing the effectiveness of the DfS review process were identified, such as the training each of the project team members received to prepare them to carry out DfS. The themes identified in this research may be used to identify key themes and components to study the climate within a DfS review process.

This study is of significant use to those looking to implement or revise a DfS review process to prevent construction-related accidents. Behaviour observed during DfS review practice is remarked, allowing future adopters of DfS to be aware of potential pitfalls that they might face. For example, the lack of understanding on the part of the design team for performance of the task.

This case study studied one project, from which it would be difficult to capture a sense of the overall practice in Singapore. Observations were made only during the projects' design stage. It is unknown how project teams would take to DfS review in the later stages of the process. Since this meeting was observed at the early stages of the design process, further research should be done on the later stages of the design process. In particular, how the contractor and the design team review the design work. Although DfS is to account for the design of temporary structures that are used in construction, in practice, it is felt that these structures are the scope of the contractor's work. Designers may be more reluctant to review any such work. Further research can be conducted on this, as the present study did not account for the role of the contractor.

This research focused on the practice of DfS review in the early stages of mandatory implementation. Further research could explore process maturity as the regulation becomes more firmly entrenched in the local practice. Process maturity could differentiate between projects that are implementing DfS review only for compliance, and those who are practicing it to actively improve the design and reduce risk inherent in the design. In addition, identifying the differences in practice and attitude of team members between mandated review processes and those that were voluntarily implemented could prove to useful for regulators seeking to regulate the practice.

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A Retrospective Assessment of Safety in Design (SiD) in Existing Public Buildings

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Abstract

The concept of Safety in Design (SiD) is strongly influenced by the UK CDM Regulations and the drive to improve safety and health in the industry. Designers have a responsibility not only for design and build; but for use and maintenance by designing out any hazards at any of these phases. The impact that designers have on site safety is dependent on their skills, knowledge, experience and organisational capability to modify designs towards improving safety. This study reviewed the impact of SiD during use and maintenance of 12 existing public buildings in London by visually inspecting and adopting a scoring matrix for the design hazards. The inspection data acquired were evaluated using a design control-measure database with recommended alternative design decisions capable of improving safety. The findings suggest that buildings post-CDM 1994 incorporated better safety initiatives in the designs than buildings pre-CDM. In principle, 9 out of the 12 (75%) buildings inspected had good level of SiD implemented in the design e.g. the foyer. Eight (8) of the 12 buildings had safety-related issues with manhole chambers/access shafts located in busy access areas, damaged or uneven entrance to the buildings, external wall-window systems, working at height, slips and trips, location of plant rooms and SiD implementation in buildings pre and post-CDM regulations. This study contributes to the discussions around public building safety by demonstrating that the implementation of SiD in the overall design of the entire building significantly improves the safety of buildings rather than SiD in some specific areas of the building. The limitations of this study included restricted access to plant rooms and small sample size which inhibits the generalisation of the findings. Therefore, future studies would benefit from using larger sample sizes and prior permission from the building operators to gain unrestricted access to conduct inspections.

Keywords: Safety in Design Design hazards CDM Regulations Designers Site safety

Contextualising SiD

Every construction project is unique in its own right and it is acknowledged that there is a connection between design and construction related accidents as suggested by Haslam et al. (2005). The evolution of the UK Construction (Design and Management) Regulations from 1994 - 2015 places emphasis on the role and duties of designers involved in construction projects to consider the health and safety implications of their designs.

The EU directive 92/57/EEC which was transposed into UK law in 1995 as the Construction (Design and Management) Regulations (CDM) 1994 recognises that the CDM Coordinator (presently duty of principal designer) has the responsibility for coordination of health and safety in construction projects. The duty of the designer using the pre-construction information however, is to take account of the general principles of prevention with the aim of eliminating foreseeable risks. The CDM Regulations have since undergone changes from CDM 1994; replaced by CDM 2007 to address the perceived shortfalls and presently, the CDM 2015, see Table 1. The rationale for incorporating Safety in Design (SiD) in construction project is to address the workers' health and safety needs in the design and redesign processes to prevent or minimize work-related hazards and risks associated with the construction, use, and maintenance of structures. However, some designers still struggle to recognise how to incorporate and improve health and safety through design (Haslam et al., 2005), even though it is mandated by the Construction (Design and Management) Regulations, 2015.

lthough construction accidents in the UK are in the downward trend year-on-year, it does not however infer that the implementation of SiD alone has been the main precursor to these fall in numbers as there are other multiple factors responsible. Hayne et al., (2017) suggests that the construction industry needs to evaluate the effectiveness of graduate training programmes to ensure that suitable on-site experience is gained, otherwise there is a danger that the principles of eliminating design hazards that are enshrined in the CDM Regulations will not be achieved. Howarth et al., (2000) identified that a survey of civil engineers found that an issue commonly raised was the lack of understanding of the CDM Regulations. Also, the abolishment of the role of the CDM Coordinator in CDM 2015 has further split the responsibility of health and safety between the client, principal designer and contractor. CDM Regulations provide a broad spectrum of responsibilities for designers to design a facility that is safe to construct, maintain, use and demolish. However, there are trade-offs between designing a building to be safe to construct and designing a building that is safe to operate. Some design decisions that improve health and safety during operation and maintenance of a building could increase some risk in the construction phase. Therefore, Lingard et al., (2013) suggest that SiD policy documents and guidance notes should provide practical guidance on how to identify and manage conflicts and trade-offs in reducing health and safety risks across the life cycle of a project.

There are existing criticisms of CDM 2015 regarding the lack of legislative guidance and lack of clarity for designers (Carpenter 2016); same issues raised by Gambatese et al. (2009) regarding CDM 2007. The lack of guidance on best practice from the HSE makes it difficult for projects to be benchmarked against best practice criteria which could help designers manage risk to an acceptable level. Such guidance would also be useful for scoring the safety of the design in terms of build, use and maintenance similar to the BREEAM sustainability rating matrix. Carpenter (2016) suggests that guidance is therefore required in order to establish acceptable risk in a project and with proportionate response.

Research shows that designing to eliminate or reducing the impact of hazards should be given higher priority than simply controlling a hazard within the worksite (Gambatese et al., 2008). The long-term benefit of implementing SiD results in lower construction costs and improved safety during construction, operation and maintenance. The use of design and build promotes partnership between the design and construction teams, thus providing a natural motivation to address safety in design. Haslam et al. (2005) further suggested that the use of design and build on a project could overcome the barriers to SiD because the responsibility of design and construction is assigned to one project team. Sacks et al. (2015) argued that the use of design-bid-build where there is a complex hierarchy of contractors and subcontractors may well limit the input the designers can have on the construction process. Design and build also have the capacity to limit the use of SiD because construction contractors may prioritise the need to maximise profit before the safety of the design. According to Bell (2017), the aim of construction contractors is to make projects as cost-effective as possible and therefore, they have less commercial interest in the manageability or running of a building.

Also, designers face conflicting priorities such as client requirements and cost which could impede the implementation of SiD. Pirzadeh & Lingard (2017) identified that there is a disconnect between design and construction functions because the absence of free and effective flow of information is still a major hurdle due to iterations made in the design. Collaboration and communication between the design and construction team facilitates SiD and Pirzadeh & Lingard (2017) indicate that the design of a project involves complex and dynamic interdependencies between activities and parties and this is best undertaken collaboratively; resulting in a better flow of knowledge (tacit and explicit) and information which reduces iterations and resolve inter-task issues. The adoption of Virtual Reality (VR) technology to facilitate dialogue or collaboration between the design and construction teams to overcome the difficulty of knowledge transfer has been highlighted by Sacks et al., (2015). Sacks et al., (2015) found that dialogue with construction professionals conducted while touring a virtual construction site improved designer's awareness and sensitivity of hazards with the designers openly expressing that some design changes will improve safety. This further emphasises the importance of close collaboration between designers and other construction professionals including Facility Managers (those in charge of use and maintenance) towards integrating SiD in designs (Bell, 2017).

The designers play a major role in securing the safety of maintenance workers for example, the location, design and size of plant rooms can reduce ergonomic hazards and working in confined spaces, (Stanford, 2010). Therefore, the adoption of design decision tools in the form of a mixed-media approach according to Hare et al., (2019) can aid designers in their statutory duty to identify, prevent and mitigate hazards emanating from their designs. Iterations and design changes are characteristic of the construction design process and this can be mitigated by improved information quality and reduced uncertainty in decision making (Pirzadeh & Lingard, 2017), and hazard identification should be repeated with every iteration to ensure hazard reduction (Hayne et al., 2017).

Table 1. Construction (Design and Management) Regulations - A Timeline

Time	Event	Rationale
June 1992	Temporary or Mobile Construction Sites Directive (TMCSD) adopted	
March 1995	The Construction (Design and Management) Regulations 1994 (CDM 94) come into force	To implement, in part, the TMCSD
Sept 1996	The Construction (Health, Safety and Welfare) Regulations 1996 (CHSW 96) come into force	
Late 1996 – 1998	Interim evaluation of CDM 1994	To establish stakeholders' views on implementation
Sept 2003	HSC agrees to revise the CDM 94 and CHSW 96 regulations (paper HSC/03/93 for the review)	To respond to industry's comments on the discussion document
April 2007	CDM 2007 Regulations come into force	
Oct 2010	Draft evaluation report of CDM 2007	Showed general improvement over CDM 94 with concerns remaining in areas of competence assessment, coordination and bureaucracy
Nov 2011	Publication of Löfstedt report – An independent review of health and safety legislation	Recommended that: - the CDM 2007 evaluation should be completed by April 2012 - HSE should review all ACOPs, although the CDM 2007 ACOP should be managed separately

April 2015	CDM 2015 Regulations come into force, HSE Legal Series (L153) guidance and industry guidance published

Aim

The aim of this study is to evaluate the implementation of SiD as part of the CDM Regulations and how it improves safety during use and maintenance of existing buildings. Buildings pre-CDM and post-CDM were visually inspected to establish how SiD has made buildings safer based on the requirements under the CDM Regulations. It is important to reaffirm that buildings pre-1995 may likely not have SiD implemented in the initial design but those retrofitted and refurbished after 1995 should have SiD implementations. The study adopted the use of a scoring matrix to assign scores for each of the public buildings based on ease of use and maintenance, through the identification of design hazards from inspections.

Benefits of SiD

The implementation of SiD can improve the safety and health of construction and maintenance workers and potentially benefit the end-users. For example, designing structural steel, plumbing, heating, ventilation, and air conditioning (HVAC) and electrical systems should take into account whether workers are required to install or fix such connections overhead or at an awkward position that could result in musculoskeletal injuries (Toole & Gambatese, 2008). The adequate consideration of ergonomic hazards during designs can also mitigate musculoskeletal injuries which often lead to lifetime disability and early retirement. Other benefits of implementing SiD is productivity improvement and Manuele (2008) alluded that it could decrease operating costs and avoidance of expensive retrofitting. Therefore, the design of the workplace, work task etc. are important considerations in accident causality and Hare et al., (2019) indicated that few designers in the UK embrace the principles of designing for occupational safety even though it is a requirement.

Method

A multiple case study approach was adopted to examine 12 public buildings selected through purposive non-probability sampling. The case study method explores a real-life, contemporary bounded system (a case) or multiple bounded systems (cases) over time, through detailed, in-depth data collection involving multiple sources of information… and reports a case description and case themes (Creswell, 2013, p. 97). Multiple case study strategy was adopted (Fellows & Liu, 2015), using structured inspection to enable replicating same SiD ideas across several public buildings (Saunders, et al., 2012). The use of public buildings was profoundly due to accessibility issues to allow structured inspection to be undertaken by adopting the Likert scale scoring methodology to assess SiD issues within the buildings. The Likert scale was developed to score design hazards from 1-5 depending on the level of SiD implemented within the design. The significance of using the visual inspection was to identify design hazards using an adapted hazard identification checklist made up of 22 design hazards to produce an overall safety score for each building inspected, (Hare et al., 2019).

Sampling

The purposive non-probability sampling technique was used to identify twelve (12) key public buildings in London with the aim to have unrestricted access and to acquire relevant information through inspection as opposed to using private buildings with limited access for the study. Table 2 gives a description of the six categories of buildings used for this study (DWQR, 2007).

Table 2 – Description of the buildings inspected

Public Building	Description
Education	University – Postgraduate campus
	University – Institute of Education
Health Care	GP Surgery
	Dental Surgery
Hostelries	Restaurant
	Café
Exhibition	Art Gallery
	Museum
Sports	Leisure Centre
	Cinema
Miscellaneous	Jobcentre Plus
	Library

In the UK, a building is regarded as a public building if it is occupied by a public authority and frequently visited by the public. Two buildings per category were assessed to provide a reasonable sample size, although larger sample sizes would potentially have provided more depth and variance on the impact of SiD during use and maintenance.

Data Collection

Design hazard data was collected through structured observation and inspection (Saunders, et al., 2012), using a scoring matrix (Likert scale) that scores the quality of SiD implemented during the design phase by the designer, see Table 3. The use of structured observation as the data collection tool allowed the researcher to utilise inspection procedures as a measuring tool using predetermined template adapted from the design hazard identification list (Hare et al., 2019) to mitigate against observer bias. Using this design hazard identification list allows for replicability of the study and updating the repository for list of undocumented design hazards. The inspection process is a relatively smooth and quick process that can last between half a day or one full working day depending on the size, complexity and accessibility of the structure.

Table 3 - Description of the observation using Likert Scale scoring matrix

Scale	Definition	Description
1	Unacceptable	Nil or inadequate SiD implemented in design. Hazard is present
2	Poor	Poor attempt to design out hazard. Hazard present but mitigated through control measure
3	Acceptable	Hazard designed out using SiD; but design could have been improved
4	Good	Hazard avoided through good implementation of SiD
5	Excellent	Hazard avoided through excellent implementation of SiD in design.

***NA** - Not Applicable to the building; ***NI** - Not Inspected

Inspection considerations included:

- Inspections conducted within normal opening hours of the buildings

- The researcher observed the interaction between people, processes, premises, plant and substances e.g. slippery floor and people, wall cladding and the cleaning process.
- Asking questions without disrupting work activities e.g. how the windows are cleaned - rope access or ladder
- Roofs visually inspected from the ground level
- Hazards and the existence and effectiveness of related control measures

Design hazards found during inspection were mapped on to the design hazard checklist to score individual buildings against the criteria (the quality of SiD implemented in design), see Table 4. Once a design hazard is identified, the researcher examines if control measures are put in place to reduce the risk of the hazard and scores the hazard using the Likert scale. These are then recorded on the inspection form.

Table 4 – Design hazard identification checklist

Design Hazard types	
1. Structural openings	12. Fragile surface/roof light
2. Lifting operation risks	13. Cleaning glazing
3. High-level light	14. Fall from ladder
4. Open edges	15. Confined space
5. Plant maintenance at height	16. Manual handling
6. Manholes in traffic route	17. Struck by plant/vehicle
7. Single-step trip hazard	18. Fire/explosion
8. Foyer entrance slip risk	19. Working using rope access
9. Clean/maintenance pitched roof	20. Small step trip hazard
10. Slip/trip on stairs	21. Hazardous Pinch Points
11. Large floor-ceiling heights	22. Fall from open edge

The procedure for scoring the buildings adopted the following steps:

Step one: Identify the hazards. For example, the building may not have curtain wall systems (non-structural cladding systems) therefore the hazard will not be inspected. This will vary from building to building.

Step two: Inspect and score the building. Inspect up, down, around and inside the building thoroughly and methodically. Score the design hazard using the Likert scale on the inspection form. Document inspected areas with photographs.

Step three: Repeat step two for all the hazards applicable to the building.

Step four: Calculate the final score. Add all the scores from the inspection. Divide the overall score by the number of hazards inspected to get the final mean score for each building, see Table 5.

Table 5 – Retrospective inspection of design hazards

Rank	Building	Identified Design Hazards (H)	Total Score (T) = Sum (H*Scale)	Ave. Score = (T/H)
1	Leisure Centre	19	83	4.4
2	University – Postgraduate Campus	14	53	3.8
3	Library	10	47	4.7
4	Art Gallery	12	44	3.7
5	University – Institute of Education	9	40	4.4
6	GP Surgery	8	30	3.8

7	Museum	8	28	3.5
8	Restaurant	8	28	3.5
9	Cinema	7	25	3.6
10	Café	6	24	4
11	Jobcentre Plus	8	23	2.9
12	Dental Surgery	5	15	3

This study acknowledges that certain areas in some of the buildings were not accessible for inspections due to security and other safety related issues. Therefore, to mitigate this problem and to acquire consistent and reliable data, the 22 commonly occurring design hazards was adopted for uniformity (Hare et al., 2019).

Findings and Discussion

The findings from the retrospective inspection of design hazards involving 12 buildings and the impact of SiD in their designs are shown in Table 5. A score of 1 indicates inadequate or no implementation of SiD and a score of 5 indicates excellent implementation of SiD in design. The average score for each of the building indicates the category of that buildings within the Likert Scale; from unacceptable to excellent SiD implementation.

Buildings pre and post-CDM

Table 5 show that the Library had the highest implementation of SiD (4.7) in the design which reflects in the use and maintenance of the building. The Jobcentre Plus had the least implementation of SiD (2.9) initiatives in the design and this directly impact on the use and maintenance of the building. The Art Gallery, Jobcentre Plus, Museum and Restaurant were the buildings with the highest design hazards within the scale of 1, i.e. inadequate SiD implemented in design with the hazards still present. The Jobcentre Plus was built before the introduction of CDM 1994 and ranked lowest amongst the 12 buildings inspected based on the inadequate attempt to design out hazards and the lack of adequate control measures. However, the Library built under CDM 2007 had excellent implementation of SiD i.e. level 5 within the Likert scale with practical hazards avoided.

The Leisure Centre was opened to the public in 2010 and the newest building from the list of 12 buildings inspected. Seventeen (17) of the design hazards at the Leisure Centre were classed between 5 and 3 while two design hazards were ranked at one on the scale (e.g. manhole in traffic routes). This suggest that the designer of the Leisure Centre holistically integrated SiD in the design of the building. The Leisure Centre, Library, GP Surgery, University, Café and Cinema all had average inspection score of above 3.5 per building. It suggests that designers of buildings post-CDM implemented SiD measures to an acceptable level through designing out the hazards, including the buildings that were retrofitted or refurbished. The Art Gallery which was formerly a power station was converted in 2000 to a public building. Although the construction work was under the CDM Regulations and the implementation of SiD should have been a requirement; the designers would have struggled to fully integrate SiD into the design as the building project commenced same time that the CDM 1994 Regulations was introduced. Therefore, the designers may have struggled to understand and incorporate SiD in their designs which thus limits full implementation of SiD. Also, research identifies that refurbishment projects are more difficult to manage than new construction works due to the high level of uncertainty associated with the works (Egbu, et al., 2002). The four least performing buildings (Museum, Restaurant, Dental Surgery and Jobcentre Plus) in terms of SiD implementation were all designed and built before CDM 1994 Regulations came into effect in the UK. With these four buildings, the inspection revealed that there was little effort on display regarding designing out the hazards during the build phase and the future use and maintenance of these buildings were not adequately considered. Inspection of buildings post-CDM suggests that the adoption of the CDM Regulations since 1994 has encouraged progressive steps toward implementing SiD initiatives by designers in the design of safer buildings.

Manholes in traffic route

The most common hazard to all the buildings was location of manholes in very busy locations (pedestrian and vehicular access routes). Eight (8) of the buildings were ranked on the Likert scale at 1 because the location of their manholes was in busy traffic and access routes; i.e. inadequate or no SiD measures implemented in design and the hazards are still present. The RIDDOR report 2018/19 indicated that ‘struck by moving object’ accounted for 10% of the entire non-fatal injuries to employees by most common accident kinds, and it is essential that the welfare of maintenance workers is addressed in the design including the location of major sewerage systems. Other issues with open manholes in some busy pedestrian areas was the lack of edge protection and this could result in disproportionate numbers of members of the public falling into such manholes. It is also important that designers review the site layout during the design phase as this could influence the planning and design of access or busy traffic routes away from such existing manholes.

Working at Height

In order to manage work at height, the task being carried out is required to adopt the hierarchy of controls, i.e. to avoid, prevent and mitigate if such a task cannot be carried out safely from the ground. The lack of implementation of SiD in some of the buildings could obviously result in falls from height with tasks involving high-level light fittings and fixtures, working near open edges, plant maintenance at height, maintenance involving large floor-ceiling heights, frequent use of ladders, and working using rope access. Four buildings were grouped at level one (1) on the Likert scale indicating inadequate implementation of SiD and the hazards that were visually identified from inspection had no control measures in place. One of the inherent risks identified included workers potentially falling through fragile pitched roof light with no preventive measures. Also, the use of mobile elevating work platforms (MEWPs) in the Museum and Art Gallery to perform some maintenance work due to extreme ceiling lighting heights presented its own challenges and hazards such as entrapment, overturning, falling and collision during MEWP deployment. These dangers typically arise from operation and use of the machine rather than from their movement as a site vehicle. Falls from height continue to account for a significant number of workplace injuries and fatalities every year. The inspections revealed that the use of leaning ladders and stepladders for jobs of a slightly longer duration was pervasive and guidance regarding compliance with the Work at Height Regulations 2005 (WAHR) regarding the use of ladders for low-risk, short-duration tasks was not enforced in some of the maintenance and repair works carried out. The buildings with high-level light also had issues with large floor-ceiling heights, thus presenting major risk of workers falling from height during the use of ladders. Six buildings were classed as level three (3) indicating that although the hazards were designed out, the design itself is still susceptible to further improvement.

Slips and trips

The installation of suitable flooring in buildings could potentially minimise the risk of slips and trips on surfaces that are used as main access or foyer areas in buildings. Maintenance of the floor (cleaning) can significantly cause slip and trips to both the cleaning staff and users of the public buildings and during rainfall most especially around entrances of the buildings. Instances of damaged and uneven block paved areas around entrances of the buildings were captured from the inspections and these could further aggravate the risk for trips and falls. The Workplace (Health, Safety and Welfare) Regulations 1992 require floors to be suitable for the purpose for which they are used and free from obstructions and slip hazards. The likelihood for slips (foyer entrance slip risk), trips and falls on same level or uneven surfaces was recorded in majority of the buildings inspected. The imbalance of work equipment from uneven surfaces could also impact maintenance work and result in accidents.

Location of plant rooms

The plant room which is also referred to as the mechanical or boiler room contains the equipment that majorly provides the building services including but not limited to water, electrical distribution, and ventilation. The size and design of the plant room reflects the size and complexity of the structure and the requirements of the building services. There was restricted access to inspect nine (9) of the plant rooms due to their location and other safety related issues. Two (2) buildings however granted partial access while one (1) granted full access to inspect the plant room situated on the ground floor. The two buildings that granted restricted access due to health and safety risks had their plant rooms located on the roof of the buildings. The record of inspection noted issues related to ease of access for maintenance crew and the possibility of replacing larger equipment and expansion would prove difficult because of the location and size of the rooms. However, the Library building which was redesigned in 2009 indicated evidence of integration and implementation of SiD under the CDM 2007 Regulations with the plant room located on the ground floor. The designer of the Library complex considered SiD in the design of the plant room from build, use, safe maintenance and future expansion capabilities. The Jobcentre Plus which is classed as the least functional buildings amongst the 12 buildings inspected was built pre-CDM Regulations and SiD was not legislation driven at that time. This therefore highlight the significant differences in the ways safety related issues were addressed in the design of the plant room.

Conclusion

The most common hazard was the risk of slips, trips and falls at the entrance of the buildings resulting from cleaning or when it rains. There was poor attempt to design out this hazards in ten (10) of the buildings but these were mitigated in some instances through adequate control measures. However, two of the Grade 2 listed buildings that were refurbished had no mitigating control measures put in place to reduce slips and trips. It further reinforces the suggestion that designers struggle to fully incorporate SiD in their designs in refurbishment projects when compared to newer projects. This study reveal that there are significant variations in the implementation of SiD in buildings built pre-CDM and post-CDM. Eight of the buildings inspected exceeded the threshold of an acceptable integration of SiD in designing out the hazards or avoiding the hazards through excellent implementation of SiD by adopting the principles of prevention. The findings suggest that the adoption of CDM Regulations positively encouraged the use of SiD and buildings built post-CDM 1994 are safer to use and maintain than older buildings pre-CDM that had minimal or no SiD integrated during the initial design and build. The inspection show that the refurbished buildings had low safety ranking compared to buildings designed and built with full integration of SiD. There are still divisive opinions in terms of SiD integration in designs as some designers still contend that the design statement of a building overrides any of the safety concerns. Overall, the incorporation of SiD in the refurbishment of public building stock can potentially enhance the safety of such buildings for maintenance workers and users. The internal areas of refurbished or retrofitted buildings ranked highly on the Likert scale but the external areas e.g. the entrance to the buildings, external wall window systems and location of manhole chamber/access shafts ranked very poorly. The buildings post-CDM that integrated SiD from the conceptual phase of the projects were considered significantly safer. This study therefore recommends the integration of mixed media digital tool to improve designers' knowledge of SiD and also provide alternative design options that could prevent hazards emanating from their designs.

Limitations of study

The sample size of twelve (12) inspected buildings should be increased to improve the validity of the study and the focus of this present study which is London-centric should reflect other parts of the UK. Therefore, findings from the study based on sample size is too small to generalise to all public buildings in the UK. The restricted access to some parts of the public buildings for inspection hindered the acquisition of other relevant information that could improve industry practice.

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A prototype model for ethically aligned design in Construction and Construction A/IS

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Abstract

Autonomous and intelligent systems (A/IS) (also known as artificial intelligence) are recent, developing and expanding technologies in use in construction and are the defining element of the 4th Industrial Revolution. New technologies bring promise to society but unless the wider social implications of their implementation are considered they also have the potential to negatively impact and change society in unintended and undesirable ways.

The use of A/IS raises moral and ethical questions relating to privacy, agency, data protection, etc., as well as the potential for unforeseen consequences in the hands of both benevolent and disingenuous actors. Ethically aligned design is a comprehensive set of recommendations developed by IEEE to guide designers and end users of A/IS towards considering the values and intentions of the organisation and the consequences for human agency and well-being beyond the technical objectives of using the system. Adapting and expanding these principles this model draws upon contemporary and classical thinking on moral responsibility and accountability and describes a methodology for establishing an agreed ethical foundation and moral objectives for projects in the context of socially responsible design and construction.

Keywords: designers knowledge, fourth industrial revolution, sustainability, UN Sustainable Development Goals.

Introduction

Humankind has so permanently influenced the major earth system processes, including atmospheric, geologic, hydrologic and biospheric that the current geological time period is defined as anthropogenic and accordingly has been named the *Anthropocene*. The global landscape that we see today is one that is in part, maybe a major part, that has been transformed by human activity (Berger 2010), and in that construction and agriculture are the most visible, though not sole vehicles for that transformation.

It is thus, with no pretensions to grandiosity that the engineering professions at the 2018 Global Engineering Congress (GEC) recognised that, "*[t]he infrastructure designed and built by our members to ensure human well-being is the critical interface with our planet. It dictates the patterns and flows through which we live our daily lives and affects our long-term prosperity,*" (ICE 2018a). In the context of the UN Sustainable Development Goals (UNSDG) (UN 2015), the GEC identified the problems that increasing infrastructural interconnectivity and resource demands make on sustainability (social, economic and environmental) and asked how would the engineering community remain consistent with environmental stewardship whilst maintaining their commitment to constructing for the well being of Mankind (ICE 2018a, ICE 2018b, ICE 2020).

In their work on the design and application of Artificial Intelligence (AI) systems (henceforth Autonomous and Intelligent Systems, (A/IS)), Sekiguchi et al. (2009) and Sekiguchi and Hori (2020) have advanced a model of a design thinking hierarchy that has a bearing in the wider field of construction engineering, particularly when the profession and the industry are being encouraged to adopt digital technologies (Barbosa et al. 2017) or are already beginning to embrace the use of such systems, albeit with some concern regarding unintended consequences, in areas of health and safety, (McAleenan et al. 2019).

When applied to construction project development it can be acknowledged that engineering design thinking begins with consideration of the user interface where-in the project to be constructed is viewed in the context of the environment in which it will sit (Dynn et al. 2006); what is to be built, its function and the constraints imposed by the environment in physical, economic, social and political terms. These are often, but not exclusively technical matters requiring technical solutions and engineers comfortably excel in this area. Sekiguchi and Hori (2020) have elaborated on the knowledge levels accessed in project design through advancing social and ethical levels of knowledge required to achieve a design that is ethically sound. When applied to construction, looking above the level of consideration of the interface between the construction artefact and its environment, there is a case for a deeper consideration of how the artefact's interaction with the environment creates change in both the physical and the social environment. It is therefore appropriate to evaluate this change in the context of social relationships and personal and societal values, (King 2000). This level of consideration effectively connects with the concerns raised at the GEC and engineers' commitment to environmental stewardship and human well being.

Sekiguchi and Hori (2020) have developed an "*organic and dynamic tool* [named *dfrome*, an abbreviation of "website for Design FROM the Ethics level"] *for use with a knowledge base on ethics to promote engineers' practice of ethical AI design to realise further social values"*. Their work has been substantially influenced by the Institute of Electrical and Electronics Engineers' Ethically Aligned Design (IEEE 2019), the Asilomar Principles developed by the Future of Life Institute (FLI) and the AI Network. Their tool is essentially a database of ethics knowledge designed to support engineers grasp of the ethics issues associated with their designs and in their use of it, recommends scenario paths that connect ethics with the technology.

The IEEE's Ethically Aligned Design (1st edition (EAD1e)) is founded on the pillars of Universal Human Values, Political Self-determination and Data Agency, and Technical Dependability. These pillars connect to general principles that are designed to guide all manner of A/IS design. The principles are:

- Human Rights
- Well-being
- Data Agency
- Effectiveness
- Transparency
- Accountability
- Awareness of Misuse
- Competence

These principles are not exclusively the preserve of A/IS design and development; with minor adjustments they can also effectively contribute to the design thinking process in construction, as Sekiguchi and Hori's *dfrome* aims to do.

However these principles (as adjusted) coupled with the type of ethics knowledge base as envisaged by Sekiguchi and Hori (2020) would not be sufficient to address the concerns of engineers for a consistent system of construction that recognises the transformative nature of human interactions on the planet and facilitates a morally positive transformation. McAleenan (2020) outlined a range of difficulties associated with developing morally neutral A/IS, difficulties that EAD1e was designed to address, and all difficulties that stem from a human inability to agree on what ought to be done in any particular circumstance, or what constitutes morally good actions. For example McAleenan (2019) opines on the Camden Bench as something that is simple and seemingly innocuous, designed as an aesthetically pleasing point of rest for pedestrians, but;

> *"… its fundamental purpose it is a tool of social control. It is an icon of "aggressive architecture" that has been designed to prevent anti-social behaviour such as graffiti, drug dealing, congregating and homeless people sleeping, (Swain 2013). [When] put in the context of many other features of architectural furniture (stones under bridges, spikes, anti-stick walls, etc., and we see construction contributing to the control of users of city spaces".*

Outlined below is a prototype model that builds upon the principles detailed in EAD1e, the design thinking hierarchy outlined by Sekiguchi et al. (2007) and Sekiguchi and Hori (2020), and which draws on the work of Floridi (2016) on faultless responsibility in social networks. The model is praxic in nature, iteratively integrating an ethically aligned thinking process with the design activity and the construction process.

Moral Responsibility and Ethics Information Base

Distributed morality (DMA/DMR)

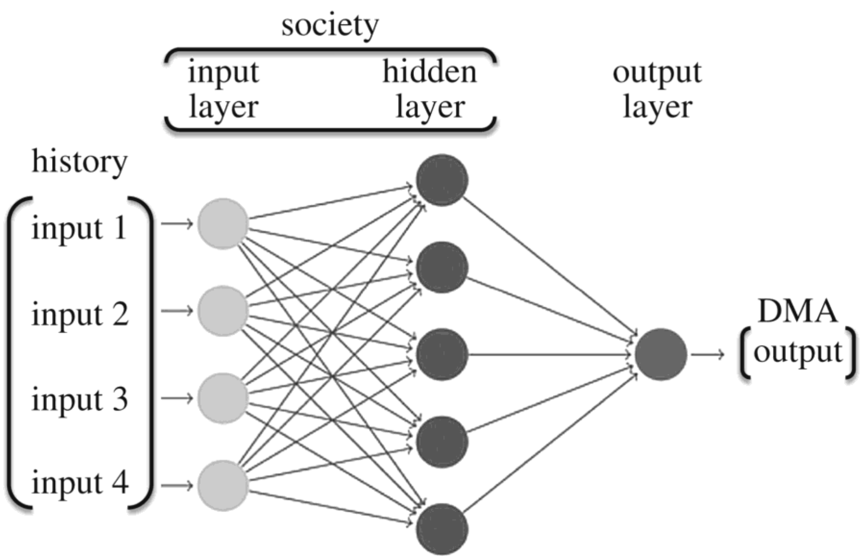
Ethically aligned design is grounded on an awareness of moral responsibility and the potential for actions by autonomous agents to have moral consequences, whether good or bad (morally loaded). When there is a direct and immediate connection between the agent carrying out an act (which includes decisions) and the recipient (person, property or environment) of that action then blame or praise can be clearly attributed. However in complex social networks where the acts of different agents are essentially neutral, it becomes more difficult to attribute blame or praise for the outcomes. This difficulty has contributed to a barrier to thinking on moral responsibility where there is a substantial distance between the initiating act and ultimate output with a complex intermediary web of agents propagating the act towards the output, (Floridi 2016).

By way example, the New York High Line project that transformed a derelict rail infrastructure into a raised linear public park through Manhattan had the effect of gentrifying areas of the city, raising rents and thereby forcing out long established residents and local small business who could no longer afford to remain in their districts, (McAleenan & McAleenan, 2017). The transformative nature the project was such that whilst the initial intent was beneficial the unintended consequences created other transformations that were morally loaded vis the residents of the area, yet conversely beneficial to the newer influx of wealthier residents. The client, design-team and contractors could in truth not be held legally liable for these negative consequences of the project, but morally could be considered responsible for them.

Floridi (2013) uses the term distributed morality to refer "*only to cases of moral actions that are the result of otherwise morally-neutral or at least morally negligible interactions among agents constituting a multi-agent system, which might be human, artificial* [A/IS]*, or hybrid"*. Notwithstanding the many ethical nuances outlined by Floridi the concept may be simplified as a moral action that ultimately causes harm to a recipient even though that was not the intent of the agent immediately causing the initiating action nor indeed of any other agent in the system. For example, an accident occurs that causes harm to a person, property or the environment though the action causing it was not intended (by definition). That causal action is rarely the initiating action; it is often the final causal action in a series of causal events and circumstances involving a network agents none of whom may have any direct connection to or intention regarding the recipient of the final action. Such an action propagating forward through a networked system is a distributed moral action (DMA).

Distributed moral responsibility (DMR) is not concerned with guilt, but rather with faultless responsibility (Floridi 2016), namely when propagating back from the DMA the initiating action(s) without which the DMA could not have occurred is ascertained. In this sense agents in the network may be deemed responsible though guiltless for the end results of their decisions or actions where those actions or decisions are necessary precursors to the DMA and the agents themselves are autonomous, able to interact with each other and capable of learning from and changing their interactions. Figure 1 is Floridi's (2016) concept of the network.

Figure 1: A multi-agent system as a multi-layered neural network, (Floridi 2016)



In the context of design and construction the input layer can be taken to represent the design decisions and the agents involved in making them. The hidden layer is the network of agents and their actions and decisions in constructing and use the project designed. At the output layer the recipient(s) of the DMA are, e.g., construction workers, end users, society and the environment.

In a simple Prevention through Design example, the decisions of the client, architect, engineer, financial backer (inputs) to opt for a glass enclosed atrium at the fourth floor of a ten floor structure impacts ultimately on a worker who task is to clean the external glass and any negative DMA (output) is traceable back to the initiating decisions and agents responsible for them (DMR).

However in a small multi-agent network and a short propagation path some or all of the initiating agents may be liable, criminally and civilly, e.g.,the Express Park, Bridgwater fatality where the contractor and the architect were both held liable, (Croner-i 2010). But in more complex networks with longer propagation durations, some of decades or even centuries the picture changes. The social need for mobility and the manufacturing industry's production of faster, safer and more affordable transport vehicles cannot be held liable for the vast global roads infrastructure with it concomitant habitat fragmentation and atmospheric pollution, but they are responsible for it and thus morally responsible its consequences.

Information base

Sekiguchi and Hori (2020) have observed that, in relation to A/IS ethics studies have not sufficiently been incorporated into the research and development of A/IS, that A/IS ethics it too broad and the information base very large, engineers have little time to understand and construct a relationship between A/IS ethics and their own research, and that engineers find A/IS ethics too abstract. These observations relate very much to the nature of ethics as a field of study and the difficulties of non-specialists, whether A/IS engineers or construction professionals, in getting a sufficient grasp of the subject matter so as to inform their work of its ethical implications and moral consequences, (McAleenan 2020). Their project is designed to fill these gaps through the provision of a knowledge base of A/IS ethics that can deal with the complex relationships between them and provide engineers with scenario paths that connects the ethics to their research. It is interactive and has scope for addressing varying social values and personal ethics.

Applying these observations to the field of construction design Floridi's schematic (Figure 1) can be modified to include types of information and knowledge informing the input layer, (Figure 2)

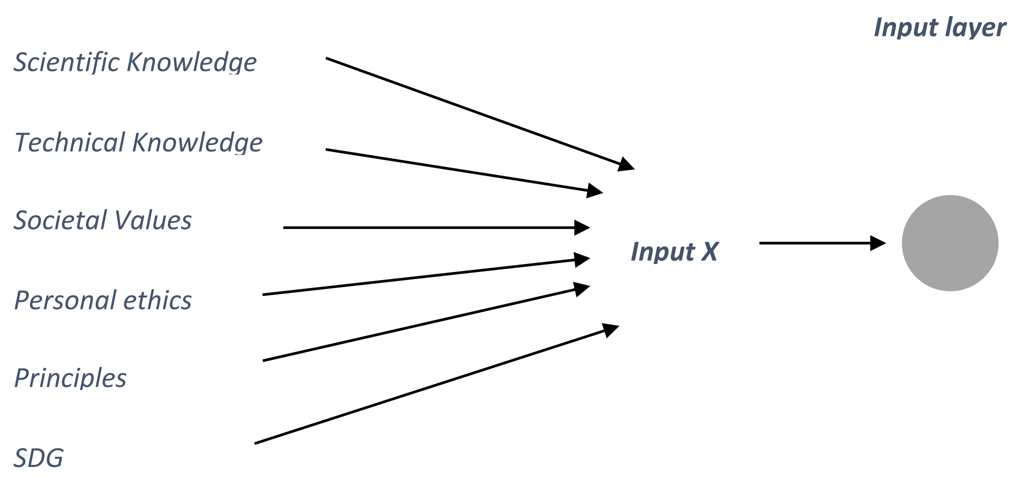


Figure 2: Knowledge base informing inputs to Floridi's multi-agent system

To exercise ethically aligned design thinking the knowledge base must grow substantially beyond the technical knowledge necessary to meet the physical requirements to construct the project and the ethics associated with professional codes of conduct.

The anthropogenic influence on the planet has not been wholly positive and it is important for designers to have a deeper awareness of how construction impacts on the environment if they are to effectively mitigate the harm it causes. Current environment considerations are often inadequate, primarily because the knowledge used in informing environmental design is limited and therefore inadequate. By way of example, the effects of construction, e.g., roads or even something as simple as a cabin in the wilderness, on trophic systems can be detected many kilometres into an unfragmented habitat (Soulé 2010). The nature of those impacts and their harmfulness varies on the basis of the construction project and the changes it manifests and continues to manifest on the flora and fauna in the immediate area of the project. Changes to mega biomes are observable to the average person, micro biomes in the soils and water sources need specialist investigation to understand what changes have occurred. Inadequate knowledge of the science means that environmental policies of engineering and contracting companies can be ineffective, or even more harmful (e.g., laying nutrient rich soils to seed wildflowers on road verges) when it comes to remediating environmental impacts.

If construction is to benefit humanity (ICE 2018b) a knowledge of the social sciences is also important if designers are to understand the impacts of projects on society. Disciplines such as sociology, psychology and economics are pertinent to that understanding. Mega sporting projects such as the Olympics and the World Cup are held up as opportunities for urban improvement and economic growth through increased trade, jobs and income. But often the reality is very different, with host cities ending up in massive debt and poor populations reallocated when gentrification occurs on the sports campus, (Kumar 2012, McBride 2016).

Table 1 maps the General Principles of ethically aligned design (EAD1e) against the UN sustainable development goals. Principle 3 has been broadened from “data agency” to “agency" and Principle 7 “awareness of misuse” amended to “awareness of consequences”. There is insufficient scope in this paper discuss the interpretations of how the principles relate to the goals but it is sufficient to illustrate that two major societal initiatives interrelate. These are to be considered an adjunct to the societal values necessary to effective ethical thinking.

UN Sustainable Development Goals / **EAD1e General Principles**	1. Human Rights	2. Well-being	3. Agency	4. Effectiveness	5. Transparency	6. Accountability	7. Awareness of consequences	8. Competence
1. No Poverty	✔	✔		✔				
2. Zero Hunger	✔	✔		✔				
3. Good health & well-being	✔	✔		✔				
4. Quality Education	✔	✔	✔	✔				
5. Gender equality	✔	✔		✔				
6. Clean water & sanitation	✔	✔		✔				
7. Affordable & clean energy	✔	✔		✔				
8. Decent work & economic growth	✔	✔		✔				
9. Industry, innovation & infrastructure	✔		✔	✔	✔	✔	✔	✔
10. Reduced inequalities	✔	✔	✔	✔	✔	✔		
11. Sustainable cities and communities	✔	✔		✔				
12. Responsible consumption and production	✔	✔	✔	✔	✔	✔	✔	✔
13. Climate Action	✔	✔		✔				
14. Life below water	✔			✔				
15. Life on land	✔			✔				
16. Peace, justice & strong institutions	✔	✔	✔	✔	✔	✔	✔	✔
17. Partnerships for the goals	✔	✔	✔	✔	✔	✔	✔	✔

Table 1: UNSDG mapped against EAD1e General Principles

Prototype Model for Ethically-Aligned Design Thinking

A design thinking methodology

Awareness of the nature of faultless responsibility and the designer's role as an initiating causal agent in a multi-agent network combined with access to an appropriate information base (via personal knowledge or an A/IS system such as dfrome (Sekiguchi and Hori 2020)), is the platform on which design thinking can take place. Given that ethics and moral behaviour is a complex field of study fraught with disagreements about what ought to be done and contractions between and varying interpretations of competing theories (McAleenan 2020) such a platform cannot produce ready made solutions to the ethical questions posed by the design project. Indeed it can be as difficult to frame the correct ethical question as it is to interpret a solution. On top of this, not all moral agents act morally, including agents who input to the decision making process.

To align what can be done with what ought to be done requires an appreciation of consequentialism (even a deontic or a virtue ethic must be carried out in an appreciation of the consequences) and the ability to decide between a range of consequences in order achieve an outcome that promotes the wellbeing of mankind. This includes decisions on what is to be accepted as "wellbeing".

Figure 3a outlines a basic praxic model for design thinking. It is a methodology wherein theory (design thought) and practice (design output and construction action) are integrated and weighed against each other in a continuing iterative process of critical evaluation of design and output in a moral matrix.

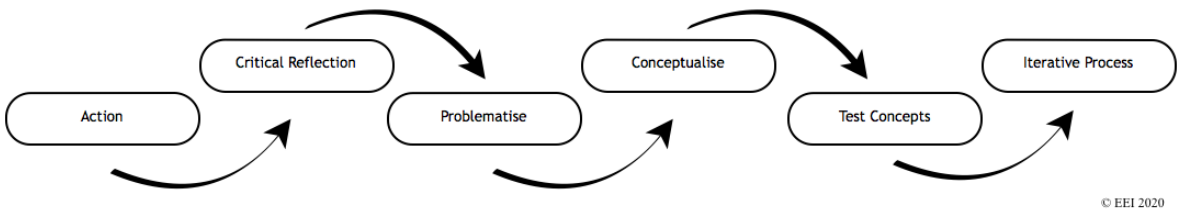


Figure 3a: Prototype praxic model for Ethically Aligned Design

Several steps in the process are highlighted in Figure 3b. The foundational platform described above forms the starting point for a critical evaluation of the project being undertaken, an aspect of which is consideration of the project as an object in space and time rather than as something static on the landscape. From its inception it is recognised that it has come with a history of matters and events that preceded it and is being developed in anticipation of what will come after. In other words there are reasons for its development, and for its function and purpose going forward.

A new high-rise office block in a city centre comes into being on the basis of a complex multi-disciplinary history of the development of the city and its centre. It further exists in a dynamic environment that will continue to change into the future; changes that may be as a result of the office block being built or changes that in combination with the office block will impact the local climate/weather and natural, social, political and economic environments, etc.

But the overt reasons for a project do not explain the project completely. It will impact on the environment immediately and over time, it will impact and alter social, economic and political relations through processes such as gentrification, economic corridors and urban expansion. Critical evaluation reflects on these causes and effects in order to understand them and to achieve a controlled transformation.

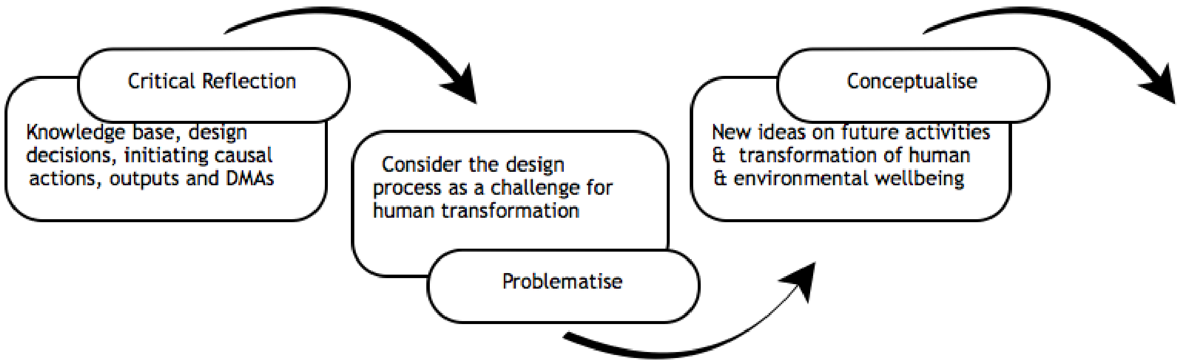


Figure 3b: Prototype praxic model for Ethically Aligned Design, detail

Problematisation is a key element of praxis in which the designer considers the project as a challenge with the purpose of transforming human and environmental wellbeing. As an element of critical thinking it is a method that rejects the taking of common knowledge for granted and opens the way for reflection, new viewpoints and ultimately brings about positive change.

However well or poorly done problematisation develops new ideas, solutions and activities that are aimed at achieving a positive transformation. The ideas are then tested in practice and are in turn are critically evaluated in a continual cycle of reflective action and active reflection. The iterative nature the process ensures continual advancement, continual improvement in the design process and implementation, not just technically but transformatively. This means that the engineer, the client and society through its government agents must envisage the changes that is both desirable and necessary and then design and build for that change.

The advantage of this model is that it overcomes fixed thinking and therefore fixed solutions. Praxic thought and action on ethically aligned design recognises that the built environment impacts of Man and nature and aims to ensure that that impact if beneficial in the immediate and long-term future.

Conclusion

The use of autonomous and intelligent systems is growing exponentially worldwide and though the construction industry is lagging behind other industries in its use it is being encouraged to adopt A/IS to exploit the potential for increased productivity (Barbosa et al. 2017). A major concern is that the pace of technical development of these systems far outpaces the development of ethical codes and practices that will regulate and control what is developed and how it is used.

At the same time species depletions, environmental degradation and climate change are immediate critical issues that humanity must address, not least because much of these are anthropogenic effects. Construction, extraction, agriculture, and manufacturing, etc., will of necessity continue and therefore humanity's impact on society and the environment will continue. A defining quality of humankind is each persons awareness of themselves as an ethical and moral being. Developments in moral theory, ethically aligned design and methodologies for critical thinking provide the tools for engineers to more effectively design for humanity and the welfare of the planet.

In construction the agents for change, clients, engineers, contractors and government, must begin by recognising and accepting their role as morally responsible agents for the moral consequences of their decisions and actions in an extended multi-agent network. In doing so they must act on that responsibility by quantifying the moral benefit or moral loadedness of any project they undertake. A/IS systems such as *dfrome* are useful tools but are no substitute for decision making by human agents who have made sufficient inquiry and continually reflects upon their decisions through to completion and onto the next project.

The model described draws upon social, ethical, technical and political initiatives, merging them into a workable process of ethically aligned design that prioritises societal well-being and environmental sustainability a step principal outputs of all construction projects.

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An Evaluation of Health and Safety Competency Attributes for the Delivery of Construction Projects

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Abstract

Purpose – Health and safety performance within the South African construction industry is still characterized by poor delivery in terms of fatal accident rates and associated costs. This research explored health and safety (H&S) attributes relevant in current practice in order to develop strategies to improve H&S performance in the construction industry. Attributes including training, qualification level and attitude towards health and safety implementation were assessed, from the perspective of practitioners and construction professionals.

Design – To achieve the aim of this study, desktop research backed by questionnaire survey was undertaken. The questionnaire was distributed among internationally and locally-based H&S professionals and researchers at a conference in South Africa. Empirical data were analyzed to output descriptive statistics.

Findings – The study revealed that practitioners' attributes such as skills and professional status within the construction sector, formal specialized training in construction, qualification level of H&S practitioners, and practitioners being built environment professionals with H&S-specific training contributes to H&S performance improvement in the industry.

Limitations – The study includes a small sample of practitioners and researchers at an academic conference and thus the findings may not be generalizable.

Originality – The study emphasizes the importance of specific competencies for H&S practitioners in the construction industry.

Practical implications – Better H&S performance can be achieved with emphasis on H&S- and construction-specific training for practitioners.

Keywords: competency, construction, health and safety performance, practitioners, South Africa

Introduction

The construction industry contributes greatly to the economy of any nation through job creation, physical infrastructure provision, and contribution to gross domestic product (Ngandu et al., 2010; Loney et al., 2012; Okoye et al., 2016). An estimated $10 trillion is spent on construction-related goods and services each year in the United States (US) (Lynch, 2018). The sector also has a stimulatory effect on other production activities and households at all income levels (Ngandu et al., 2010). However, despite the significant role of the construction sector, its health and safety (H&S)

performance is a continual worry. The H&S status within the construction sector, globally, is higher than other sectors, with the highest injuries and deaths resulting from falls (Loney et al., 2012).

In the US, a total of 1,013 fatalities were recorded in 2017 (Bureau of Labour Statistics (BLS), 2019). In Britain, statistics from the Health and Safety Executive (HSE) revealed that the rate of fatal injury in construction is 1.64 per 100, 000 workers, accounting for as much as four times the average rate of "All industry" (HSE, 2018) (Figure 1.1). In South Africa, H&S performance is no different. While the construction sector contributed 12% to the country's gross domestic product (GDP) in 2017/2018 financial year, the sector had at least 1.5 to 2.5 fatalities per week (Republic of South Africa (RSA), 2019).

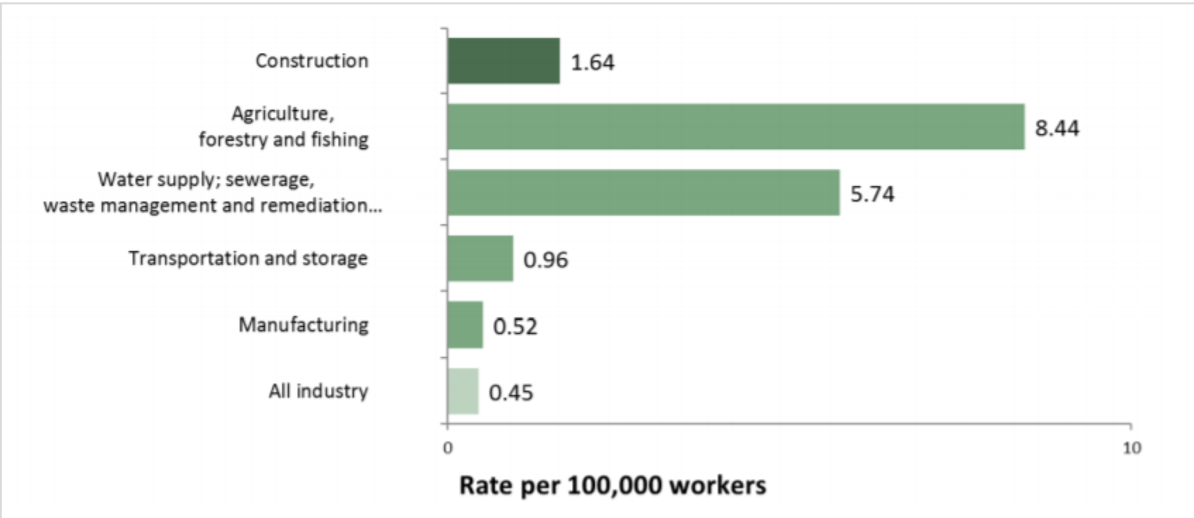

Figure 1.1: Fatal injuries in industry (Source: HSE, 2018)

The high rate of accidents and mortalities are attributed to lack of compliance with H&S legislative requirements, and sufficiently lack of skilled, experienced, and knowledgeable persons to manage H&S on construction sites (Othman, 2012). Inadequate multi-level interventions including improved management and safety supervision, adequate and appropriate engineering controls and educational programmes, worker behaviour, as well as poor knowledge management and exchange of smart ideas on ways to reduce accidents have also resulted in poor H&S performance (Loney et al., 2012). Further, the high rates of accidents and injuries in South Africa are partly as a result of limited number of safety officers and competent personnel to implement H&S and ensure safety on site (RSA, 2019). Therefore, there is a need to continuously conduct research on new and smart ways to improve H&S performance on construction sites, especially given the opportunity provided by the fourth industrial revolution. Consequently, attention to the role of the H&S practitioners in achieving improved H&S performance warrants continuous attention.

Previous studies on improving H&S in the construction industry have focused on contractors (Othman, 2012), clients (Musonda et al., 2012), management's commitment and culture (Okorie and Smallwood, 2010), worker behaviour and engagement (Wachter and Yorio, 2014), and construction workers' health and safety knowledge (Okoye et al., 2016). It appears that little attention is given to practitioners' and their attributes, which could improve the status quo with regard to construction H&S performance, with the exception of a study by Smallwood (2011), which investigated the importance of knowledge areas and composite skills relevant to H&S occupations. However, Smallwood's (2011) study was conducted among contractors and thus the findings may not reflect the views of H&S practitioners themselves. One of the major needs with regard to the construction industry is to enhance professionals' interests and participation in active and smart safety management and implementation of awareness programs (Okoye et al., 2016) and this can be achieved through investigation of attributes as viewed by the practitioners themselves.

Undoubtedly, H&S practitioners within the construction sector contribute significantly towards safety performance. Health and safety experts and practitioner's knowledge on safety improves the H&S delivery within the construction sector and thus minimises accidents and promotes profitability. It is likely that the construction industry will continue to experience costly and fatal accidents if the overall culture of the industry on safety is not addressed as a fragment of the designed accident preclusion programmes. Additionally, professionalizing construction health and safety is a significant factor to culture change in the industry. However, professionalising H&S is influenced by H&S practitioners' attributes such as skills and professional standing within the construction industry. Further, the industry's unwillingness to support a specialized health and safety academic qualification is seen as a constraint to culture change in the construction industry (Alli, 2008). To respond to this relatively high incident rate and its associated cost and fatalities within the South African Construction industry due to poor safety compliance, there is the need to solicit the attributes of construction experts and safety practitioners viewpoints as a standpoint to enable improve on safety. It is against this backdrop that the study seeks to explore practitioners' attributes towards effective Health and Safety with the context of the South Africa construction industry.

The objective of the current study is therefore the explore practitioners' perceptions with regard to attributes that could contribute to H&S performance in the construction industry. The succeeding sections of this paper presents an overview of construction H&S performance and professionals' attributes. The methods adopted in conducting the study and the findings from the study are presented and discussed thereafter.

Review of Literature

Health and Safety in the Construction Industry

The construction sector is a momentous contributor to employment and economic growth. In South Africa, the sector contributes 3.9% to national gross domestic product (Lekula, 2018). The construction sector plays a more fundamental role in the economy compared to many other sectors. However, the sector faces challenges with regard to H&S implementation and practice, among others (Windapo and Cattell, 2013).

Health and safety within the construction industry deals with both physical and psychological well-being of workers on construction sites and other stakeholders whose health are likely to be directly or indirectly affected by construction activities (Hudges and Ferrett, 2008). Construction H&S is of primary concern to government, employers, employees and project participants. It is an economic as well as humanitarian concern that requires proper management control.

In the construction sector, and other industries, generally, provision of health and safety policy and rules enable workers in all fields of industry face workplace dangers that can threaten their health and safety (Molenaar et al, 2009). In other construction related activities such as in the mining and oil industries, the dangers can be evident: exposure to harmful chemicals, fires, explosions and breakdown of machinery are just some of the health risk that workers in these fields face in their daily work (Molenaar et al., 2009). For other industries including pharmaceuticals and the business sectors, the safety hazards may not be as obvious as suppose to the construction sector. Kheni et al. (2007) asserted that lack of resources, inadequate legal and institutional arrangements for the management of health and safety (H&S) have compounded the problem of H&S performance in developing countries. This has contributed to the construction industry being characterised by poor knowledge and awareness of H&S apart from its labour intensiveness and use of old technology in approaching safety (Kheni, et al., 2007; Musonda and Smallwood, 2008).

Health and Safety Practitioners' Competency Attributes

Competency of H&S practitioners is important in improving H&S performance in the construction industry. Competency entails achieving skills and standard of performance (Smallwood, 2011). Occupational safety and health (OSH) practitioners including professionals employed as external or internal advisors, client-appointed H&S agents, site managers and H&S officers, , project team and representatives elected by employees to supervise H&S implementation, should be competent (Harris, 2011; Smallwood, 2011). According to the Construction Regulations 2014, a competent person means “any person who has, in respect of the work or task to be performed, the required knowledge, training, experience and qualifications specific to the work or task ...” (RSA, 2017).

Therefore, the lack of competence usually increases the rate of accidents on a project. Kheni (2008) stated that lack of skilled human resources, was one of the major challenges facing occupational safety practice (in addition to inadequate government support for regulatory institutions and inefficient institutional frameworks responsible for health and safety standards). Generally, industry's attitude to health and safety (H&S) and the organizations that operate within is influenced by the professional status of H&S practitioners who function within the sector. This implies that when safety professionals are abreast with emerging trends of safety, there is ease of compliance and implementation.

Accordingly, Spayd (2012) stressed that the relationship between attitude and behaviour has a strong impact on the relationship between job satisfaction and organizational commitment. The relationship between attitude and behaviour has been studied vastly and has been determined that the two exist on a variety. Leka et al. (2018) pointed that occupational health and safety (OSH) practitioners play a key role in understanding and addressing current challenges in workplace health. To this end, their perception of priorities as well as knowledge and skills base are critically important. Knowledge in this sense is more than information, since it involves an awareness or understanding gained through experience, familiarity or learning (Okoye et al., 2016).

Leka et al. (2018) further posited that designed and developed training and auditing skills which yield qualification level of H&S practitioners is prudent. This training will assist individuals in becoming more marketable in today's workforce and to improve the entire industry's H&S culture. According to Giang and Pheng (2010), training is one of the most vital components within our company's safety management system. This is because training gives employees an opportunity to learn their jobs properly, bring new ideas into the workplace, reinforce existing ideas and practices, and it helps shape safety and health program into action (Giang and Pheng, 2010). Therefore, formal specialized training in construction H&S will contribute to a better H&S performance in the construction industry. Health and safety practitioners within the construction industry should be built environment professionals who have training in H&S.

High accidents have been attributed to the high-level of non-compliance of the legislative requirements of construction health and safety professionals (Council for the Built Environment

(CBE), 2012). More importantly, this indicates lack of effective management and supervision of H&S on construction sites, which partly occurs as a result of inexperienced supervisors on the job. The lack of sufficiently skilled, experienced and knowledgeable professionals managing health and safety on construction sites leads to poor health and safety implementation (Loney et al., 2012).

Smallwood et al. (2008) also noted that the institutional and legal governance frameworks on occupational H&S in developing countries have little impact on implementation because H&S officers' lack of training and this trumps all implementation efforts. More significantly, H&S officers employed to monitor site safety compliance sometimes do not have the desired skills and training should not necessarily be construction- practice oriented (Smallwood et al., 2008; Wachter and Yorio, 2014). Therefore, practitioners in H&S need to possess the relevant knowledge, qualification, skills and expertise in order to be able to supervise, train and impart knowledge on others.

Materials and Methods

To achieve the purpose of the study highlighting the specific health and safety attributes from the perspective of practitioners, the quantitative research method was adopted. This method is efficient and cost-effective research method (Gerhardt, 2004). Data for this study were collected using primary and secondary data sources. Secondary sources of information include journal article s and conference proceedings, to identify relevant competency attributes for H&S practice. The primary data source for this study involved the use of questionnaire. The questionnaire contained questions related to the safety attitudes of practitioners. Responses were sought on a 5-point Likert scale ranging from 1 = strongly disagree to 5 = strongly agree. The questionnaires were distributed to a population selected using convenience sampling. The participants comprised attendees to an international H&S conference, the CIB W099 and TG59 International Safety, Health, and People in Construction Conference held in Cape Town, South Africa in 2017. Therefore, the attendees were made up of international and locally-based H&S professionals and researchers. The questionnaires were hand-distributed during intermittent breaks at the two-day conference. A total number of thirty-six completed questionnaires were received and used for data analysis. Data were analysed using the Statistical Package for the Social Science (SPSS). The outputs were percentage frequency scores, showing the level of consensus on the attributes considered, among the sampled respondents.

Results

The results of the descriptive analysis of empirical data are presented in Table 4.1. The table evinced that 56% of the respondents were of the view that the professional status of H&S practitioners influences attitude towards H&S practice and implementation in their affiliated organizations and the industry as a whole. With regard to qualification level of the practitioner not being an important factor in H&S culture improvement, 72% of the respondents disagreed. This suggested that respondents were in agreement that the qualification level of H&S practitioners is a key factor that impacts on the implementation of H&S in organizations.

The table also indicated that 91% of the respondents were in agreement that formal specialized training in construction health and safety will contribute to a better H&S performance in the construction industry. Additionally, it was found that 81% of the respondents were of the view that safety officers should be trained in construction processes; while 56% deemed that H&S

practitioners in the construction industry should be built environment professionals with H&S-specific training.

Table 4.1: Findings on H&S practitioners' attributes

Item ID	H&S attributes	Percentage frequency of responses (%)				
		Strongly disagree	Disagree	Neutral	Agree	Strongly agree
1	Organizations and industry's attitude to H&S is influenced by the professional status of H&S practitioners within the construction industry	6	8	30	39	17
2	Qualification level of a H&S practitioners is not a factor in improving the industry's H&S culture	39	33	19	6	3
3	Formal specialized training in construction H&S will contribute to a better H&S performance in the construction industry	0	3	6	47	44
4	H&S practitioners within the construction industry should be built environment professionals who have training in H&S	8	11	25	31	25
5	H&S officers, usually employed to monitor site safety compliance, do not have to be trained in construction processes	47	34	8	8	3

Discussion

The study established that practitioners' attributes such as skills and professional status within the construction sector are relevant as they augment the implementation of H&S on site and in organizations. This finding is aligned with the suggestion of Kheni (2008) which emphasized on the lack of skilled human resources, inadequate government support for regulatory institutions and inefficient institutional frameworks been responsible for health and safety standards.

The finding that formal specialized training in construction contributes to better H&S performance aligns with a study by Giang and Pheng (2010) which emphasized on training as one of the most vital components within our company's safety management system. This further infers that formal education is relevant and must be encouraged and be the focal point if health and safety is to be enhanced as an attribute of practitioners.

The current study further revealed that the qualification level of H&S practitioners is a factor in improving the industry's H&S culture. This supports the study of Smallwood (2006) which points that many of the barriers to H&S implementation stem from lack or inadequate education and training relevant to H&S practice on a construction site. This should be a prerequisite for inclusion of personnel in general site management. Therefore, this suggests that basic acquisition of knowledge level on health and safety is prudent in promoting a continuous and sound health and safety culture within the sector.

The findings that H&S officers need to be trained in construction processes and should be built environment professionals with H&S-specific training correspond with Leka et al.'s (2018) study, which supported that a designed and developed training and assessing skills produces competent and qualification level of H&S practitioners. Further, the need to train construction H&S professionals using scenario-led training and new digital applications enhances information sharing and targeted learning to reduce H&S risks on site (Kassem, 2014). Moreover, to foster healthy construction safety practices within the sector, practitioners need to be trained, specifically on new ways to improve site awareness and impart knowledge of spatial dangers that workers are faced with on site. For effective implementation of H&S practices on site and in organizations, capabilities including technological skills, need to be developed to achieve targets with regard to hazard identification through risk assessment to risk mitigation and response planning (Calantropio, 2019). The promotion of competence allows for responsible and informed decision-making and contributions to the H&S effort (Health and Safety Authority (HSA), 2019).

Conclusion and Recommendations

The current study sought to explore H&S performance attributes of practitioners. The objective of the study was met. To achieve the objective, both desktop research backed by questionnaire survey was undertaken. The study established that formal specialized training in construction for practitioners is laudable since formal education promotes sound health safety culture hence it must be encouraged to enhanced in the safety knowledge of practitioners. Therefore, it can be concluded that practitioners' formal education and training is prudent. The study suggests that health and safety officers employed on construction sites must be well knowledgeable with training and emerging trends of safety compliance standards. Further, the study concludes that, to maintain continuous safety culture, practitioners must be knowledgeable about health and safety at work. This leads to the conclusion formal education and training would have to be encouraged.

The limitations of the study warrant mention. Since the study was conducted with a small sample, future studies could include a wider sample. In addition, the study used descriptive statistical techniques to determine the level of consensus on the attributes considered. Further studies are recommended to establish the extent to which these attributes influence H&S performance in the construction industry.

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Knowledge of Scaffolding Requirements in Construction: An Assessment

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Abstract

Scaffolding features regularly in terms of construction-related accidents reported in the media. Furthermore, it contributes a fair percentage in terms of the agencies linked to construction accidents.

A range of health and safety (H&S) legislation, and South African National Standard (SANS) 10085 informs with respect to the requirements relative to scaffolding.

The study reported on, investigated the knowledge of delegates attending four scaffold safety information sessions with respect to various aspects related to scaffolding. A self-administered questionnaire was circulated and completed prior to commencement of the information sessions.

Findings include: the highest level of response was relative to the length of a timber sole board when under a single scaffold standard / base jack; the lowest level of response was relative to 'name the five occasions where scaffolds may need to be inspected by the appointed scaffold inspector as per the SANS Scaffold Code' - 'before dismantling'; the highest level of response within 10% of the range was relative to the 'acceptable height for a scaffold platform guard rail above the platform', and the lowest level of response within 10% of the range was relative to the 'what is the approximate weight of a pallet of bricks'.

Conclusions include: the attendance of the scaffold information sessions indicates that there is a need for knowledge relative to scaffolding; there is a need to assess practitioners' knowledge, and there is a lack of knowledge in terms of the specifics with respect to scaffolding.

Recommendations include: practitioners must familiarise themselves with the specifics of SANS 10085; employer associations, professional associations, and statutory councils should evolve and or promote scaffolding-related continuing professional development (CPD); the industry should evolve a consolidated guide to scaffolding, and more scaffolding-related knowledge sessions should be staged.

Keywords: construction, health and safety, knowledge, scaffolding.

Introduction

The International Labour Office (ILO) (1999) defines scaffolding as "A temporary structure supporting one or more platforms, and which is used either as a workplace or for the storage of materials in the course of any type of construction work, including both maintenance and demolition work."

The Health and Safety Authority (HAS) (1999) contends scaffolding performs several important functions during the construction process. It enables work to be performed at a height, it is used to protect persons working at height from falling, and to protect persons working below from falling objects. According to Davis (2002), scaffolding can provide an efficient and safe means to perform work, however, unsafe scaffolding practices can lead to accidents, serious injuries, and fatalities.

Scaffolding and staging accounted for 15.0% of fatal falls to a lower level in construction in the United States of America for the years 2011-2015 (Dong, Wang, Katz, West, & Bunting, 2017). Within the context of South Africa, according to the Federated Employers Mutual Assurance Company (FEMA) (2020), scaffolding, which is one of 188 (0.53%) agencies in terms of accidents, contributed as follows to accidents in terms of agencies during 2019: 2.5% of total accidents; 3.2% of total fatalities; 4.9% of total lost days; 4.4% of permanent disablements, and a cost of R62 428 per accident versus an overall mean of R31 803.

Scaffolding has featured periodically in terms of construction-related accidents reported in the South African media. The notable 'Investec' scaffolding collapse in Sandton, Johannesburg on 26 August 1997 resulted in three fatalities and sixteen seriously injured, and a plethora of articles in the media. It is alleged that too many marble tiles were stacked on the scaffolding, the weight of which brought it down (Cresswell, 1997). A 27-year-old worker, who was believed to be working on scaffolding on a project in Sandton, Johannesburg, fell four floors to his death when he accidentally fell from a temporary platform in February 2011 (news24, 2011). Five workers were injured when they fell between 10 to 15 metres when the scaffolding they were working on, collapsed at a construction site in Pretoria in June 2015 (Masinga, 2015).

The Construction Industry Development Board (cidb) (2009) report 'Construction Health & Safety Status & Recommendations' highlighted the considerable number of accidents, fatalities, and other injuries that occur in the South African construction industry. The report cited the high-level of non-compliance with H&S legislative requirements, which is indicative of a deficiency of effective management and supervision of H&S on construction sites as well as planning from the inception / conception of projects within the context of project management. The report also cited a lack of sufficiently skilled, experienced, and knowledgeable persons to manage H&S on construction sites.

Limited research has been conducted relative to scaffolding, including scaffolding H&S, in South Africa. Furthermore, invariably research has investigated practices and causes of accidents and / or failures, however, not the scaffolding-related knowledge of participants in the construction process. Anecdotal evidence underscored by the status of scaffolding alludes to inadequate scaffolding-related knowledge of such participants.

Given the abovementioned, a study 'scaffolding knowledge' was conducted to determine industry participants' scaffolding knowledge, which effectively constitutes the research gap.

Review of the Literature

Legislation

A range of legislation and regulations impact on scaffolding, including knowledge relative thereto.

The Occupational Health and Safety Act (OH&SA) (Republic of South Africa, 1993) schedules generic requirements. Employers are required to provide such information, instructions, training, and supervision as may be necessary to ensure, as far as is reasonably practicable, the H&S at work of their employees.

The General Safety Regulations (Republic of South Africa, 1986) address a range of scaffolding related aspects. In terms of scaffold framework: categories in terms of loads; foundations; spacing of standards; bracing; provision of ladders; securing to structure; factor of safety; supervision of erection and dismantling; frequency of inspections, and supervision. In terms of scaffold platforms: width of platforms; distance of platforms from structures; dimensions of planks; guardrails; toe boards, and housekeeping.

The Construction Regulations (Republic of South Africa, 2014) require that contractors ensure that scaffold erectors, team leaders, supervisors, and inspectors are competent.

Standards

'SANS 10085-1:2004 The design, erection, use and inspection of access scaffolding Part 1: Steel access scaffolding' is the South African National Standard applicable to scaffolding.

The standard addresses: scaffolding materials; components; chains, ropes and fasteners; foundations for scaffolding; design requirements for access scaffolding; erection of scaffolding; safety precautions; inspection; maintenance and storage; control of scaffolding operations; responsibilities of the scaffold user, and training requirements for scaffolding personnel.

Problem aspects

The Construction Safety Association Ontario (CSAO) (2001) cites the following as problem areas: erecting and dismantling; climbing up and down; planks sliding off or breaking; improper loading or overloading; platforms not fully decked; platforms without guardrails; failure to install all required components; electrical contact with overhead wires, and moving rolling scaffolds with workers on the platform.

Erecting and dismantling results in between 15 to 20% of scaffolding-related injuries, the most common problem being the failure to provide an adequate working platform for workers when installing the next lift of scaffolding. The next most important consideration are tie-ins, which should be installed as the scaffolding is erected. Doing so prevents sway or movement, which could result in falls, the situation being exacerbated during erection and dismantling as platform boards and guardrails may have been removed. Climbing up and down results in approximately 15% of scaffolding-related injuries due to workers using frames and braces, as opposed to ladders. Planks sliding off or breaking cause many scaffolding-related injuries. Planks must be cleated or otherwise secured. Furthermore, planks must be of the correct grade of timber, maintained, and overloading must be averted. Improper loading or overloading results in deflection, and leads to deterioration and breaking, which is often related to the masonry trade. Platforms not fully decked during use, but also during erection and dismantling, are related to injuries. Platforms without guardrails are a serious issue in construction and are important for both high and low platforms. Guardrails should consist of a top rail, a middle rail, and a toe board. Failure to install all the required components is a further serious safety issue. Electrical contact with overhead wires does not occur often, however, when it does, it invariably involves a fatality. Failure to maintain safe distances from overhead powerlines while moving scaffolds is a major problem. There are recommended minimum distances depending on the voltage rating of the powerline. Lastly, moving mobile scaffolding with workers on the platform can be dangerous.

Causes of scaffolding-related accidents

A scaffolding study conducted in South Africa investigated a range of aspects (Smallwood, 2006). In terms of the contribution of various aspects to scaffolding-related accidents, the following aspects can be deemed to make between a contribution and a near major / near major contribution to scaffolding-related accidents: overloading (materials) (joint 1st); inadequate guardrails (3rd); inadequate access (joint 4th); inadequate framework (joint 6th); inadequate platform (6th); overloading (plant and equipment) (joint 8th); non-compliance to legislation (joint 8th); inadequately educated / trained Scaffold Supervisors (joint 11th); inadequate base (16th); inadequately educated / trained Scaffold Erectors (joint 17th); overloading people (joint 17th); lack of written safe work procedures (SWPs) (joint 19th); inadequate ground / founding conditions (joint 19th); inadequate tying to structure (joint 23rd) ; inadequate screening (or lack of) (joint 23rd), and lack of scientific design (26th).

According to Davis (2002), the causes of scaffolding accidents include failures at attachment points, parts failure, inadequate fall protection, improper construction or work rules, and changing environmental conditions such as high winds, temperature extremes, or the presence of toxic gases. Furthermore, overloading of scaffolding is a frequent cause of major scaffolding failures.

A study conducted by Enshassi & Shakalaih (2015) in the Gaza strip, Palestine determined the top ten factors influencing the occurrence of falls from scaffolds as: absence of personal protective equipment (PPE); missing ladders; wind loads; disguised the design code; lack of proper assembly or inspection; overhead tools and materials; climbing and neglect using ladders; lack of guardrails; missing bracing, and working during fatigue.

Importance of interventions

The scaffolding study conducted in South Africa also investigated the degree of importance of various aspects / actions / interventions relative to scaffolding aspects (Smallwood, 2006). The following can be deemed to be between more than important to very important / very important: scaffold supervisor training (joint 1st); scaffold erector training (joint 1st), and written safe work procedures (SWPs) (joint 6th).

Research

Research method and sample stratum

Four Association of Construction Health and Safety Management (ACHASM) scaffolding information sessions were conducted by the lead co-author, which were attended by a total of 123 delegates as follows:

- 24 March 2017: 13 No.
- 17 October 2017: 53 No.
- 20 June 2018: 41 No.
- Date not recorded - 16 No.

The delegates were primarily construction health and safety agents, managers, and officers, and not necessarily scaffold erectors or inspectors.

An 18-question self-administered questionnaire was circulated, completed, and recovered prior to the information sessions commencing. The questionnaire was based upon sixteen aspects addressed in SANS 10085 and is in fact similar to the test paper used during scaffold inspector training courses. Therefore, the questionnaire was not pilot tested, and there was no need to verify the questions. The questions are presented below:

1. What are the dimensions of a timber sole board when under a single scaffold standard / base jack (length x breadth x thickness)?
2. What is the maximum load per square meter (in kg) for a typical kwikstage scaffold platform with supports (ledgers or similar) every 2.5m?
3. What is the minimum width (or number of platform boards) of a general-purpose bricklayer's scaffold platform?
4. What is the minimum width, in mm (or number of platforms boards) of a scaffold platform specifically used by painters?
5. The maximum height of a scaffold is based on its minimum base width. For a mobile scaffold tower being used outside a building with a minimum base width of 2.5m, what would the maximum permissible height (in meters) be?
6. As per the above question, what is the maximum permissible height of a static scaffold tower (not on wheels) inside a building where the minimum base width is 3m?
7. Scaffolds need to be tied in so as to prevent them from displacing and falling over. Based on the scaffold face area, what is the ratio of movable fixed ties to square meters of scaffold face – in other words one tie is required for how many square meters?
8. Similarly, if a scaffold is shade clothed, what is the ratio of movable fixed ties to square meters of scaffold face?
9. What is the maximum height that a scaffold ladder may extend before a rest platform or stagger is required?
10. What is an acceptable height for a scaffold platform guard rail above the platform?
11. When do scaffold platforms need to be fitted with toe boards?
12. What is the approximate weight of a typical clay brick?
13. What is the approximate weight of a pallet of bricks?
14. What is the weight of a 2.5m steel scaffold board?
15. Name the five occasions where scaffolds may need to be inspected by the appointed scaffold inspector as per the SANS Scaffold Code.
16. Can you name the three types of scaffold bracing?
17. What scaffold code regulates scaffolding in South Africa – number and year?

18. What is deemed to be hazardous weather (wind in km/h and rainfall in mm/h) in terms of the Scaffold Code?

Research Findings

Table 1 presents the extent of the respondents' scaffold knowledge relative to sixteen aspects.

The five highest percentage responses were relative to the 'length of a timber sole board when under a single scaffold standard / base jack' (86.2%), followed by 'maximum height that a scaffold ladder may extend before a rest platform or stagger is required' (83.7%), 'acceptable height for a scaffold platform guard rail above the platform' (83.7%), 'approximate weight of a pallet of bricks' (83.7%), and 'when do scaffold platforms need to be fitted with toe boards' (82.9%).

The five lowest percentage responses were relative to 'minimum width (or number of boards) of a general-purpose bricklayer's scaffold platform' (mm) (35.8%), preceded by 'minimum width (or number of boards) of a scaffold platform specifically used by painters' (mm) (39.8%), 'minimum width (or number of boards) of a scaffold platform specifically used by painters' (No.) (41.5%), 'minimum width (or number of boards) of a general-purpose bricklayer's scaffold platform' (No.) (43.9%), and 'if a scaffold is shade clothed what is the ratio of movable fixed ties to square meters of scaffold face' (56.9%).

The highest 'overstated' percentage difference was 403.7% relative to 'length of a timber sole board when under a single scaffold standard / base jack' - mean response (2 518.4 mm) versus actual (500 mm). This was followed by 299.6% relative to 'approximate weight of a typical clay brick' – mean response 10.39 kg versus actual (2.6 kg), 237.6% relative to 'acceptable height for a scaffold platform guard rail above the platform' - mean response (3.38 m) versus actual (1.0 m), 206.3% relative to thickness of a timber sole board when under a single scaffold standard / base jack – mean response (116.39 mm) versus actual (38 mm).

The highest 'understated' percentage difference was -51.0% relative to 'approximate weight of a pallet of bricks' – mean response (1 273.6 kg) versus actual (2 600 kg), preceded by -50.5% relative to 'if a scaffold is shade clothed what is the ratio of movable fixed ties to square meters of scaffold face' – mean response (12.9 m^2) versus actual (26.0 m^2), and -30.7% relative to 'one tie is required for how many square meters of scaffold face' - mean response (20.2 m^2) versus actual (32.0 m^2).

The highest response within 5% range of the actual is relative to 'minimum width (or number of boards) of a scaffold platform specifically used by painters' (No.) (43.1%), followed by 'minimum width (or number of boards) of a general-purpose bricklayer's scaffold platform' (No.) (40.7%), and 'mobile scaffold tower being used outside a building with a minimum base width of 2.5m, what would the maximum permissible height be' (38.8%).

The lowest response within 5% range of the actual is relative to 'minimum width (or number of boards) of a general-purpose bricklayer's scaffold platform' (mm) (0.0%), preceded by 'ratio of movable fixed ties to square meters of scaffold face of a shade clothed scaffold' (1.4%), 'approximate weight of a pallet of bricks' (1.9%), 'approximate weight of a typical clay brick ' (4.0%), and 'length of a timber sole board when under a single scaffold standard / base jack' (6.6%).

The highest response within 10% range of the actual is relative to 'acceptable height for a scaffold platform guard rail above the platform' (62.1%), 'maximum permissible height of a mobile scaffold tower being used outside a building with a minimum base width of 2.5m' (44.9%), 'minimum width (or number of boards) of a scaffold platform specifically used by painters' (No.) (43.1%), 'maximum load (kg) per square meter for a typical kwik-stage scaffold platform with supports every 2.5m' (29.5%), and 'minimum width (or number of boards) of a general-purpose bricklayer's scaffold platform' (mm) (29.5%).

The lowest response within 10% range of the actual is relative to 'approximate weight of a pallet of bricks' (1.9%), preceded by 'ratio of movable fixed ties to square meters of scaffold face of a shade clothed scaffold' (2.9%), 'approximate weight of a typical clay brick' (5.0%), 'minimum width (or number of boards) of a scaffold platform specifically used by painters' (mm) (8.2%), and 'thickness of a timber sole board when under a single scaffold standard / base jack (9.5%).

Table 1: Extent of respondents' scaffold knowledge

Aspect	Response (%)	Mean	Actual	Difference (%)	Response within 5% range (%)	Response within 10%
Dimensions of a timber sole board when under a single scaffold standard / base jack:						
• Length (mm)	86.2	2518.42	500	403.7	6.6	21.7
• Breadth (mm)	77.2	293.12	225	30.3	16.8	17.9
• Thickness (mm)	68.3	116.39	38	206.3	7.1	9.5
Maximum load (kg) per square meter for a typical kwikstage scaffold platform with supports every 2.5m?	71.5	401.01	260	54.2	6.8	29.5
Minimum width (or number of boards) of a general-purpose bricklayer's scaffold platform? (mm)	35.8	1702.11	1125	51.3	0.0	29.5
Minimum width (or number of boards) of a general-purpose bricklayer's scaffold platform? (No.)	43.9	4.00	5	(20.0)	40.7	40.7
Minimum width (or number of boards) of a scaffold platform specifically used by painters? (mm)	39.8	1094.74	675	62.2	8.2	8.2
Minimum width (or number of boards) of a scaffold platform specifically used by painters? (No.)	41.5	3.61	3	20.3	43.1	43.1
Mobile scaffold tower being used outside a building with a minimum base width of 2.5m, what would the maximum permissible height be? (m)	79.7	9.73	7.5	29.7	38.8	44.9
What is the maximum permissible height of a static scaffold tower (not on wheels) inside a building where the minimum base width is 3m? (m)	78.0	8.44	12	(29.7)	10.4	10.4
One tie is required for how many square meters of scaffold face?	68.3	20.16	32	(37.0)	15.5	22.6
If a scaffold is shade clothed what is the ratio of movable fixed ties to square meters of scaffold face?	56.9			(50.5)	1.4	2.9
Maximum height that a scaffold ladder may extend before a rest platform or stagger is required?	83.7	8.86	8	(10.8)	14.6	14.6

Acceptable height for a scaffold platform guard rail above the platform?	83.7	3.38	1	237.6	34.0	62.1
When do scaffold platforms need to be fitted with toe boards?	82.9					
What is the approximate weight of a typical clay brick?	81.3	10.39	2.6	299.6	4.0	5.0
What is the approximate weight of a pallet of bricks?	83.7	1273.59	2600	(51.0)	1.9	1.9

Table 2 presents the percentage respondents that identified the five occasions where scaffolds may need to be inspected by the appointed scaffold inspector as per the SANS Scaffold Code, and the three types of scaffold bracing. Respondents were required to record the occasions i.e. options were not presented.

In terms of the five occasions when scaffolds may need to be inspected by the appointed scaffold inspector as per the SANS Scaffold Code, after erection (26.8%) was identified the most frequently, followed by after alteration (25.2%), weekly (15.4%), after incidents (15.4%), and lastly, before dismantling (2.4%).

In terms of the three types of scaffold bracing, face / long (34.1%) was identified the most frequently, followed by plan (33.3%), and ledger / transom (26.8%).

Table 2: Respondents' knowledge scaffold inspections and the types of scaffold bracing

Question	Yes (%)
Name the five occasions when scaffolds may need to be inspected by the appointed scaffold inspector as per the SANS Scaffold Code:	
• After erection	26.8
• Weekly	15.4
• After incidents	15.4
• Before dismantling	2.4
• After alteration	25.2
Name the three types of scaffold bracing:	
• Face / Long	34.1
• Ledger / Transom	26.8
• Plan	33.3

Conclusions

There is a lack of knowledge on the part of the delegates assessed in terms of the specifics with respect to scaffolding. Furthermore, given this shortcoming, it is likely that the delegates' employers identified a need for their employees to be 'developed' in terms of scaffolding knowledge. This leads to the further conclusion that most were not competent should they have been involved with the scaffolding process or overseeing sites or sections thereof.

There is an inability to apply logic in the case of many aspects e.g. surely scaffolding should be inspected after it is erected, and after incidents, yet only 26.8% and 15.4% identified the occasions, respectively.

There is a lack of knowledge with respect to the dimensions of standard materials / equipment i.e. scaffold boards. This lack of knowledge extends to a basic and common construction material in South Africa, in the form of a brick, and a pallet of bricks, the point being that scaffold platforms are frequently stacked with bricks.

Lastly, given that delegates were not able to access reference material, print or electronic, while completing the questionnaire, the findings can be deemed a reliable reflection of their knowledge.

Recommendations

Contract and site managers, supervisors, and H&S practitioners must familiarise themselves with the specifics of SANS 10085, and employers should address SANS 10085 and the specifics of scaffolding during scaffolding toolbox talks. Upon the commencement of scaffolding on a project scaffolding should be designated the 'H&S theme of the month', or for another period such as a week.

There is a need for scaffolding-related continuing professional development (CPD), which should be promoted and facilitated by industry employer and professional associations. Furthermore, organisations can conduct in-house scaffolding-related training and knowledge interventions.

ACHASM as the professional association for construction H&S management, should conduct more such scaffolding knowledge sessions.

Graphic visual guides or aids that indicate the salient issues relative to the components of scaffolding should be evolved and made available on site for all participants for easy reference during the construction process.

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Safety Instructors' Role in the South African Construction Industry

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Abstract

The purpose of this reported study was to determine how contractors could improve construction using a safety instructor. The research data were collected through semi-structured interviews and focus group interviews from multiple case projects in Bloemfontein, South Africa. The results showed that the safety leader either in the form of a manager or officer on a construction site is saddled with the responsibility of designing appropriate safety management systems (SMSs) that should assure the health, safety and wellbeing (HSW) of people on site. The design of SMSs must incorporate adequate training required to empower the workforce to complete projects without harm. Further, safety training must be specific and fit for purpose as it promotes a safe working environment while the workers learn how to identify hazards and prevent them from causing accidents. The role of safety instructors should be prioritised by contractors to promote a safe working environment.

Keywords: construction safety, health and safety, safety management system, safety training.

Introduction

South African construction is under ever-increasing pressure from clients to deliver projects that adhere to occupational health and safety (OHS) regulations. The industry no longer has a choice on whether to adopt the OHS Act, No. 181 Of 1993 (Construction Regulations 2014) or cater for the health and safety (H&S) of persons at work (Department of Labour, 2014).

Smallwood and Haupt (2007) pointed out that the Construction Regulations lay down important requirements concerning the duties of clients, designers, and contractors. For instance, clients have to prepare a suitable, sufficiently documented, and coherent project site-specific H&S specification for the intended construction work based on the baseline risk assessment. Also, work stoppages may occur regarding executing a construction activity, which poses a threat to the H&S of persons that is not following the H&S specifications and plan for the site (Department of Labour, 2014). The importance of safety through design and plan is emphatic in projects (Lingard & Rowlinson, 2005).

Despite the enforcement of the Construction Regulations 2014 in South Africa, the industry is still experiencing a high number of accidents. For instance, the Federated Employers Mutual (FEM) in 2018 reported that the South African construction industry recorded 8 384 accidents, of which 65 were deaths (Hlati, 2019). The causes of accidents leading to injuries and fatalities in the South African construction industry are reported to be rooted in lack of supervision and commitment by management and poor workmanship (Department of Labour, 2017). It is reported that the industry is hazardous and plagued by occupational risks and poor working conditions in which fatal and nonfatal work-related injuries occur frequently (Jabbari & Ghorbani, 2016).

At the construction site operational level, managers are expected to either reduce or prevent accidents. This is partly because managers' commitment to safety can be defined as the extent to which they place a high priority on safety and how effectively they communicate and act regarding safety issues (Tappura et al. 2017). Tappura et al. (2017) in their study underscore the criticality of the impact of safety awareness and challenges in the construction industry.

The objective of this paper is to report on the research question that investigated 'how contractors could improve construction using a safety instructor?' According to Reese and Eidson (2006), the responsibility of a safety manager is to implement practical and effective methods, both preventative and remedial, of promoting H&S and a safe environment in the workplace. The next section of this paper presents the literature review addressing safety issues and the role of an instructor in engendering improvement. Then the research method is presented before the research findings and discussion. Thereafter, the overall conclusion is presented.

Literature Review

The construction industry is one of the most dangerous sectors in the world accounting for a high percentage of occupational injuries and fatalities despite the establishment and application of OHS regulations (Awwad et al., 2016). The establishment of OHS regulations in South Africa is regulated by the Department of Labour through the Construction Regulations 2014 (Department of Labour, 2014). However, despite the adoption of the Construction Regulations 2014, the industry is still experiencing a high number of accidents (Hlati 2019).

The main causes of construction accidents have been identified and include factors such as human behaviour, difficulty worksite conditions, and poor safety management (Ahmed, 2013). Choudhry et al. (2008) highlighted that management commitment and involvement in safety is the most important factor for a satisfactory safety programme. It is further reported by Awwad et al. (2016) that the development of the safety programme in the industry is aimed at evaluating the safety practices and investigating the causes behind poor safety performance. The impact of poor safety performance is attributed to uncooperative clients, improper enforcement of regulations, and inadequate work procedures (Awwad et al. 2016). While high-quality safety performance increases corporate competitiveness, poor performance results in a bad corporate reputation leading to competitive disadvantage (Gao et al., 2018).

Mohammadi et al. (2018) also highlighted that the implementation of safety regulations and rules may improve the competence of workers in finishing their work but cannot guarantee that they will work safely because they probably might lack adequate awareness. One effective method used to modify safety awareness is safety training practice. The effectiveness of safety training practices is an important part of improving safety awareness of the workers (Demirkesen and Arditi, 2015). For example, the adoption of first aid training helps workers to be aware that their behaviour is an important factor in the avoidance of occupational injury and also appeared to reduce their willingness to accept prevailing levels of the safety risk on site. It is further reported that workers trained in the first aid training have also expressed a greater willingness to take personal responsibility for safety and a willingness to adopt safe behaviour (Lingard, 2002). The first aid training can have a positive effect on construction operatives' attitudes towards H&S practice (Lingard, 2017).

Choudhry et al. (2008) emphasized that implementing a safety management system (SMS) on construction sites is very important. It is important because poor safety management leads to accidents which cause loss of lives and project delays, and accident-related costs may be incurred (Lai et al., 2011). The implementation of the SMS underscores the need for a safety instructor that will promote both compliance-based and behaviour-based safety on site. The instructor will advise on a range of life saving issues to engender a safer working environment (Choudhry et al., 2008). Such an instructor will emphasise the notion that good safety practices and records create a positive, hazard-free, and productive work environment, and planning for safety at the front-end of a project is not only the first but also a fundamental step for managing safety (Zhang et al., 2013).

Li et al. (2015) further explained that safety instructors are responsible for providing workers with verbal feedback about behaviour-based safety on sites. Safety instructors must consider several issues when developing a comprehensive safety program (Gunter, 2007). For instance, the safety instructor must model appropriate safety strategies, and the safety planning should be a cooperative effort between safety instructors, workers and clients (Gunter, 2007). The objectives of designing an effective safety program as a means to prevent improper behaviour of people in construction that may lead to accidents, to ensure that problems are detected and reported, and to ensure that accidents are reported and handled accordingly by safety instructors (Aksorn and Hadikusumo, 2008).

Research Method

To answer the research question which asked, 'how contractors could improve construction using a safety instructor?' The data were collected from multiple case study projects in Bloemfontein, South Africa as highlighted in Table 1. The multiple case study projects were selected based on the nature of the projects (building projects), and accessibility to the sites. After consulting with respective gatekeepers in each project site, the researcher was given access to interact with the participants regarding the investigated phenomenon.

The data were collected through semi-structured and focus group interviews. The participants who were interviewed belong to the construction teams highlighted in Table 1. The selection of the interviewees was purposive as recommended by Maxwell (2013) and this is because the researcher aimed at interviewing the participants based on their life experiences and challenges on project sites. The use of semi-structured interviews implies that an interview protocol with open-ended questions was compiled before the actual data collection exercise. In broad terms, the open-ended questions cover:

- Why is it important to have a safety instructor on construction sites?
- Describe the appropriate safety training standard to be adopted on sites.
- How will you improve the behaviour of the workers through safety training?
- How do contractors continue to deliver projects according to clients' specification without violating the safety regulations?

The open-ended questions enriched the textual data, and its analysis. The focus group interview was used to interview groups of general workers and artisans in case project 1 and 3 as shown in Table 1. During the focus group interview sessions, the topic was introduced to the participants and the participants were asked to allow free expressions of opinions without interferences. The interviews were held during the lunch periods, and the duration ranged from 30 to 45 minutes. All the interview sessions were recorded using a cell phone and were later transcribed and responses that failed to answer the research questions were deleted. The qualitative data were thematically analysed and in total 39 interviews were conducted.

Table 1: Research sample

Case studies	**Interviewees**	**Response rate**	
		No	(%)
Project 1: **The construction of a new retail distribution warehouse project**	1 x construction manager 1 x safety manager 1 x site engineer 1 x senior foreman 1 x junior foreman 4 x a group of the artisans 9 x a group of general workers	18.0	46.0
Project 2: **The construction of a new university student housing residents-05**	1 x safety manager 1 x construction manager 1 x senior site engineer 1 x senior site quantity surveying 1 x senior foreman 1 x junior site engineer 1 x junior foreman 2 x student supervisor	9.0	23.0
Project 3: **The construction of a new university student housing residents-06**	1 x construction manager 1 x safety manager 1 x site engineer 1 x senior foreman 1 x junior foreman 7 x a group of the artisans	12.0	31.0
Total interviewees		39.0	100.0

Research Findings

The thematic analysis of the textual data from the multiple case study projects presented similar results. From all the three case studies, the interviewees were asked to respond to the interview questions based on the real-life challenges they were experiencing on their construction sites.

In response to the importance of having a safety instructor on construction sites, most of the interviewees noted that their organisations hired a safety management team, which is directed by a safety manager. The team designs an effective safety system to be adopted on their project sites. For instance, some of the interviewees say:

> *Our safety manager is not just responsible to design a safety system, they manage the safety operation on our construction sites, prepare safety training to our workers and are working with site managers to identify hazards and propose on how to prevent them (senior site foreman in case study project 3)*
>
> *It is the responsibility of our safety management team to design a safety training program, a risk assessment plan and safe work procedures to be adopted on our project sites (safety manager in case study project 2).*

It is further reported by an interviewee in case study project 2 that safety managers do not just teach workers to work safely but they also establish the safety regulations, which would govern the construction sites. The safety regulations are not just focusing on promoting safety in terms of hazard identification but are also promoting the health and well-being of the workers in terms of promoting a healthy working environment, which will not cause diseases to workers. There are reported cases on sites whereby some of the workers are forced to work in dangerous activities without using appropriate personal protective equipment (PPE). This statement is corroborated by a group of the general workers and artisans in case study project 1. The interviewees explained that safety managers should protect them from abusive supervisors who often tend to put their lives in danger due to the production target.

In response to describing the appropriate safety training standard, the interviewees reported that safety managers design a safety training programme, which highlights the organisation H&S policies. Such a programme will also embed learning on how to identify and prevent hazards. A safety manager in case study project 3 explained that in their organisation they have a safety training programme, which involves site management team only and this is because site management team must address OHS policy and related matters in the worksite. Also, a safety instructor should train workers and artisans how to work safely, how to operate tools and equipment safely, how to identify hazards, how to report safety risks and how to use appropriate PPE concerning the specific task.

In response to improving the behaviour of the workers through safety training, a construction manager in case study project 1 says that the desire to improve performance often leads to workers to work unsafely. This is because workers are put under pressure to deliver the project and they tend to focus more on productivity, and this often results in the lack of concentration and stress, which influences them to make errors causing accidents on sites. A site foreman in case study project 3 stated that it is important that the workers are taught on how to identify hazards and a behavioural change among co-workers to prevent accidents. A group of artisans in case study project 3 reported that the safety training programme, which they had helped them to understand the consequences of working under pressure. They explained that the safety instructions direct them not to push themselves to the limit trying to impress their superiors. The suggestion is that if they are extremely tired, they must request a break. A safety manager in case of study project 1 says that it is very critical that the operations of machines and equipment are handled by certified workers, this is because some of the workers have the tendency of using machines even when they do not know how to operate such machines and this might result in an accident.

In response to outlining how contractors continue to deliver projects according to clients' specification without violating the safety regulations, the interviewees flagged compliance mechanisms in their firms. For instance, an interview in case project 1 says that their OHS unit, which is led by a safety manager ensures their SMSs complies to Construction Regulations 2014. The SMSs provide a guideline on how to carry out a safety training programme, how to design a risk assessment plan, to implement safe work procedures (SWPs) and how to carry out safety inspections.

Discussion

The importance of having a safety instructor either as a manager or officer on a construction site is highlighted in the previous section. The participants explained that in their organisations, they have teams, which is led by a safety manager. Among other tasks, the team designs an effective SMS's for their project sites to prevent accidents. The perspective of the interviewees is consistent with the view that poor safety management that leads to accidents must be avoided (Lai et al., 2011). However, the effectiveness of SMS's depends on the design capabilities of the leader of the team, either a safety manager or safety officer. The central role of the safety manager in relation to the design of an effective SMS's is supported by Choudhry et al. (2008) who clarified that safety advisor/manager should advise on actions to be taken to ensure a safer working environment. For example, a senior site foreman in case study project 3 is quoted as saying:

> *Our safety manager is not just responsible to design a safety system, they manage the safety operations on our construction sites, prepare safety training to our workers and are working with site managers to identify hazards and propose on how to prevent them.*

In terms of having a safety training, it is reported by some interviewees that the purpose of having a safety training is to promote a safe working environment, which shows workers how to identify hazards and prevent risks from causing accidents. This statement regarding safety training is supported by Demirkesen and Arditi (2015) who pointed out that the effectiveness of safety training is a vital part of improving safety awareness among workers.

Conclusions

It can be concluded that the role of a safety instructor helps contractors to promote a safe working environment. The thematically analysed data from multiple case projects showed that the safety lead either in the form of a safety manager or safety officer on a construction site is saddled with the responsibility of designing appropriate SMSs that should assure the HSW of people in the worksite. The design of SMSs must also incorporate adequate training required to empower the workforce to deliver a project without harming anyone. The safety training has to be specific and fit for purpose as it promotes a safe working environment while the workers learn how to identify hazards and prevent them from causing accidents. Therefore, it is recommended that the role of the safety instructor should be prioritised by contractors. This is because the role makes significant contributions to the safe performance of activities in projects. However, the qualitative nature of the data presented in this paper necessitates further research that would determine the essential drivers of effective safety instructions and instructors in relation to project types and sizes. Such a study should go beyond qualitative analysis to understand patterns in data derived from onsite actors involved in construction safety.

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Development of the Human Safety Intervention Questionnaire on Construction Projects

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Abstract

Safety interventions targeted at strengthening safety climate are needed to improve safety behaviour and minimise accidents. This study describes the development of the human safety intervention questionnaire (HSIQ) to better the understanding of climate formation and related safety outcomes at the group level. A 12-item questionnaire was developed through literature search and the use of experts. The questionnaire adopts the referent-shift approach for data aggregation. Data were obtained from 317 trade workers in large construction projects. Reliability and correlation analysis revealed high Cronbach alpha and a reasonable level of correlation among the twelve items respectively. Exploratory factor analysis (EFA) extracted two factors: namely sociological safety interventions and psychological safety interventions. Both interventions offer opportunities for cross-fertilisation by considering contextual and structural constraints associated with a unidimensional view when offering insights on safety events. The EFA also demonstrates good construct and face validity. The HSIQ provides a means of investigating safety intervention strategies. The paper concludes with a discussion and potential uses of the HSIQ.

Keywords: human safety interventions, safety climate, questionnaire, factor analysis, construction.

Introduction

The construction industry continues to be a high-risk industry irrespective of significant advancements. For instance, in Australia, the number of fatalities and serious claims over the last 10 years continue to be relatively high (Safe Work Australia, 2018). A capable means to suppress accident rates and improve hazard management is to enhance the social and organisational factors that influence occupational health and safety (OHS) (Scott, Fleming and Kelloway, 2014). This has urged researchers and practitioners to focus on organisational and social factors, including safety climate, to encourage positive change to the industry's poor OHS performance (Lingard, Cooke and Blismas, 2010). Safety climate is "the workers' perceptions or the organisation's policies, procedures, and practices as they relate to the value, importance, and actual priority of safety within the organisation" (Huang, Chen and Grosch, 2010, p. 1421). Focus on safety climate minimises the number of occupational accidents, improves employee motivation to behave safely, and reduces compensation costs (Loosemore *et al.*, 2019). According to the social exchange theory, when individuals perceive that their organisation values their welfare, they will cultivate an inherent commitment to give back by performing behaviours that benefit their organisation (Neal and Griffin, 2006). Organisations can thus, form an atmosphere that promotes safety performance by prioritising workers (Mearns *et al.*, 2010).

While considerable research has sought to study the influence of safety climate on safety performance and outcomes, few studies have investigated how climate perceptions are formed in construction. Put simply, what predicts safety climate in construction? The few studies investigating into climate formation in construction identified communication network density (Lingard, Pirzadeh and Oswald, 2019), psychological contract (Newaz *et al.*, 2019a), and social identity (Andersen *et al.*, 2018) as antecedents of safety climate. In this regard, how employees cognitions are developed remains less understood (Newaz *et al.*, 2019a; Lingard, Pirzadeh and Oswald, 2019). Owing to this, empirical findings from a recent longitudinal study (data ranging from 2001 to 2013) give partial support to the notion of utilising safety climate as a predictor of future safety outcomes (cf. Gilberg *et al.*, 2015). Likewise, contrary to the majority of literature, studies such as Glendon and Litherland (2001) in the construction industry revealed no relationship between safety climate and safety behaviour. Further, meta-analytic evidence by Clarke (2006) found a weak correlation between safety climate and safety outcomes such as accidents and injuries. As such, the climate-behaviour-accident route is not as straightforward as usually presumed (Cooper and Phillips, 2004).

Given these, Zohar (2014) comments that it time to proceed to the subsequent chapter of research where safety climate concepts are improved by examining its association with antecedents, moderators, and mediators, and in addition to its link with additionally established constructs. Similar calls had earlier been made on behavioural safety research by Krispin and Hantula (1996). There is a need to institute interventions that adjust the value utility for safety behaviour (Zohar and Erev, 2007). However, no suitable research has been recognised in terms of interventions to better safety climate (Huang, Chen and Grosch, 2010). There is, therefore, a dearth of safety climate studies testing intervention strategies intended to improve safety climate (Zohar, 2014). In consequence, there has been a call for research into identifying interventions which aim at augmenting safety climate (Huang, Chen and Grosch, 2010), as a means to ameliorate the link between safety climate and safety behaviour (Boateng, Davis and Pillay, 2020). As such, the formation of a positive safety climate involves effort and safety-related interventions (Cheung and Zhang, 2020).

Human Safety Interventions

Human safety interventions (HSIs) denote methods to change human understanding and reasoning concerning safety practices that directly impact the employees (Shakioye and Haight, 2010; Zaira and Hadikusumo, 2017). This intervention is relevant for industries where there are diverse cultures and decision making is often made under risk and uncertainty. For example, an emblematic attribute of the construction industry is the inevitable cultural diversity among the workforce (Loosemore *et al.*, 2010). Likewise, there is a growing recognition that construction workers' behaviour towards safety is influenced by their perception of risk (Mohamed, Ali and Tam, 2009). As argued by Boateng, Davis and Pillay (2020), human safety interventions are suitable to mould workers perceptions about safety priority in construction organisations.

Zaira and Hadikusumo (2017) identified 15 practices of HSIs and developed a preliminary questionnaire. Items in their questionnaire were rated using a three-point Likert scale and then validated in the Malaysian construction industry, leading to an 11-item questionnaire for the construct. However, some key improvements could be added to the questionnaire to ensure high explanatory and predictive power. Owing to reasons such as modification of measurement instrument to align with particular features of the industry (Zhang, Lingard and Nevin, 2015), for instance, from an agent's point of view (Meliá *et al.*, 2008). Moreover, the type of Likert scale, institutional and cultural contexts could influence the size of the sieve-holes through which an item is maintained or removed. Furthermore, the rendering of Zaira and Hadikusumo (2017) questionnaire items do not show the directional impact of the worded questions as they are not in sentences. This scenario could lead to potential biases as workers may distinctively perceive different meanings of what is expected from them as questionnaire respondents. Given these, Zhang, Lingard and Nevin (2015) recommend that considering the comparatively lower education level of construction workers and cognitively tedious efforts required, survey instruments developed within construction should eliminate negatively worded questions to ensure reliable and valid responses. Following this, improved Cronbach's alpha coefficients were attained when the researchers (i.e. Zhang, Lingard and Nevin, 2015) deleted negatively word sentences. As such, this paper places Zaira and Hadikusumo (2017) questionnaire items into positively worded sentences. On the other hand, double or multiple-barrelled questions in one question are streamlined to eliminate ambiguity by forming a "one-question, one-idea" sentence. This paper thus develops and validates the HSI tool in the Australian context using a five-point Likert scale while considering the co-workers' agent point of view.

Considering the call for research into testing safety climate with safety interventions (cf. Zohar, 2014), it is projected that further research is geared towards this cross-pollination among these and other established constructs. In line with these discussions, it is of utmost significance that, detailed surveys are required to be developed, then administered occasionally to detect contemporary experiences with safety implementations (Wirth and Sigurdsson, 2008).

Methodology

The 11-items identified by Zaira and Hadikusumo (2017) are "behavioural-based safety programme", "safety training", "safety inductions for new workers", "safety awards, safety promotion, safety incentives", "safety supervision", "safety awareness programme, safety campaigns, safety knowledge programme, safety education", "safety information, safety bulletin boards", "requisite safety expertise for high-risk operations", "job hazard analysis, job safety analysis", "daily tailgate, toolbox meeting", and "penalty, accident repeater punishment programme". Full details of the sources of these items can be found in the extensive review by Zaira and Hadikusumo (2017). A pilot study was then conducted with a group of experts, which consisted of a statistician, construction and safety academics to ensure content and face validity. The items were measured on a five-point Likert scale ranging from 1=strongly disagree to 5=strongly agree. Feedbacks from the experts resulted in restructuring of the items in terms of their clarity, framing, theoretical considerations, and suitability for the construction industry. Also, standalone phrases/terminologies were placed in sentences to indicate their directional impact. Overlapping content and multiple-barrelled questions such as "safety awareness program, safety campaigns, safety knowledge program, safety education" were streamlined to eliminate ambiguity. The item "penalty, accident repeater punishment programme" was deleted because of its inapplicability and inappropriateness for the Australian construction industry. After incorporating the feedbacks, twelve questions (see Table 1) were developed from the initial 11-items. All twelve questions were retained after review by the experts.

In the main study, each question was displayed on-screen and the participants responded by clicking on their answers using an audience response system. The survey took place during toolbox meetings. Respondents were asked to indicate how well their co-workers are provided with the following safety intervention practices by their employer using the 5-point Likert scale (1=strongly disagree to 5=strongly agree). Thus, this study adopts the referent shift approach to shift the referent from the self to the collective before consensus evaluation (Chan, 1998). This composition model encourages employees to report on cognitions agreed upon in the organisation as well as its subunits. The use of self-report data or direct-consensus approach could result in common method variance (Andersen *et al.*, 2018) and construct validity issues. Several limitations associated with self-reports have also been expressed by numerous safety researchers (e.g. Newaz *et al.*, 2019b; Andersen *et al.*, 2018).

The participants in this study were 317 trade workers from five large commercial construction project sites in New South Wales. Overall, 297 valid responses were used for the analyses after data cleaning. 77.1% were males, 0% were females, and 22.9% selected the "not applicable" option. In terms of their trades, 21.5% were labourers, 16.2% were electrical and mechanical workers, 4% were roofers, 2% were metal workers, 2% were welders/boilermakers, 18.2% were carpenters/form workers, 7.7% were plumbers, 6.1% were scaffolders, 2% were dogmen, and 20.2% were plant/equipment operators. There were no participants with the remaining nine listed trades. 30% of the respondents had less than 5 years of experience in the construction industry, 26.3% had 5-10 years, 6.1% had 11-15 years, 8.4% had 16-20 years, and 29.3% had more than 20 years of experience. 64.3% were full-time workers while 35.7% were part-time. Missing data below the 5% criterion (Schafer, 1999) were replaced using the multivariate imputation by chained equations (MICE) technique. MICE is known to give reasonable replacements than other methods (Buuren and Groothuis-Oudshoorn, 2010). Reliability analysis, correlation analysis, and exploratory factor analysis (EFA) were performed on the data using the IBM SPSS v25 software. This study further satisfies the "N:q hypothesis" (Jackson, 2003), hence confirms the required number of samples as preferable. The data was collected in accordance with approved Ethics application, H-2018-0462.

Results

Various assumptions are fulfilled before using factor analysis. For normality test, the ±2.2 guideline for skewness and kurtosis (Sposito, Hand and Skarpness, 1983) is employed. In this study, skewness coefficients of all items ranged between -0.306 to 0.679, and -1.752 to -0.498 for kurtosis, suggesting a normally distributed data. Next, we check for the correlative adequacy among the items to avoid multicollinearity issues. Bivariate correlations higher than 0.85 signals potential problems (Kline, 2005). In Table 1, all correlations are below the 0.85 threshold. The Cronbach's alpha was used to measure the internal consistency reliability across all items. Cronbach's alpha if item deleted ranged from 0.876 to 0.885, while the overall coefficient was 0.889, implying that responses are consistent (Kline, 2016), hence all items remained intact.

Table 1. Correlations among variables

Factor	HSI_1	HSI_2	HSI_3	HSI_4	HSI_5	HSI_6	HSI_7	HSI_8	HSI_9	HSI_10	HSI_11	HSI_12
HSI_1	1											
HSI_2	.556**	1										
HSI_3	.618**	.604**	1									
HSI_4	.466**	.451**	.686**	1								
HSI_5	.541**	.459**	.596**	.674**	1							
HSI_6	.318**	.263**	.305**	.370**	.315**	1						
HSI_7	0.087	.142*	.204**	.363**	.242**	.633**	1					
HSI_8	.299**	.284**	.444**	.353**	.343**	.528**	.544**	1				
HSI_9	.319**	.309**	.437**	.356**	.368**	.444**	.372**	.528**	1			
HSI_10	.345**	.442**	.378**	.386**	.306**	.467**	.432**	.466**	.575**	1		
HSI_11	.222**	.353**	.337**	.310**	.393**	.562**	.456**	.603**	.460**	.429**	1	
HSI_12	.282**	.197**	.274**	.228**	.267**	.407**	.342**	.420**	.478**	.386**	.432**	1

Exploratory Factor Analysis

EFA was performed using maximum likelihood as the extraction method with promax rotation to identify the underlying structures among the observed variables. As far as the adequacy of the sample size for assessing the measurement model is concerned, the Kaiser-Meyer-Olkin measure of 0.853 sample adequacy indicates that the number of responses (n = 297) is meritorious for model assessment (Kaiser and Rice, 1974). The Bartlett's Test of Sphericity compares the correlation matrix to an identity matrix. The test was significant ($p = 0.00$). The unforced extraction revealed two factors explaining 52.29% of the total variance, which is higher than the 50% criterion. For discriminant validity, the factor correlation matrix yielded a coefficient of 0.561, which is less than the 0.85 threshold, hence the two factors are not highly correlated. Also, deviations between cross-loadings differ significantly. For convergent validity, all factor loadings were greater than the 0.5 rule of thumb (Hair *et al.*, 1995). The factors and associated items also demonstrate sufficient face validity. The two factors are named HSI1 and HSI2. HSI1 comprises of HSI_6 to HSI_12, and HSI2 contains HSI_1 to HSI_5. The EFA results confirm the validity of the theoretical considerations for developing the questionnaire items.

Table 2. Pattern Matrix

Factor	Items	HSI1	HS12
HSI_1	My co-workers are provided with adequate safety training for their job	-0.071	0.754
HSI_2	Toolbox meetings are frequently organised for my co-workers to attend	-0.010	0.690
HSI_3	My new co-workers are given safety inductions before commencing work	-0.039	0.893
HSI_4	My co-workers are encouraged to get involved in safety campaigns	0.086	0.709
HSI_5	My co-workers are always involved in job hazard analysis for specific tasks	0.055	0.700
HSI_6	My co-workers have easy access to safety information	0.791	-0.047
HSI_7	My co-workers are given adequate safety supervision on site	0.831	-0.199
HSI_8	My co-workers are provided with safety awareness programs	0.711	0.076
HSI_9	My co-workers are provided with workplace programs designed to influence their actions toward maintaining safe workplace	0.546	0.190
HSI_10	My co-workers are offered safety incentives (e.g. safety awards) for working safely	0.540	0.181
HSI_11	My co-workers have easy access to safety bulletin boards	0.704	0.026
HSI_12	My co-workers have the requisite safety certification for undertaking high-risk activities	0.540	0.036

Discussion and Conclusion

This study described the development of a human safety intervention questionnaire (HSIQ) to evaluate safety practice implementations at the group level. The questionnaire appears to be psychometrically sound with good fit and validity. It follows a more robust aggregation strategy, thus the referent-shift approach, which is also well-aligned with the multilevel model of analysis. The validated questionnaire comprises of two factors: psychological safety interventions (HSI1). sociological safety interventions (HSI2). Though distinct, we expect an interplay between the psychological safety interventions and sociological safety interventions, particularly because of their mutuality in explaining various phenomena (Thoits, 1995). This could be a reason for the fairly strong intersection between the two factors shown by the factor correlation matrix coefficient. This interplay between the factors is important as it offers opportunities for cross-fertilisation by considering contextual and structural constraints associated with a unidimensional view when offering insights on safety events. On this background, the factors should be specified as reflective-reflective constructs. With reflective-reflective constructs, there is possibility of item substitution, good positive correlation, similar indicator antecedents and consequences, and a unidimensional nature (Bollen and Lennox, 1991; Jarvis, MacKenzie and Podsakoff, 2003). As such, reflective indicator loadings, convergent and discriminant validity, as well as reliability and internal consistency should be considered when testing the constructs (Xiong, Skitmore and Xia, 2015; Hair *et al.*, 2019).

We define sociological safety interventions as safety practices that improve workers knowledge and reasoning concerning safety through social-related activities at work. This construct follows the sociological theory of industrial accidents positing that "industrial accidents are produced by social relations of work" (Dwyer and Raftery, 1991). According to this perspective, greater integration of workers concerning safety issues could be expected to minimise accidents. For example, when management initiates safety campaigns, it informs workers about the primacy of safety over other competing company goals, and hence workers feel valued and appreciated (Törner, 2011). These activities encourage social ties and friendships and hence needs to be regarded as highly influential on performance outcomes (Zohar and Tenne-Gazit, 2008). The development of friendships, social and emotional ties between crew members will increase the degree to which co-workers develop considerate and responsible attitudes toward each other (Burt, Sepie and McFadden, 2008). A supportive environment is therefore the most important factor in influencing workers' safety attitude (Mohammadfam *et al.*, 2017). Similarly, to boost workers safety attitude, it is recommended that their participation in safety-related activities such as hazard analysis should be promoted (Mohammadfam *et al.*, 2017). The sociological safety interventions therefore follow the view that, safety events that offer opportunities for social interactions exert greater influence on socially proximal individuals (see Erickson, 1988). These interactions have been found to predict group safety climate (Zohar and Tenne-Gazit, 2008).

On the other hand, psychological safety interventions suggest methods to alter workers perceptions of risks and safety practices. This construct is guided by learning behaviour and social exchange theory. Consistent with the social exchange theory, when an organisation is thought to fulfil their duties, care for workers fairly, and offer valued services and benefits, workers reciprocate with higher levels of commitment and performance (Mearns *et al.*, 2010). As such, social externalities impact others as an effect of the decision of the decision maker (Zohar and Erev, 2007). Fundamentally, psychological safety interventions target the reduction of interpersonal risks in times of uncertainty and change (Schein and Bennis, 1965). We contend, in contrast, that unlike psychological safety climate which forms at the individual level, psychological safety interventions is a group-level construct. For the reason that distinct from other industries, the nature of the construction industry warrants daily possibilities for social interaction with co-workers (Zohar *et al.*, 2014; Helen, Cooke and Blismas, 2010), hence psychological safety interventions thrive within the construction industry, where workers are in physical and social proximities. As such, workers who work closely together tend to have similar perceptions of psychological safety due to shared experiences and identical contextual influences (Edmondson, Kramer and Cook, 2004). Besides, the aggregation model employed in this study connotes a shared perceptual view about human safety interventions. The workgroup/co-workers are therefore the most proximal and prominent social unit in the organisation (Ashforth, 1985). As reasoned by Schein (1993), "with psychological safety, individuals are free to focus on collective goals and problem prevention rather than on self-protection" (Edmondson and Lei, 2014, p. 25). In view of these, the psychological safety interventions could modify the value function of safety behaviour. Such interventions have been known to reduce the perceived costs associated with working safely (Zohar and Erev, 2007). For example, the use of publicly displayed safety bulletin boards depicting performance feedbacks were found to improve safety performance (Lingard and Rowlinson, 1997). Likewise, the introduction of frequent short-term incentives counteract the tendency to underweight the long-term benefits of safe conduct (Zohar and Erev, 2007, p. 132).

Similar to numerous construction studies (e.g. Zhang, Lingard and Nevin, 2015; Zohar, 1980), the questionnaire validated at the EFA could be deemed reliable and valid for monitoring and diagnoses of potential weaknesses of safety practices. For comparative analysis and global validity, we recommend further validation in other industrial and organisational settings, as well as with other advanced tools such as confirmatory factor analysis. Considering the call to proceed into the next phase of safety climate research, the HSIQ validated in this study could be examined with other established constructs as mediators, moderators, and antecedents to form a route to cultivating desired behaviours.

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A Conceptualisation of the effect of Resilience on Safety in Construction Refurbishment Projects

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Abstract

Purpose: The advance of resilience as a safety approach has contributed to improved safety performance in complex work systems. Although, passive forms of safety behaviour are more than appropriate for managing known risks, proactivity is crucial in achieving enhanced safety outcomes. This is particular to uncertain work environments such as building refurbishment projects, which is the focus of this research. Presently it remains unclear how a resilient work environment can achieve improved safety performance where latent conditions manifest in refurbishment projects. This study aims to conceptualise the role of a resilient work environment to help achieve better safety performance in building refurbishment projects.

Design: An extensive review of the literature related to resilience engineering theory and project uncertainty was undertaken. The review helped conceptualise the relationship between the constructs of project uncertainty, resilient work environment and safety performance.

Findings: The research provides a conceptual model which helps to explain the moderating effect of a resilient work environment, comparing project uncertainty and safety performance in building refurbishment projects. The conceptual model also proposes hypotheses relating to the effect of project uncertainty and resilient work environment on safety performance.

Limitations: A broad range of indicators for assessing these notions are available, for focus, the study has selected to use the indicators that are integral to the cultural and managerial perspective of resilience.

Originality and practical implications: The model would help to provide a theoretical basis for creating a resilient work environment in order to achieve more consistent levels of high safety performance despite uncertainty in building refurbishment projects. Therefore, the findings will assist construction organisations to facilitate and maximise safety outcomes through successfully engineering resilience in their projects.

Key words: Building refurbishment, Construction safety, Resilience, Safety performance

Introduction

The global construction industry is anticipated to show enormous growth by 85% to $15.5 trillion by 2030 (Loosemore, 2017). The building construction industry mainly constitutes new construction and refurbishment of existing built assets (Hon et al., 2012). Recently, refurbishment has gained more attention than new construction as they are financially, economically and socially beneficial (Ali et al., 2018). This study defines building refurbishment as a major change carried out to an existing building which includes retrofit, major improvements, adaptation, major repair, major renovation, upgrading, or conversion, but excludes routine repair and maintenance work (Ranasinghe et al., 2019).

The main challenge of refurbishment as opposed to new construction are the inherent factors of project uncertainty and complexity (Ishak et al., 2018). Many studies argued that building refurbishment is a safety-critical projects due to inherent uncertainty along with other project risk factors. Safety has been a major concern in construction management research over several decades, however it is but somewhat under-explored in building refurbishment (Chen et al., 2017b; Danso et al., 2015; Hon & Liu, 2016). Despite this, there are several studies that argued the importance of safety management in refurbishment projects due to safety risks associated with uncertainty; complexity; unforeseen contingencies and other high risk activities engaged with structural modifications and obstructive building services, see (Egbu et al., 2002; Hon et al., 2011b; Rakhshanifar et al., 2015). In line with the nature of refurbishment projects researchers have identified several project uncertainty factors that potentially affect project safety outcomes such as unavailability of information, regular changes in design, and lack of space (Noori et al., 2016b). To address these issues and improve safety performance, researchers have suggested several safety management strategies such as policies, safety audits, safety training programs (Hon et al., 2011a); risk management strategies (Gottfried, 2004); technical advances such as decision support systems (Kashyap et al., 2005); and behavioural approaches, safety climate (Hon et al., 2012; Nadhim et al., 2016). Despite this, safety performance in building refurbishment projects still warrants significant improvement.

An uncertain work environment demands a new perspective of safety in order to respond to unexpected events, more than simply preventing accidents (Patterson & Deutsch, 2015). The effectiveness of traditional safety approaches have been limited by the nature of uncertainty as they largely developed based on fixed and static environment (Wachter & Yorio, 2014). Noteworthy in project environments there is constant change. Therefore, it is increasingly important to discover effective safety management strategies for the building refurbishment sector to improve safety performance (Hon et al., 2011a). Fink (2016) has emphasized the applicability of a control approach such as Resilience Engineering (RE) rather than eliminating uncertainty from the system. Similarly, Saurin et al. (2013) described a “resilience work environment” as a more flexible and suitable approach for managing uncertainty in building refurbishment projects. Contrary to conventional approaches to safety management, RE is a promising approach to maintain natural operational conditions in unexpected circumstances (Bellamy et al., 2018). From the perspective of resilience, people individually or collectively adjust their performance to match the conditions of work (Hollnagel, 2014b).

Resilience enhances the capacity of an entire organisational as a system to create a robust process by way of revising risk models and utilizing resources efficiently (Azadeh et al., 2014a). It is the basis of managing risk in an incompletely described and underspecified systems (Hollnagel, 2017). Therefore, resilience offers an interesting lens to manage safety performance under uncertainty in building refurbishment projects. Whilst researchers identified RE as a more feasible and suitable approach for managing uncertainty in building refurbishment projects (Saurin et al., 2013), the role of a ‘resilient work environment’ in managing project uncertainty and safety is yet to be conceptualized when specifically applied to building refurbishment project. A clear understanding of the way resilience and project uncertainty influences safety would help modify to modify the safety management system that creates a safe work environment for the building refurbishment workers. Thus, this study proposes a conceptual model taking in account the role of a resilient work environment and the impact of project uncertainty on project safety performance. The proposed conceptual model enables a comprehensive assessment of project uncertainty and resilient environment that helps a project manager grasp the dynamic nature of their project. They become better prepare for surprises as the project progresses and consequently enabled in the management of uncertainty to deliver a safer project.

Key Constructs

Resilient Work Environment

The concept of resilience originated in the early 1980s in cognitive system theory (Schafer et al., 2009). From its inception, resilience was inspired by various disciplines from different perspectives including ecology, psychology, sociology, engineering and management science (Bellamy et al., 2018). Recently, there has been a dramatic shift in resilience studies which focused on the perspective of safety (Bergstrom et al., 2015). The literature reveals that there is a lack of consensus regarding a definition of resilience. The term 'resilience' is defined as an ability to recover after something unpleasant such as injury or ability to return to original shape after it has been changed from original (bent, stretch or pressed). More specifically, several definitions reflect that resilience implies an ability/capability to adapt or absorb disturbances and changes (Bergström et al., 2015), sustain control over a system (organisation, society or ecosystem), and have the ability to foresight risks before any adverse consequences happen (Woods, 2017). However, the key notion of resilience is to adjust performance prior to, during or after any crisis (Hollnagel et al., 2007). Opposed to traditional safety management approaches that look for system disruptions, resilience focuses on success that helps avoid adverse events (Hollnagel, 2011). Adopting this view, the major concern of RE is to create a resilient system (Shirali et al., 2016). RE helps develop practical implications and principles in order to create a resilience work environment (Hollnagel, 2014c). RE is concerned with the normal functions of a system rather than looking for incidents (Azadeh et al., 2014a) and safety is achieved by concentrating on performance (Hollnagel, 2008).Therefore, RE articulate all the indicators and activities that would help to develop system resilience (Steen & Aven, 2011). RE falls under Safety-II which encompasses how people adjust and perform in both expected and unexpected circumstances (Hollnagel, 2014a).

There are four main cornerstones of RE anticipating, learning, monitoring and responding which help to identify resilience indicators for systems (Patriarca et al., 2018) and how systems stretch to respond to surprises (Woods et al., 2014). Costella et al. (2009) have conceptualised the concept of RE at individual, group and organization level. Therefore, it is a collective effort of everyone whether in a work group or an organisation to motivate their colleagues/employees to react and avoid blindly following rules in unforeseen circumstances (Adolph et al., 2012). This suggests that complex safety systems should focus on strategic development of a resilient work environment as part of OHS management. RE harmonizes the terms "performance" and "safety" rather creating contradiction (Shirali et al., 2016). Similarly, Wehbe et al. (2016) have argued that, RE should be a strong predictor for improved safety performance with fewer safety incidents. This is because RE models incite managers to impose proactive safety management strategies that reduce the risk related to system operation (Niskanen, 2018). A number of researchers have argued the scope of RE in managing safety in high risk industries such as construction (Chen, 2017; Chen et al., 2017a; Saurin et al., 2014; Wehbe et al., 2016), including the category of building refurbishment (Saurin et al., 2013). Therefore, this provides an opportunity to examine the influence of resilience on safety performance of building refurbishment projects.

Project Uncertainty

Whilst existing literature is rich in risk identification and management in building refurbishment projects, there have been few studies on project uncertainty factors and their influence on performance. Thus, uncertainty factors are often considered as the major reason for the unsatisfactory performance in building refurbishment work (Nibbelink et al., 2017). Researchers have unveiled uncertainty factors, and their influences on cost and time (Ali, 2009), quality (Yacob et al., 2017) and design performance (Ali et al., 2005; Ali et al., 2009). There is a paucity of literature that investigates project uncertainty from a safety perspective (Ranasinghe et al., 2019). Uncertainty refers "a subject's conscious lack of knowledge about an object, which is not yet clearly defined (or known), in a context requiring a decision" (Hassanzadeh et al., 2011, p. 663). In general, many construction projects lack important information at the beginning and this increases project uncertainty at a project's inception phase (Winch, 2009). Contrasting new construction, building refurbishment projects are more difficult to control due to inherent uncertainty factors associated with an existing structure (Noori et al., 2016a). Therefore, unlike new construction, project uncertainty continues throughout the project life cycle (Yacob et al., 2018). Thus, uncertainty ensures building refurbishment projects are less amenable to determined outcomes and actions (Rahmat & Ali, 2010) and they risks into the project (Burnard & Bhamra, 2011). Safety issues may increase disproportionately in refurbishment sites compared to a new build (Reyers & Mansfield, 2001). During refurbishment project, workers are required to put in extra effort into decision making beyond new build procedures to ensure project safety in response to unexpected events (Saurin et al., 2013). Unanticipated discoveries related to characteristics of existing buildings demand change in planned work which potentially leads to increased workforce numbers and equipment required to ensure the safety and quality of work (Saurin et al., 2013). Project uncertainty cannot be completely eliminated from the system, but only managed to a certain extent (Perminova et al., 2008; Saunders et al., 2013). In the context of safety, effectiveness of traditional safety approaches have been limited by the nature of uncertainty as they largely focused on prevention and protection (Wachter & Yorio, 2014). Saurin et al. (2013) emphasised the need for a resilient work environment in building refurbishment projects to enhance successful project delivery.

Safety Performance

Safety performance can be defined as "actions or behaviours that individuals exhibit in almost all jobs to promote the health and safety of workers, clients, the public, and the environment"(Burke et al., 2002b, p. 432). Safety performance is one particular type of measurement used to evaluate general work performance (Xia et al., 2018) which encompasses promoting safety among the workers (Abuashour & Hassan, 2019). It is a measurement used to ascertain the safety level of work systems with regards to accidents, fatalities and injuries or tendency of incident (Abuashour & Hassan, 2019). Researchers have used occupational injuries, the rate of accidents as measurements for safety performance (Ghosh & Young-Corbett, 2009). As a result its reactive nature the positive aspects of safety are not emphasized, accordingly, researchers have moved towards more proactive safety measures (Ghosh & Young-Corbett, 2009). For example, safety-associated behaviour is considered as a proactive safety measurement for assessing the safety performance in workplace activities (Cooper & Phillips, 2004). These performance measurements are focused on success scenarios rather than failures (Cooper & Phillips, 2004). Safety associated behaviour is evaluated by using a model which measures the employee engagement in safety related behaviour (Burke et al., 2002a). Safety performance is highly affected by the workers who are following correct preventive strategies and actively improve working conditions (Fernández-Muñiz et al., 2007). Therefore, both accident indicators and human factor elements contribute to established safety performance in organizations (Abuashour & Hassan, 2019). Thus, safety outcomes related to accidents and near misses remain as effective safety performance measures depending on their context (Nadhim et al., 2016). Succinctly, both the reactive and proactive nature of safety performance is vital in assessing organization safety performance.

Conceptual Model Development

The conceptual model and research hypotheses were developed based on the literature review to identify the role of RE in refurbishment project. Therefore, indicators for conceptualising a resilient work environment and determinants of project uncertainty pertaining to building refurbishment projects were identified in this section. This was followed by the development of relationships between the three main constructs identified (RE, project uncertainty and safety performance) and the hypotheses underpinning the relationships. Finally, the conceptual model is presented.

Indicators of Resilient work environment

One of the key aspects of safety management is to measure performance through indicators and audits (Righi et al., 2015). RE indicators can provide a guideline for managing safety in the work environment and are a helpful analytical tool. By their nature, key features of RE indicators are closer to the leading indicators taken to prevent accidents/dangerous events (Rubio-Romero et al., 2018). Determining appropriate indicators of RE for a building refurbishment project is critical. There is no common understanding of RE dimensions identified in prior research. RE dimensions can provide a parameter for managing safety in work systems and are a helpful analytical tool, and by their nature, key features of RE dimensions are similar to the proactive measures taken to prevent accidents/incidents (Rubio-Romero et al., 2018). Top management commitment, learning culture, anticipation, awareness, and flexibility are widely recognised dimensions of RE (Azadeh et al., 2017; Pillay et al., 2010; Shirali et al., 2018). However, each of the dimensions has its special identity in different applications to industry and researchers are able to alter the dimensions to match with specific industry in favour of better evaluation of performance (Azadeh et al., 2014b). Reviewing dimensions of RE utilised in a high-risk environment demonstrated that preparedness, awareness and flexibility are the most highlighted dimensions in petrochemical plant, whilst the factors of redundancy and teamwork remain insignificant (Azadeh et al., 2014a). Similarly, anticipation and preparedness are the most significant factors in rail engineering planning (Chen et al., 2018). Azadeh et al. (2014b) introduced an “integrated resilience engineering” framework for effective work processes with four new RE dimensions (i.e. teamwork, redundancy, fault-tolerant, and self-organisation). However, there is a scarcity of RE studies in the construction industry. It is worth focusing on tacit or abstract dimensions such as management commitment, and learning in this introductory stage. Ranasinghe et al. (2020) have conducted a comprehensive literature review on indicators of RE with a particular focusing on identifying RE indicators for the construction refurbishment sector. Accordingly, top-management commitment, awareness, learning and flexibility can be used to assess the “resilient work environment” in building refurbishment project.

Determinants of Project Uncertainty

Identifying project uncertainty at an early phase would give project managers a broader understanding of uncertainty (Yacob et al., 2017). In the literature relating to project uncertainty, a number of researchers have articulated different determinants of uncertainty. These determinants are listed in different perspectives/categories for research purposes. For instance, in the context of a safety-critical civil nuclear and aerospace organisations Saunders et al. (2015), classified uncertainty into environmental, individual, complexity, information, temporal and capability categories. Complexity, information, knowledge/experience, individual manifestation, supplier organisation and project organisation are other classifications provided by Perminova (2011). Cleden (2017) has identified four categories of uncertainty, namely, uncertain information, uncertain understanding, uncertain temporal and uncertain complexity. It is apparent that not only project information and project complexity due to complications on existing buildings can determine project uncertainty but also individual/project team capability in understanding and responding in a timely way is an important aspect in determining project uncertainty. The determinants of project uncertainty may be captured under the aforementioned classification. Therefore, this study used the classification of Cleden (2017) on project uncertainty (information, understanding, temporal and complexity) which covers the broad aspects of determinants of project uncertainty from different perspectives and throughout the project life cycle.

Relationships Among Resilience, Project Uncertainty, and Safety Performance

Project uncertainty is associated with unanticipated outcomes and it has a connection to accidents (Ramasesh & Browning, 2014). Socio–technical systems define the variance as unplanned events that critically influencing the performance (Cherns, 1976). The review of project uncertainty indicates four determinants that can be used to measure the project uncertainty, namely uncertain information, uncertain understanding, uncertain temporal and uncertain complexity. In practice, it may be difficult to progress work as that planned and outlined at the design stage in building refurbishment projects due to high uncertainty. This is consequent to important information being unavailable at the execution, in unforeseen discoveries at a later stage, or construction carried out in the operational working environment etc. This Inherent complex nature makes construction projects more vulnerable to uncertainty that influence the construction safety (Saurin et al., 2019).Therefore, the following hypothesis is proposed:

> H1 – Project uncertainty has a negative influence on the safety performance of building refurbishment projects.

In an intractable system, restricting human performance variability may result in poor safety performance (Zarrin & Azadeh, 2019). This is consistent with the notion of resilience which welcome the variability as a basis of preventing failures. RE is developing and provides tools to ensure an organisation is achieving the required level of safety proactively (Wreathall, 2017). In relation to this, the present study identified and elaborate the proactive indicators of RE (top management commitment, learning, flexibility and awareness) to create a resilient work environment in building refurbishment projects. These indicators from the lens of resilience potentially contribute to enhanced safety performance. For instance, the ability of workers making decisions based on their own experience is challenged during refurbishment. Workers are required to make trade-offs between production and safety, work beyond the procedures and rules to ensure the safety in their work environment, often have to be made. This highlights the necessity of management support and flexibility in the workplace. Therefore, the following hypothesis is proposed.

H2 – Resilience at the workplace has a positive influence on the safety performance of building refurbishment projects.

In the notion of RE, accidents happen not because of the system failing to deal with risks, but due to the failure of the system which does not adapt and respond to system complexity (Woods et al., 2017). It is apparent that these unforeseen safety risk cannot be eliminated from the system and what is possible is the adjustments of work practices to minimize the effect of uncertainty risk. The importance of adaptation rather than eliminating project uncertainty is one of key aims of resilience engineering. Blay et al. (2014) have suggest resilience at the workplace is a capability which enables organizations to moderate the effects of risk and uncertainty and take advantage of emergent opportunities. Resilience is the ability to overcome the adverse effect allied with risk exposure (Wisniewski et al., 2015). For instance, the influence of project uncertainty on safety performance becomes weaker when there is a higher level of resilience at the workplace. Therefore, the negative influence on uncertainty on project safety performance is likely to be moderate by a resilient work environment. Accordingly, RE at the workplace offers an opportunity to manage impact of project uncertainty on safety performance in building refurbishment projects. Consequently, the following hypotheses is presented:

H3 – Resilience at workplace moderate the relationship between Project uncertainty and safety performance of building refurbishment projects.

The hypotheses within the conceptual model signify the relationships between three variables of resilience, project uncertainty and safety performance (as illustrated in Figure 1). The model explains how refurbishment-project safety is influenced by resilience and project uncertainty and the moderating role of the resilience work environment on the impact of project uncertainty on safety performance in building refurbishment projects.

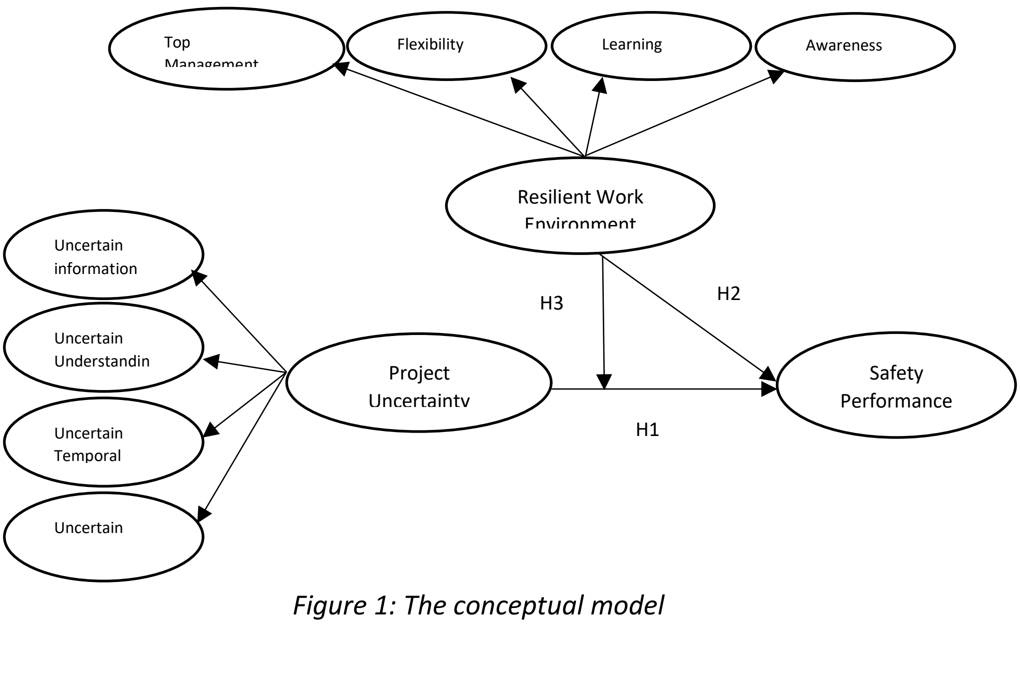

Figure 1: The conceptual model

Conclusions

Building refurbishment projects have become increasingly important to the construction sector. Despite the fact that safety has been a major concern of construction management researchers, there is a dearth of safety research with a particularly focus on building refurbishment projects. This study suggests resilience engineering theory and its application in the building refurbishment projects is a useful safety management tool. The conceptual model presented in this study explains the role of the resilient work environment on the impact of project uncertainty on safety performance in building refurbishment projects. It is hypothesized that the relationship between project uncertainty and safety performance is moderated by the resilient work environment. The dimensions of RE proposed in this study would be useful in determining the best strategies to develop a safe work environment and assess organization potential to anticipate, monitor and respond to project uncertainties. Building refurbishment projects would gain positive extraction from the proposed dimensions of RE for the development of a resilient work environment. A more robust understanding of the initial measures will encourage further research on other RE dimensions that can integrate into the construction work environment. Besides, assessing project uncertainties from a safety perspective are crucial to successful project delivery. Considering the construct of project uncertainty and its impact on safety performance, the research enables project managers and academics to better understand and assess project uncertainty and deliver safer building refurbishment projects by successfully managing them. Finally, by testing the hypotheses, the findings will help to explain the level of influence of project uncertainty and resilience on safety performance. This is expected to achieve high safety performance consistently despite the uncertainty in building refurbishment projects. It is anticipated that this conceptual model will be further validated through empirical research to test the hypotheses. Indeed, the data collection from major refurbishment project in Australia is underway as the next stage of broader research project. The researchers intend to present the results from analysis of empirical data in near future. The findings will inform project managers what RE and project uncertainty factors need more attention in developing safe work environment.

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Sustainable contractor development: do CEOs/company leaders make a difference?

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Abstract

The construction industry is one of the major contributors to the GDP of many countries. However, just like many other countries, the South African construction industry has been facing challenging times with the decrease in expenditure and investment from private and public clients. This has led to decrease in the industry's GDP and subsequent increase in the number of liquidation and insolvency of construction companies. The purpose of this study is to identify the key leadership and entrepreneurial factors for sustainable construction companies. Semi-structured interviews of higher experienced CEOs/leaders of 11 large construction companies in the Western Cape, South Africa and thematic analysis were adopted. For a broader analysis of the CEOs/leaders, the company's financial performance records of the CEO/company leaders over a five-year period were also obtained. The main findings of study include that successful construction companies were managed by CEO/leaders that possess high entrepreneurial skills, good understanding of construction and maintains positive attitude. However, other non-entrepreneurial factors may also contribute to the success. The study recommends that a larger sample size be used to test the hypothesis proposed by the study that leaders make the difference in the success of construction companies, using a quantitative research approach. Contractors, investors, policymakers, and financial institutions may find this study beneficial.

Keywords: Big contractors, Contractor development, Entrpreneurship, Leadership, Sustainability

Introduction

This study examines the role and importance of the Chief Executive Officer (CEO)/company leadership in the sustainability of construction companies, and sustainable contractor development. Leadership is the process of social influence that employs the tools of management in a manner that yields superior results and attributes causation to individual social actors (Antonakis and Day, 2017; Merritt, 2017; Kruse, 2013). Several scholars have illustrated the power of the CEO/company leadership in driving organisational performance outcomes, submitting that a firm's CEO/company leader is an important member of the firm's dominant coalition, with profound impact on the strategic direction and performance of the firm (Windapo, 2018; Gow, *et al* 2016; Peterson, *et al* 2012).While April and Hill (2000) contend that the CEO/company leader does not matter in driving organisational performance outcomes, there is agreement on the positive role of leadership in improving people, business and organisations' performance (Windapo, 2018; Carmeli and Edmondson, 2012; Nadkarni and Herrmann, 2010; Bass and Bass, 2009).

The poor performance and failure of construction enterprises have been widely reported in literature. In the UK, Korman and Reina (2018) reported the collapse of Carrillon Plc, the U.K.'s second largest contractor and a major construction service provider. Wong and Ng (2010) provide substantive evidence for business failure of Chinese construction companies based in Hong Kong while in the African and sub-Saharan African context, there are concerns on the demise of construction businesses and poor performance of construction in different regions (Odendaal, 2018; Oyewobi, Windapo and and Cattell, 2013; Ntuli and Allopi, 2009).

For example, within the last ten years some contractors such as Filcon Construction (Pty) Limited, Basil Read, Esor and Liviero Group in South Africa have undergone business rescue (MasterBuildersSouthAfrica, 2019) while other large companies such as Murray and Roberts, Neil Muller Construction (NMC) and Group Five, have been sold been sold out. Although the reasons behind the poor performance and failure of construction businesses are many and scholars have divergent views, various researchers have held leadership in construction organisations responsible for its success, or failure. Specifically, some studies argue that leaders have profound impact on the performance of the firm, since they set the tone for the organisation through the vision expressed, decisions made and policies implemented (Mcintyre, 2018; Ofori and Toor, 2012; Ofori, 2008; CIOB, 2008). Leadership tops the change agenda and is the main driver for improvement of construction organisations in Egan (2002) re-thinking construction report. It was also identified as the foremost criterion in the construction excellence model developed by Bassioni *et. al.,(*2005).

Despite the links established between leadership characteristic and company performance by author such as Day and Lord (1988), previous streams of research on leadership in construction have focused mainly on project leadership and leadership in the construction industry as a whole, overlooking its implications for construction business performance (Graham *et al* 2020; Liphadzi *et al* 2015; Ameh and Odusami, 2014; Lloyd-Walker and Walker, 2011; CIOB, 2008; Ofori, 2008). Given the backdrop established so far, the aim of this study is to investigate the role of the CEO/company leadership in the sustainability of construction business organisations in South Africa. This study therefore identifies the key leadership and entrepreneurial factors responsible for the sustainability of large contractors in the Western Cape, South Africa. The paper starts by reviewing relevant literature on leadership, entrepreneurship and sustainable contractor development followed by a presentation of the methods, and findings and discussion. The conclusion and recommendations are the last section.

Literature Review

The Concept of Leadership

Leadership has been examined extensively in the literature (Northhouse, 2018). McManus and Perruci (2019) suggest that leadership as a field of study has expanded dramatically in recent years in more organisations due to its recognized importance in the twenty-first century. *Researchers* have argued whether leadership is an art or science, a process or position, and wondered which style is best in each situation or context. This has brought about several theories, cumbersome definitions, and numerous classifications (Graham *et al* 2020; DePree, 2011; Goleman, 2004). In only the past 50 years, there have been as many as 65 different classifications of leadership dimensions and even the 'over- 90' variables of leadership dimensions uncovered in a study was still not enough to understand leadership (Sydänmaanlakka, 2003; Winston and Patterson, 2006). Leadership research began empirically by studying leaders and their actions; continued with the incorporation of followers and their relationships with leaders; and more recently has incorporated identity-based, environmental, and systemic considerations (Simmons *et al* 2017). By implication, the leadership characteristics construction must integrate the workers, construction process complexities, agendas/goals/discourse in construction such as sustainable construction and other aspects of the environment in which the industry operate.

The Upper Echelon Leadership Theory

The Upper echelon theory examined the predisposition of executives' characteristics on organisations. They argued that organisations are reflection of top manager's cognitions and values (Hambrick and Mason, 1984). The theory further asserts that organisational outcomes are partially predicted by the managerial background characteristics of the top-level executives. Malik *et al* (2016) held that leaders play a vital role in the success of organisation. Likewise, Pihie *et al* (2011) argued that in organisations, leadership is important for facilitating and monitoring favorable change, cultivating relationships, creating solution to organisational problems, directing human resources towards organisational objectives, aligning organisational functions with the external environment, and in determining directions for organisations, and influencing performance. Day and Lord (1988) revealed that executive leadership could explain as much as 45% of the organisations' performance establishing a strong link between leadership characteristic and company performance.

Leadership, Entrepreneurship, and Sustainable Contractor Development

The leadership process creates uncertainty and change in the organization since it involves various factors such as developing a vision for the organization; aligning people with the vision through communication; and motivating people to action through empowerment and basic need fulfillment (Antonakis and Day, 2017; Bass and Bass, 2009; Kruse, 2013; Goleman, 2004). Evidence of this can be found in Windapo (2018). In addition to the leadership roles of CEO or other senior management positions in companies, they also have entrepreneurship attributes, skills and knowledge that if properly harnessed will have positive implications for the performance of construction companies (Oyewobi et al 2013; Windapo 2018). On other hand, while leadership and entrepreneurship differ, Windapo (2018) shows that entrepreneurs have leadership characteristics where the traits, include responsiveness to criticism and suggestions, and getting along with people. The definition of entrepreneurship supports this. Typically, while the operational diversity of entrepreneurs makes the definition challenging (Windapo 2018), but according to Carland *et al* (1984) in Windapo (2018, operationally, it can be defined as an '…individual person who sets up a business or businesses, taking on financial risk for the principal purposes of profit and growth, who is characterized principally by innovative behavior, and employs strategic management practices in the business'.

Given the uniqueness as well as features of the construction industry, leadership within the context is critical, and it is evident there is a greater need for leadership in construction than arguably any other industry (Ofori and Toor, 2012). Construction is one of the most dynamic and complex industrial environments; it has many stakeholders, processes and disjoints (Wild, 2002). Different professionals and bespoke teams from different backgrounds work simultaneously and temporarily often at dispersed geographical locations usually a distance from the central management each time a new project is awarded to achieve the same goal (Raiden and Dainty, 2006). This project based and multi-organisational nature of construction affects leadership in its context (Burke and Barron, 2014; Ofori and Toor, 2012; Hillebrandt, 2000). The entrepreneurial attributes and activities of the CEO foster sustainable growth and success of the construction company (Windapo, 2018). Oyewobi *et al* (2013) stated that entrepreneurs in construction have the skill to diversify the company and increase the performance of the construction firm. Diversification is a marketing strategy employed in an operating company that seeks to grow its profits by venturing into providing new products or services to new markets or similar industries (Paulraj and Saravanan, 2012).

Entrepreneurship knowledge and skills can be through formal or informal education, personal history, or experience (Gomezelj and Antoncic, 2008). Lebambo e*t al* (2017) stated that establishing the entrepreneurial knowledge an entrepreneur possessed requires identifying the education the entrepreneur acquired or the experiences to which they are exposed. There are also social and non-psychological factors such as training, networks, and family proposed as other important factors that influence performance improvements and entrepreneurial success of leaders (Soriano, 2010). Mumford *et al* (2000) recognized that capabilities such as wisdom and perspective to identify restrictions, 'go outside oneself' develop plans and build support, acquired from experience, influence leader performance. According to Windapo (2018), formal education may not necessarily be a key entrepreneurial factor necessary for individuals desirous of establishing successful companies in construction industry.

Toomer *et al* (2018) are instructive that a key factor for leadership effectiveness includes realistic optimism, psychological resilience and generating momentum. According to Torres *et al* (2012), the advantage for organisational executives comes from reading and responding to signals faster than rivals do, adapting quickly to change and capitalizing on leadership to influence how demand and competition evolve. The company's team will ideally comprise of competent members with enough technical expertise, knowledge, and skills. Having an efficient organizational structure in a company ensures individuals know their roles and responsibilities in a company. The entrepreneurial factors and activities contributing to the sustainable growth and success of a construction company and its strength lies in a methodology that links the concept of entrepreneurship to management strategy and business performance in the construction industry (Windapo, 2018).

Methods

To achieve the research objectives, the study adopted a purposive sampling and qualitative approach where semi-structured interviews of 11 stakeholders in the South African construction industry was conducted. Greenfield and Greener (2016) stated that qualitative research method is appropriate for understanding complex phenomena and providing very detailed descriptions and provides rich-case information which are consistent with the current research. According to Creswell (2015), the fundamental idea of this approach is to let research evolve based on what is learnt from participants in the study. The ethical approval for the research was obtained from the EBE faculty ethics clearance committee and a peer debriefing were conducted on the 4th of July 2019, to ensure that the research instrument was useable.

The interview began on the 15th of August 2019 and concluded on the 14th of February 2020, lasting for a period of 7 months. The average interview duration was 55mins 30 sec and both telephonic and personal means were used as reflected in Table 2. There were questions about the major challenges of the executives and how they have managed their companies over time. Data obtained concentrated around the objectives of the research although the questions remained open-ended to uncover different perspectives. Data collected was first transcribed using the otter software and was more carefully organised using manual means. Finally, the company leaders were asked to give advice to upcoming leaders to understand what matters to them the most.

As shown in Table 2 below, the samples of this study are Group Chairmen, CEOs, and Managing Directors of large Civil, Building and Geo-technical Engineering Construction Companies in the Western Cape — they are in grades 7-9 category on the construction industry development board (cidb) list of registered contractors (cidb, 2017). The construction companies of the study samples are either affiliated with the Master Builder Association (MBA) or the *South African Forum of Civil Engineering Contractors* (*SAFCEC*) in the Western Cape Province of South Africa.

The feedback from the pilot improved the interview protocol and helped to focus on the right questions based on the objectives of the research. This contributed to improving the trustworthiness of the research. The characteristics of the respondents shown in the Table 2 helps provide an in-depth understanding of how and where some of the finding emerged, generating confidence and credibility. Further, other company financial records such as revenue and profit over a five-year period was also obtained. The analysis was carried out manually using emerging themes. The emerging themes identified from the ideas and patterns that come up repeatedly from the interview transcripts included: 'survival mode', 'adapting', 'some other business' and are presented as the findings below.

Table 1: Information on interviews and Profile of respondents and their companies

Respondent	Position	Background Discipline	Company Age in years	Years In construction	Years with current company	Years in current position	Present Grade on cidb	Interview means date/duration
A	Managing Director	BSc Civil Eng. & Geo-technical	55	36	29	10	7CE/GT	Telephonic, 14/02/20 38m.36s
C	Managing Director	HNC Construction Supervision	117	40	25	4	9GB/CE	Personal, 15/08/19 79min.56s
D	Managing Director	BSc Civil Engineering	49	23	23	12	9GB/CE	Personal, 20/08/19 49min.03s
E	CEO	BSc Building Mgt.	69	50	50	16	7GB	Personal, 27/08/19 75min.17s
F	CEO	BSc Civil Eng	22	24	22	22	7CE	Personal, 8/10/19, 30min.38s

G	CEO	BSc Engineering	35	58	35	35	8CE/GT	Personal, 8/10/19 35min.41s
H	CEO	BSc Ind & & Mech Engineering	88	35	33	16	8GB/CE	Personal, 24/1019 76min.52s
I	CEO	BSc Quantity Surveying	27	33	27	27	7GB	Personal, 14/11/19 55min07s
J	Group Chairman	BSc Mechanical Engineering	52	30	27	14	8GB	Personal, 21/01/20 67min 01s
K	Group Chairman	BSc Qty Survey. & Project Mgt	36	46	36	36	9GB/CE	Telephonic 03/02/20, 29min.35s
X	CEO	Psychology	34 before Liquidation	29	29	11	9GB	Personal, 30/07/19 33min36s

Findings and Discussion

Profile of the respondents

The over 20 years' experience in construction of each the participants and operation of all the companies provide them with significant experience in the industry, enabling them to provide rich information especially in terms of sustainable construction (Greenfield and Greenfield, 2016). The 4 to 36 years of leadership experience (Table 2), also allow for the level of insight required for this study on leadership in construction.

Family business and or academic background and training

Table 2 shows that most of the respondents have a background discipline in construction and related courses. These have implications for the construction and business skills of respondents and company performance. Some of the respondents added that early experience and a further degree in management and business was also helpful to sharpening their construction and business skills and boosting their performance and subsequently, that of their companies. All these factors appeared to be key requirements to understanding and running a successful the construction business one as reflected in the statements below:

> *"Starting from beginning, if my father were not a consulting engineer, I could never be a consultant, I was born a contractor. I like doing this work. I like to work with my hands. I matriculated in 1957 and graduated with a BSc Engineering Honors but I later went to school of business, to understand cash flow"* Respondent G.

> *"I studied Industrial and Mechanical Engineering at Stellenbosch University, and I was early exposed to construction because my family had a construction business. If you are going to be thrown into the deep end running a business that has traction, size and scale, I think you need to have studied business to handle that so, I did an MBA"* Respondent H.

> *"I have no formal qualification in the building industry, just from hands-on experience, using entrepreneurship leadership skills, I moved up the company and then, about 14 years ago we cross sorts a little, certain things happened in the marketplace and then I did buy up the balance shares here".* Respondent J

However, the deviant sample whose company is now liquidated stated that there was no prior early exposure and training in construction and business as reflected in the statement below.

> *"I joined the construction industry in 1990 as a training manager, and through that process, I got to know a lot more about the technical detail of the industry. I do not have the practical experience, and I did not train as a construction engineer neither was I a construction manager, I was educated in the field of Industrial psychology and people management".* Respondent X

The account of Respondent X does not provide enough evidence to conclude that the lack of early training/education in business or management and/or lack of family background in business impacted on their construction and business skills, boosting their performance and subsequently, that of their companies. However, the evidence in literature elsewhere in this paper suggest that it may have provided Respondent X with additional advantage. The findings in this theme agrees with Lebambo *et al* (2017) and Soriano (2010) that factors such as education, training, experience, and personal history are important influence on the entrepreneurial success of leaders. Also, the findings are in line with extant literature (e.g. Windapo 2018) that shows the little contribution that the nature of education (formal or informal) makes as a key entrepreneurial factor for a successful company in construction industry. However, the extent to which these impact on the success entrepreneurial success of leaders is not covered.

Diversification in and of Business

Further, it emerged from this study that diversification is a key factor for the sustainability of the company of the participants. Almost all the contractors diversified their businesses. This supports the conclusion of Paulraj and Saravanan (2012) and Oyewobi *et al (*2013), that entrepreneurs in construction have the skill to diversify the company and increase the performance of the construction firm. This is reflected in some of the statements below.

> *"Our decision to get involved in development work, which effectively gives us an opportunity to procure work for the construction companies, has been a change of direction"* Respondent C

> *"In this climate in South Africa, there is an element of being in survival mode and I am not sure we are getting along in terms of our mission, we have sort of moved away. I would say one of*

> *the other things we have done is to look to tomorrow's business in terms of starting a property company"* Respondent J

> *"The answer is that the downturn and deterioration has been so sudden that any changes you have to make have got to be dramatic, and we have to be looking for new areas"* Respondent G

> *"One has to constantly adapt based on government's needs and expectations. So probably one of the things that we have had to come to terms with is that the bulk infrastructure in this country is now fairly-well established. Now, a lot more focus is on rehabilitation of roads, and not these big, multi-million cubic meters to be shifted and new developments, but it was more a matter of what is basically what now needs to be upgraded and maintained. I think that has been one of the big shifts"* Respondent K

However, the deviant sample acknowledged that diversifying the business was not helpful to the business because the timing of the acquisition was wrong. This respondent noted that not reacting quickly to the market, was the worst decision by the company leadership which supports the assertion of Torres *et al* (2012).

> *"The decision in 2008 was how we are going to grow the business. And at that stage, the best decision was that we need to grow the business organically. We were not going to grow the business through acquisitions. But in many respects, the decision that we took after was probably a bad decision. We acquired a civils construction business and at that stage there was not a lot of work around. So, when we decided the government was going to spend R800 billion rand on infrastructure, we went and made our decision based on that and then it never materialized."* Respondent X

The implications of this include that while diversification of and in business may contribute to company sustainability, other factors such as its timing, the scope, and other factors account for the success. While Respondent X' company failed in the diversification, there is little if not no evidence to logically conclude that the lack of construction training was the causal factor but there is evidence of the role of leadership in this failure. However, given that the role of knowledge and education in entrepreneurship and leadership established in literature elsewhere in this paper, it can be argued that this may have played a key role in the failure of the diversification of or in the business. Further, the size of the organisation (e.g. large, medium, and small) which determine the resources available to them may have implications for the level and attention of the diversification and the performance.

Survival Mode and Resilience

Another significant finding from this study is that while most of the respondents maintained that the construction industry in South Africa is in a survival mode, their disposition revealed a positive attitude to overcome the challenges as reflected in the following statements:

> *"A lot of construction companies in South Africa are working on survival mechanism, and it has become a scary process. All those big construction companies that we looked up to are the ones that are getting out of business now. So, things are changing fast and it is a moving train all the time, but we are actually going with the flow"*. Respondent A

> *The challenges in the country now is the economy and the construction industry, which has been through the worst time to my knowledge in probably forty to fifty years. I have never seen that in these 44 years of my working career. So probably one of the things that we have had to come to terms with is how are we going to become specialists"* Respondent K

> *"*I *really think that from construction point of view, you must be adaptive. To me, adapting to our circumstances is probably one of our strongest point"* Respondent J

This supports the assertion of Toomer et al (2018) that psychological resilience and generating momentum are important for leadership effectiveness. The idea of not giving up on a mission and leader rejuvenating capabilities of 'self' and that of the team in order to be continuously successful comes to bear here. However, the deviant sample expressed some regrets about the decision to grow during the challenging times. It is also noteworthy that since the respondent having quit the business already resilience is not reflected. The respondent stated that:

> *"I think there was an element that we were growing too fast. So, we should not have. Probably the biggest mistake was that we as management, did not react quickly. We should have reduced the size of the business a lot quicker. We should have sold off our civil engineering business".* Respondent

Other Remarks

While evidence in literature and the findings of the current study point to the contributions of entrepreneurial factors to the success of companies in the construction industry, the strategies and procedures of connecting these factors to the organizational goals and management strategies remain one of the key determinants of the performance of the organization (Windapo 2018). The implications of this include the need for organisations to ensure synergy between organisational goals and management strategies and the entrepreneurial factors to achieve sustained organisational performance.

Conclusion and Recommendations

This study examined the leadership and entrepreneurial factors that impacts sustainable contractor development. Through the analysis of findings of this study, it was evident that leadership and entrepreneurial abilities of the upper echelons impact the sustainable development of construction companies, just as the diversification of business and the background experience. This study recommends early exposure to construction experience and business skills for contractor development. Further, having a positive attitude towards the industry will be helpful to developing sustainably. Contractor development programmes can be used as a mechanism in this regard. The study highlights the key entrepreneurial factors that contribute to the development and sustainability of contractors which can be and has been easily over-looked. Contractors, investors, policymakers, and financial institutions may find this beneficial. As the study was limited to large contractors, not all the findings maybe applicable to medium and small-scale companies hence a study that will draw on their experiences and views is recommended. This study was conducted in the Western Cape province of South Africa and used a few sample sizes. Further research (e.g. a survey) should be extended to other provinces, using a larger sample size for generalizability of results. Similar studies are also encouraged in other countries.

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Empowering ethnic minorities in the UK construction industry

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Abstract

One of the major calls for improvement in the construction industry is that of increasing diversity at all tiers of the professional roles. Gender balance and increase in numbers of ethnic minorities in senior roles are among the categories for these calls. The UK construction industry is known to have an underrepresentation of some of these categories of minorities although there are continuous strides to improve the situation. In this paper, challenges that face ethnic minorities as they try to gain promotion to senior management and other decision-making roles is the focus. This research explored current practices and policies adopted by some UK construction firms with particular emphasis on empowerment of ethnic minorities into leadership roles. Using an interpretivist philosophy, 12 semi-structured interviews were conducted with purposively sampled construction industry professionals. All interviewees were selected based on their ethnic backgrounds and experiences in the construction industry. The underrepresentation of ethnic minorities in leadership roles was widely acknowledged. More importantly covert discrimination was fundamental to most barriers faced by ethnic minorities in the industry. The level of discrimination was identified to be implicit and as such there are no obvious trails to be identified except accounts of individuals closely linked to the issues at hand. There were also indirect barriers created for industry professionals through formal organisational policies. It was identified that the drive for a more diverse workforce and ethnic minority empowerment would significantly benefit both management and employees. More importantly, this will open up the talent pool for professional roles in the industry. Overall, productivity and job satisfaction will directly and indirectly be improved if these sought-after progressive changes can be properly implemented.

Keywords: discrimination, empowerment, equal opportunity, ethnic minorities.

Introduction

The construction industry remains one of the most valuable industries of today, and represents the building block of a community, being recognised as the largest industry in Britain (Dainty et al., 2007; ONS, 2018) and an important sector that contributes significantly to the economic growth of the UK.

In 2017, the construction sector contributed £113 billion to the UK economy, 6% of the total economic output, employing over 2.4 million workers (7% of the UK total) (House of Common Library, 2018). While some industries have changed profoundly in recent decades, the UK construction industry is recognised not only for its massive contribution to the economic but for overly-complex, lack of empowerment, wasteful practices in its project execution, reluctance in adoption to new ideas, reactiveness in its approach to human skill development, stereotype and discrimination of ethnic minorities in decision making positions. Majority of these issues have been debated in a sequence of popular industry reports, including Latham (1994) and Egan (1998). One of the key issues identified in the construction industry is its lack of inclusion or under-representation of black and minority ethnics in decision making roles (Royal Institute of Chartered Surveyors (RICS), 2019).

In order to encourage and eliminate the barriers faced by ethnic minorities seeking a leadership role in the UK construction industry, this research project explores the challenges that lead to underrepresentation of the groups. Previous research projects (see Steel and Todd 2005; Duncan and Mortimer, 2005; Agapiou et al., 1995) have identified numerous barriers that may be limiting the entry, retention and progression of ethnic minorities into decision making position in the industry, but as the sector evolves, further work is always needed to shed light on the nuances of these everchanging challenges. Thus, the aim of this research project is to contribute to the debate of empowering UK ethnic minorities into leadership roles. It is important to highlight that this study was carried out before the killing of George Floyd and the subsequent 2020 Black Lives Matters protests.

This research project focuses on ethnic minorities in leadership roles in the UK construction industry, roles such as craftsmanship, tradespeople, and administrative roles are beyond the scope of this paper.

Ethnic Minorities and the Construction Industry

The UK construction industry as alluded to earlier, does not have a good reputation record when it comes to inclusive practices whether race or gender related.

Perceived image of the industry

Prejudice is accountable primarily for the lack of diversity and equal opportunity (Fishbein, 2012). According to Gridley et al. (2012), this results in systemic assumptions about certain groups or people of certain cultural background being treated as superior over others. These assumptions in this context are based on race, culture, and ethnicity. Grounded in human behaviour, ethnocentrism and stereotyping and in many cases, it is central to human cognitive processing (ibid). The arbitrary social categorisation and stratification based on salient and physical identification features.

The construction industry poses an unwelcoming problem with an unpleasant and negative image. Previous research suggest employment practices and industrial relation often depicted as casual and informal approach to management of people (Lingard et al. 2008; Townsend et al., 2011), with Loudoun, (2010) adding that high rates of health and safety incidents and as such, the industry has gained the reputation of 'laddish culture' in a white, male dominated environment (Caplan et al. 2009). The stereotypical and ethnocentric tendencies implicit in the activities of the industry's dominant group. This rather negative image of being characterised with stereotyped male values and building site mythology affects the recruitment and empowerment of potential employees from outside the traditional cohort.

Despite positive intent public statements, there has been no significant change concerning equality and diversity. Hence, the importance of workforce monitoring, targets and compliance have been misunderstood; hence, they hesitate to set equality targets. The business case argument shows that construction is under-utilising the skills and talents of the UK population, especially from the ethnic minority groups resulting in decreased organisational efficiency and effectiveness. As a result, the industry's practices continue to foster such strong a perception that ethnic minorities face rejection at the recruitment and contracts offices of construction firms due to ingrained racism and exclusionary practices (Vershinina et al., 2018). Ethnic minorities are considered as inferior and itself a barrier tough to surmount the ethnic minority group definitions given and how their cultural practices in the form of languages, religions and different lifestyles perceived as inappropriate (Fernández-Reino, 2016).

Exclusion of ethnic minorities

CITB (2005) revealed that the construction industry is trapped in a cycle of exclusion whilst the industry tends to attribute the low representation of ethnic minorities as the inability to attract new entrants, based on the industry's perceived image as heavy, dirty and tough. Previous research into barriers faced by ethnic minorities in the construction industry also suggested the limited access for entry, lack of support, lack of empowerment and nepotism (CCI, 2008; Ahmed at al., 2008) which favour those individuals with prior family-based links, thus the key to joining the industry is to have a family member within the industry. Unfortunately, potential ethnic minority entrants do not tend to have these links. The crucial exclusionary practice is that employers are reluctant to take a risk by employing or empowering an individual who does not fit the traditional stereotype (Construction Skills, 2007). Consequently, employers detest the potential legal consequences of a future accusations of racism or harassment, and this may make them reluctant to recruit people from ethnic minority backgrounds (ibid). Also, employers using subtle discrimination and issues of being able to fit in to give white candidates the edge over their ethnic minority counterparts, concerning either recruitment or progression on the job (CEMS, 2002; CABE, 2005).

However, some employers have been known to place ethnic minorities and other individuals of minority backgrounds in vantage positions at work for 'duplicity'. This practice is commonly known as 'tokenism'.

Ethnic Minority as Token Employee

In affirmative or positive action application, ethnic minority groups face the problem of being the "token" employee group representative rather than an individual who attained their position based on merit or equal rights (King et al., 2010). According to Renzetti and Curran (1992), this action may be associated with stereotypes, and consequently, the individual becomes a victim of ridicule and discrimination. Kanter (1977) regards tokenism as being boundary heightening, where the workers of the dominant group (white males in the context of the construction industry) exaggerate the difference between them and the token (ethnic minority) employees. For example, the exclusion of Muslims from informal networks of which membership is essential for career enhancement by organising social events that do not revolve around the dominant culture, such as drinking after work (Bertoli et al., 2020). The project manager has the duty of care to create a greater level of inclusion of non-traditional entrants in all the activities of his project.

Having explored existing literature on the industry's image and barriers faced by ethnic minorities in gaining entry into the industry as well as lack of progression, the next section considers the method adopted in achieving the research aim.

Research Method

The problematic nature, as indicated by the literature review of empowering UK ethnic minorities into a leadership role (which is the area of study), has noted human elements and their interactions as the underlying factors. An interpretivist philosophy is adopted to help with the meaning that individuals attach to events. The research took on a qualitative approach. A purposive sampling technique was utilized to identify potential participants. Using this approach, twelve construction professionals interviewed for this study. Semi-structured interviews allowed the research to explore the previously identified themes in the literature review as well as allowing for the exploration of emergent themes and ideas, hence not only relying on pre-identified concepts. All respondents were based in the UK. A wide range of experience was sought after to acquire a variety of opinions. Interview questions explored views in areas including equal opportunities, unfair treatment and how practices can improve. Although there are statutes against discrimination, previous literature has always identified the abundance of discriminatory practices particularly when dealing with ethnic minorities.

Thematic analysis was adopted for the data analysis. A focus on the intricate meaning across the transcribed data, allowed for a better understanding of the shared meanings and experiences from the interviewees' responses (Aboagye-Nimo et al., 2013). Thematic analysis carried out on the data collected helped in systematically identifying, organising and offering insight into patterns of themes across the data (Braun et al., 2014). Stringent ethical considerations were made in the study. In further ensuring confidentiality and anonymity, Peter Pan (PP) was used as a pseudonym for all interviewees. Standards of the Social Research Association were strictly adhered to.

Findings and Analysis

All interviewees have a wide range of experiences in the construction industry, and from various construction firms. They had worked from semi-large to large construction company. Due to the interpretivist nature of the study, it was important to understand respondents experience in the industry as well as their educational background. This would offer better understanding of their opinions as well as their perceived experiences. The qualitative data has undoubtedly outlined the critical impact white male-dominated cultures have upon ethnic minorities in attempting to stay and progress into leadership roles. Some respondents outlined the negatives effect of discrimination, and lack of empowerment with particular emphasis in on-site practices such as bullying. These are all fundamental barriers to the increasing lack of representation among new entrants.

PP#	*Position*	*Age range*	*Years of Experience*	*Education*	*Self-ascribed ethnicity*
PP1	Assistant Site Manager	Under 25	3	Diploma	Black African
PP2	FO Manager	31-40	4.5	Postgraduate	Black African
PP3	Director	41-50	27	Degree	Irish
PP4	Project Manager	31-40	15	Postgraduate	Black African

PP5	Technical Manager	31-40	5	Sch. cert	Black African
PP6	Supervisor	40-50	12	Diploma	Portuguese
PP7	Site Manager	25-30	3	Degree	Bangladeshi
PP8	Apprentice Site Manager	31-40	8	Degree	Black African
PP9	Senior Site Manager	41-50	9	Postgraduate	Black African
PP10	Document Controller	Under 25	4	GCSE	Black Caribbean
PP11	Site Supervisor	25-30	6	Degree	Pakistani
PP12	Director	Over 50	30+	Degree	British

Table 1: Interviewees' profile

The interviewees expressed genuine interest in joining the construction industry, although none of them were employed through formal or officially arranged Human Resources interview procedures. Some interviewees were employed as part of the council ethnic minority quota while others were employed due to recommendations from personal contacts. The rest were also employed based on recommendations from contacts of friends.

Progression in the workplace

Most of the respondents expressed difficulty in ethnic minority progression into decision making position. Views expressed included:

> *[White colleagues] do not allow us to progress because maybe they think we [ethnic minorities] will take their* jobs - (PP3)

This showed some implicit reservations that some ethnic minority respondents harboured with regard to progression or promotions at work. This was also noted by Greed (2000) and Dainty (1998) as a barrier to ethnic minority workers in the industry. Thus, the view expressed by PP3 and others was not simply an assumption.

Other interviewees added:

> *Progression to higher position means moving from company to other as I have done to attain Project Manager position, but obviously, I cannot move as finding another job with the current climate of Brexit is very difficult* - (PP4)

PP4 believes it is difficult to progress in the same organisation. He adds his past experience of having to switch organisations in order to attain a more senior role. The notion of changing employers if one wants to move up the ladder was not so simple as explained by PP1. The economic climate i.e. readily available employment opportunities greatly affect the ease of ethnic minorities progressing in the industry because some believed they had to change organisations. In a more drastic situation, some interviewees were terrified of losing their jobs.

> *I cannot afford to lose this job so I will do anything to make sure I stay at work, even if it requires me to work seven days and get paid for five. The company took a chance on me, and I will not throw that away* - (PP1).

The above shows that some workers are in a position whereby they are greatly concerned about losing their jobs. This is reinforced by the concept of workers gaining roles through personal contacts. PP1 did not believe he had the right contacts that could enable him to gain another job at the time of the interview.

Equal treatment

During the interview process, it was also discovered that many companies possessed equal opportunity statement and policies, but only a few practiced what was covered in the document. Most respondents stated that they believe the policies were not adhered to. This shows a discrepancy between implementing equal opportunity policies and formulating organisational policies when dealing with matters relating to ethnic minorities. However, some interviewees expressed that they were not aware of specific policies that covered equal opportunities for ethnic minorities.

> *Having developed an equal opportunity policy means the company has thought of implementing the policy, and as such, they are responsible people, but many companies do not have such policy* - (PP12).

One important point raised was overt resentment from white male peers and managers toward ethnic minorities. All of the respondents acknowledged the discrimination of ethnic minorities faced include but was not limited to racist name-calling, jokes, harassment, banter, bullying, intimidation and in some cases, physical abuse in the form of violence. A typical example of behaviours considered inappropriate was mocking ethnic minorities racial origin and ill-mannered accent imitations. The industry has frequently tolerated and generally accepted such culture which points the sector as one where racism could prevail.

Workplace culture was another point raised by some interviewees as maintaining the underrepresentation of ethnic minorities. Those in decision-making positions were overtly hostile towards ethnic minorities as they resisted changes to policies and procedure which might threaten the dominance of white colleagues in the organisation, hence ethnic minorities were forced to comply with such uncomfortable practices. Many of the respondents expressed the feeling that they received less support compared to their white peers and that white colleagues regularly received more feedback on their performance. PP12 added that some managers feared being labelled as racist for giving negative feedback to ethnic minorities. On the other hand, many respondents pointed out that negative feedback was used in many cases to prevent ethnic minority progression to a leadership role.

As part of unfair treatment, respondents complained of the stereotypical assumption made about them that ethnic minorities are lazy and do not know how to carry out their jobs effectively. They believed they required more academic qualifications and also had to '*put in double the effort'* as their white peers '*in order to be taken seriously'*.

Overall culture change

The key to attracting and retaining ethnic minorities was agreed to be intertwined with and overall change in the industry's culture. Industry ingrained practices, for instance, unfair terms and conditions and word-of-mouth recruitments were cited as being in need of change if the industry is to be regarded as a sector providing a fair and equitable workplace environment. Many of the ethnic minorities experienced both direct and indirect discrimination. As stated in an earlier section, overt discrimination in the form of racial name-calling, jokes, harassment, banter, bullying and intimidation is prevalent in certain workplaces. In addition, covert discriminatory practices including stereotyping and exclusion from groups, which hinder ethnic minority career progression. The practice of exclusion was also identified.

> *They had secret meetings and did not inform us [of what was discussed], except when they want our help (PP7)*

PP7 believed this practice was clearly preventing him from accessing vital information and opportunities that would prevent him from progressing to a decision-making role. From the data and opinions of the participants, a change in leadership strategies and an increase in recruitment of ethnic minorities would be imperative in the eradication of unfair treatment.

Leadership

Ensuring equal opportunity across the industry will create a real change for ethnic minority access, treatment and progression within the sector. Fundamentally, these changes required, only become apparent if driven by a well-developed business case for diversity rather than externally imposed legislation. The fundamental prerequisite in achieving the necessary change required to create a fair and equitable workplace environment is a full commitment of equal opportunity by the industry leaders.

Practice and Policies

The industry needs to develop robust, pragmatic and comprehensive equal opportunity and diversity policies as this will be invaluable to the industry's evolution. This research project suggested that construction organisation take the lead (having robust policies relating to their employees) and from clients (insisting on diversity and equality measures being in place before tendering for a project). The implementation of an industrywide code of practice was suggested as a useful way of communicating the rights and responsibilities of individuals across the entire sector and beyond.

Progress Monitoring

The above progress needs to be monitor in ensuring appropriate action are taking place and that any problem areas identified at an early stage can be rectified. Consequently, it sends out a strong message regarding the industry's commitment based on what is expected and the importance of achieving it i.e. ensuring equality by empowering ethnic minorities in the industry. Ideally, setting up a central group aimed at progress monitoring across the whole sector and identifying appropriate diversity targets for the underrepresented group. The central group should also set up a benchmark among construction companies so that diversity could be measured in relation to size and operations.

Discrimination in the workplace

This research sought to begin the discourse of empowering ethnic minorities in the construction industry. By highlighting the positive aspects of empowering workers, it is important to highlight the ongoing challenges as well. Some of these have been presented throughout the paper, but this section will compile the revelations presented by interviewees. In cases of discrimination, it is noteworthy to identify that these practices do not always have to be direct or explicit, as the implicit or perceived acts are equally 'unacceptable'. The discrimination endured by the interviewees led to the development of following themes:

- Exclusion from work communications
- Lack of recognition for productivity
- Organisational equality policies as tick box exercise
- Job insecurity
- Perception of unequal treatment for 'white' colleagues in comparison to others
- Effective leadership

Although interviewees highlighted their challenges, it was evident that they had not raised these concerns directly with decision-makers of their organisation. Raising these issues and observing management's reactions/responses would enhance the workplace discussion significantly. A key topic that is thus worth exploring in future research is the effect of candid communication and the promotion of organisational transparency on the empowerment of ethnic minorities in construction firms. However, these were beyond the scope of the current study and these have been recommended for future research.

Conclusions

The UK construction industry has made conscious efforts to increase numbers of ethnic minorities it attracts in recent years, but this has not been reflected in the area of leadership roles (which is explored in this study). Findings from this paper suggested that ethnic minorities still face considerable barriers at every stage of their careers.

The experiences of ethnic minorities described in this study illustrate a belief of severe discrimination against them. The discriminatory workplace environment where ethnic minorities face extensive barriers to entrance and progression within the construction industry needs to be eliminated. In the construction industry's informal culture (e.g. amongst most small and medium sized firms), the danger of institutional discrimination occurs as noted by Oakley, (1999):

> "*Institutional discrimination can take place through routine practices, informal culture or official policies of an organisation*".

In addressing the current exclusionary and discriminatory environment, this research project recommends a holistic approach starting from leadership structures and a conscious increase in the intake of ethnic minority employees.

Clearly, the industry suffers from institutional discrimination against ethnic minorities, which could have damaging implications for the sector's competitiveness, image, and future development as the number of white workers declines in an era of skills shortage. The increasing awareness of what constitutes direct and overt discrimination, and how a particular section of society is continuously excluded through the traditional system and practices is a step in the right direction. For fairness and equitability of ethnic minorities, the new awareness must be made to reflect throughout the entire construction industry.

This study is part of a larger study that will utilize an action research approach in future to identify the suitability of implementing measures that are aimed to improve the ethnic minorities' abilities to attain more senior roles in the industry.

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Investigation of Worker Involvement in the Implementation of Health and Safety Policies On Construction Sites

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Abstract

This study assessed the relationship between the factors influencing construction worker's involvement in the implementation and formulation of health and safety policies on construction sites. The study further investigated if construction workers fully experience the benefits of health and safety policies onsite. A quantitative method of data collection was employed and data were analysed using IBM Statistical Package for Social Sciences (SPSS) version 25. Descriptive statistics was adopted for the data analysis and further interpreted using inferential statistics. The total sample size for the study was 120 participants (80 managers and 40 construction workers) where a total of 80 construction companies in the Kwa-Zulu Natal province in South Africa were conveniently sampled. The response rate for the study was 78.3%. A total of 64 managers (representatives of the companies) and 30 construction workers completed close-ended questionnaires. From the findings of the study, both respondents had agreed that the availability of health and safety policies increased health and safety awareness on site. However, it was evident that the workers' level of education and training regarding health and safety policies was not sufficient. Furthermore, management blamed construction workers for non-compliance with the policies and as a result, they were blamed for accidents on site. The findings of the study proposed measures for managers to involve construction workers' in the formulation and implementation of health and safety policies; improve their working conditions; consider the wellbeing of workers and treat health and safety as a value and not just a prerequisite for compliance.

Keywords: Construction, Health and Safety, Policies, Workers Involvement, Workers

Introduction and Background

The health and safety of construction workers is often overlooked since construction workers are considered invaluable to construction processes (Fry, 2017; Okoro et al., 2016). It is alarming how rarely health and safety issues are addressed despite the dependence on healthy, capable and physically fit workers (Okoro et al., 2016). Construction accidents can be reduced, employability of workers improved and performance improved by engaging workers in health and safety aspects such as policy implementation on construction sites.

In South Africa, the construction industry has been found to have less than 50% rate of compliance with health and safety requirements and unacceptably high rates of incidents as a result of poor workmanship and lack of proper site administration (CIDB, 2016). Othman (2012) identified that causes for non-compliance with health and safety are attributed to, the lack of commitment and awareness by clients and managers; a poor leadership by health and safety officers; lack of enforcement procedures by supervisors especially on the use of PPE as well as a poor choice of sub-contractors who are typically appointed without their company policies being scrutinised. The ILO

(2011) attests that despite government and trade union efforts, accidents will continue to happen on-site due to lack of health and safety adherence by contractors.

Although there is a high rate of accidents in the industry, accidents are foreseeable even though they are not necessarily foreseen by those undertaking them (Bomel, 2001). Construction accidents and preventative measures are well known. However, accidents are caused by the failure to manage risks and the negligence of employers (ILO Construction OS&H, 2008). The root causes of accidents lie within the upper stream of management and often, accidents are attributed to failure to identify hazards prior to work, proceeding with work despite visible hazards and neglecting initial unsafe conditions (Asanka & Ranasinghe, 2015). Most construction accidents can be prevented through the involvement of health and safety management systems (Ibid).

Workers issues are integral to the company as the company is its people and management within a company must be responsible for the wellbeing of workers (James, 2011). Employers should be responsible for creating a working environment that does not present a threat to the health, wellbeing and safety of workers (OHS Act, 1993 as amended). When employers invest in the wellbeing of their workers, the workers often feel valued and reciprocate directly with renewed employee loyalty through improved performance efficiency and hard work (Lawani et al., 2018). Regulations and legislation are also key in directing and controlling activity, improving responsibility of business owners and health and safety (Rust & Koen, 2011). However, compliance with health and safety requirements and laws requires, but not limited to, a combination of job nature, workers and site managers' attitude (ibid).

Workers’ Involvement

The term workers’ involvement can be defined as a process where every construction worker actively participates towards the improvement of health and safety on site (Cameron et al., 2006). This participation creates an enabling environment whereby workers share their knowledge and experience with other workers and management positively encourages them to participate in the identification and reporting of hazards in order to create a safe working environment for everyone (ibid).

Although contractors have the duty to ensure safe and healthy workplaces, the law also requires construction workers to help (EU-OSHA, 2012; OH&S Act 85 of 1993). Contractors do not have all the solutions to health and safety problems and as part of the process to ensure proper health and safety on-site, they should consult their workers who are directly involved in the execution of activities in order to gather detailed knowledge and experience of how activities are executed and how they affect them (ibid). Workplaces in which workers actively contribute to health and safety have lower risk levels and accident rates (ibid).

Health and Safety Policies

To achieve effective management of health and safety on site, contractors need to have a written policy detailing all health and safety standards (ILO, 2009). The primary objective of the occupational health and safety policy is to address the needs of the workplace and to prevent or reduce occupational accidents and diseases. Section 7 of the Occupational Health and Safety Diseases Act No. 85 of 1993 (OH&S Act 85 of 1993) in South Africa provides information to employers regarding the health and safety policy of the organisation. According to this section, the employer has a duty to inform employees of work-related risks and hazards and how the risks and hazards could be prevented.

Health and safety policies should address provisions for health and safety training at all levels with special attention given to key workers operating on scaffolders and cranes whose mistakes can pose danger to other workers (ILO, 2009). The ILO recommends that workers performing hazardous operations should be involved in the preparation of policies. Furthermore, the policy document includes the duties and responsibilities of workers and supervisors; measures by which information on health and safety is to be made known; as well as arrangements for establishing safety committees. The construction workers must be involved in the formulation of health and safety policies (HSE, 2001).

Previous studies have identified some areas of workers' involvement in relation to communication lines, hazard reporting, disciplinary roles and training (Cameron et al., 2006; Lawani et al. 2017). However, further research needs to be conducted on workers' involvement with regards to health and safety requirements on site. The aim of this study, therefore, was to investigate the level of construction workers' involvement in health and safety-related issues such as the formulation and implementation of health and safety policies on construction site. The study only focused on policies in relation to general health and safety commitment by both management and construction workers and the extent of their involvement with health and safety on-site.

Methodology

To achieve the aim and objectives of the study, a quantitative research was conducted in order to establish, confirm and validate the relationships between the constructs; workers' involvement and health and safety policies. The research design uses statistical analysis to ensure objectivity, generalizability and reliability (Creswell, 2003; Weinreich, 2009). Data were analysed using IBM Statistical Package for Social Sciences (SPSS) version 25. Descriptive statistics was adopted for the data analysis and further interpreted using inferential statistics. The total of 120 participants (80 managers and 40 construction workers) from 80 construction companies in the Kwa-Zulu Natal province of South Africa was conveniently sampled based on proximity to the researchers' location and familiarity with construction companies. This method of sampling proved feasible due to the short study's duration of 12 months. The response rate was 80% for managers (as representatives of the companies) and 75% for construction workers. Managers in this study are site-based senior and middle managers responsible for making decisions on behalf of the contractors/construction companies and delegating tasks to the construction workers. Cronbach's Alpha reliability test was conducted to determine the internal consistency of the study's constructs: Workers' Involvement and Health and Safety Policies and the internal consistency of the various scales ware deemed acceptable for interpretation. Independent t-test was conducted to determine the statistical significance of the means between management and construction workers' responses with a further Spearman's correlation to identify the relationship between the constructs.

Profile of the Respondents

The median age of the construction workers was 33.50 years ranging from 26.00 years to 43.00 years and the median years of experience was 6.00 years with a minimum of 3.00 years and a maximum of 21.00 years. Most workers (60%) were employed as artisans with different trades skills. Moreover, 33.30% of the construction workers had obtained junior high school certificates while 30.00% obtained their Matric/O Levels and 36.70% had technical/vocational training qualifications. The median age for managers was 35 years ranging from 22 years minimum to 55 years maximum. The median years of experience of managers was 6.5 years ranging from a minimum of 2 years to a maximum of 20 years. The median years of experience suggested that managers were knowledgeable in most aspects of the construction industry. Most respondents were Health and Safety Managers/Officer (29.70%) followed by Civil Engineers (23.40%) and Quantity Surveyors (21.90%). The respondents had either obtained a technical/vocational or university education. Furthermore, 32.80% of the respondents had obtained their qualifications from technical/vocational schools, and the other respondents obtained their qualifications from universities, 67.20%.

Analysis and Discussion

Table 1 shows the reliability test for the construct Health and Safety Policies and Workers Involvement/Engagement. The Cronbach's Alpha coefficients between $0.70 \leq \alpha \geq 0.80$ are 'acceptable' while between $0.80 \leq \alpha \geq 0.90$ are considered 'good' and coefficients $0.9 \leq \alpha$ are 'excellent'. Therefore, the internal consistency of the various scales was deemed acceptable for further interpretation:

Table 1: Summary of Reliability Statistics

Construct	Management		Construction workers	
	Cronbach's Alpha	Reliability	Cronbach's Alpha	Reliability
Health and Safety Policies	0.864	Good	0.880	Good
Workers Involvement/Engagement	0.840	Good	0.926	Excellent

Data interpretation

The data range interpretations for the study were based on the 5-point Likert scale. The group interval coefficient value for the 5-point Likert scale was calculated as 5/3 = 1.67 and interpreted as high, medium and low. High (H) for ranges 5.00 – 3.34; Medium (M) for ranges 3.33 – 1.68 and Low (L) for ranges below 1.67.

Health and Safety Policies

Management and construction workers working in different construction companies were presented with statements to rate their level of agreement on the matters relating to health and safety policies on their construction sites. The rate of the measure was a 5-point Likert agreement scale (1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree and 5=Strongly Agree). Table 2 shows the findings:

Table 2: Health and Safety Policies

Statements	Management				Construction Workers			
	Mean	SD	Intr.	Rank	Mean	SD	Intr.	Rank
All workers undergo orientation/induction before they are allowed to start work on site	4.42	0.77	H	1	4.07	1.23	H	3
More H&S education and training is needed	4.27	0.99	H	2	4.13	1.14	H	2
Workers are encouraged to report unsafe and unhealthy	4.20	0.91	H	3	3.83	1.58	H	6

behaviour and working conditions								
Workers are trained in the proper care and use of PPE according to the requirements of construction regulations	4.16	1.01	H	4	4.80	0.41	H	1
Health and Safety policies are written and in place	4.09	0.83	H	5	3.93	1.46	H	5
We have regular H&S meetings	3.88	1.05	H	6	3.30	1.32	M	9
Construction accidents are caused by workers non-compliance with construction policies	3.79	0.86	H	7	3.60	1.10	H	7
Construction policy requirements on safe work procedures are discussed at H&S meetings	3.79	1.17	H	8	3.97	1.52	H	4
All workers are kept informed of the provisions of the H&S plan	3.77	1.15	H	9	3.33	.93	M	8
Worker have training/workshops in relation to H&S policies	3.64	1.21	H	10	3.27	1.39	M	10

Managements' response

Based on findings in Table 2, it is evident that workers underwent induction before they were allowed to work on-site (mean=4.42). However, the findings further indicated that there is still the need for more health and safety education and training (mean=4.27). Workers were encouraged to report unsafe and unhealthy working conditions and trained in the proper use of PPE (means ranged between 4.20 and 4.16). Managers also highly agreed that health and safety policies were written and in place; that health and safety meetings were conducted regularly and also, that accidents were caused by construction workers non-compliance with the regulations, even though safe work procedures were discussed in meetings (means ranged between 4.09 and 3.79). The extent to which the requirements for safe work procedures were discussed in meetings remains unclear. This finding was in line with whether regular H&S meeting were being held as the agreement level between management and workers was not the same. There is the need for further research in this regard. Management further agreed that workers were informed about the provisions for health and safety plan and had training concerning the construction regulations though the agreement level was not very high (mean = 3.77 and 3.64). It is evident that workers level of training is not sufficient based on the mean values. This could be the reason why management conceded that accidents are a result of workers' non-compliance. Additionally, this could also be the misplaced focus of incident and accident investigations which only examine the trigger event before each occurs. More education and training are required to ensure proper health and safety policy administration on site.

Construction Workers' response

From the findings, the high level of agreement by construction workers suggested that they received adequate training on the proper use of PPE (mean=4.80). However, more training and education were necessary even though workers were inducted before they were allowed to start working on sites (means were 4.13 and 4.07). There were high levels of agreement by the construction workers that the requirements for safe work procedures were discussed in meetings; health and safety policies were written on-site; workers were encouraged to report unsafe work practices; and that accidents were caused by workers' non-compliance with the regulations (means ranged between 3.97 and 3.60). There was, however, a medium level of agreement whether workers were always informed about the health and safety plan; the regularity of health and safety meetings, and whether workers were trained on the construction regulations (means ranged between 3.33 and 3.27). The finding that workers were unsure about the construction policies furthers suggests otherwise to the response given by management. It is the responsibility of the managers to inform workers about the expectations in the workplace.

Workers Involvement/Engagement

Table 3 further explored workers' involvement/engagement in health and safety-related matters on construction sites. The respondents were asked to rate their level of agreement based on a 5-point Likert scale (1=Strongly Disagree, 2=Disagree, 3=Neutral, 4=Agree and 5=Strongly Agree).

Table 3: Workers Involvement/Engagement

Statements	Management				Construction Workers			
	Mean	SD	Intr.	Rank	Mean	SD	Intr.	Rank
Workers are responsible for the H&S of their fellow workers	4.44	0.56	H	1	4.20	1.49	H	2
Workers have the right to refuse to work in unsafe conditions	4.38	1.20	H	2	4.17	1.42	H	4
Workers are responsible for their H&S	4.25	0.94	H	3	4.03	1.22	H	5
Most workers on-site view H&S as important	3.78	0.92	H	4	4.53	0.69	H	1
Workers regularly report unsafe and unhealthy behaviour and working conditions	3.75	0.91	H	5	3.93	1.14	H	6
Workers are involved with H&S inspections	3.53	1.07	H	6	4.17	0.91	H	3
Workers are consulted when the H&S plan is compiled	3.00	1.27	M	7	3.33	1.57	M	7
Workers participated in the formulation of the H&S policy	2.97	1.19	M	8	3.00	1.49	M	8

Managements' response

The findings in Table 3 indicate high levels of agreement that workers are responsible for the health and safety of their colleagues; their health and safety, and also have the right to refuse work in unsafe conditions (means ranged between 4.44 and 4.25). Management indicated that most workers regarded on-site health and safety important (mean=3.78) and regularly reported unsafe behaviour and working conditions (mean=3.78 and 3.75). There was high workers' involvement in health and safety inspections though the level of involvement was not enough (mean=3.53). There was a medium response level however, as to whether workers were consulted in the compilation of health and safety plans and the formulation of health and safety policies (means were 3.00 and 2.97). The findings suggested that workers were not fully involved in all work-related health and safety matters. According to management, workers do not fully realise the importance of health and safety. However, it could be argued that managers need to ensure that workers realise the importance of health and safety, who may not be aware of certain health and safety requirements.

Construction Workers

The workers highly regarded the importance of health and safety on site (mean=4.53). The respondents also had a high level of agreement that they were responsible for other workers' health and safety; their health and safety; their involvement in health and safety inspections; that they had the right to refuse unsafe working conditions; and reported unhealthy behaviour and unsafe working condition on site (means ranged between 4.20 and 3.93). Construction workers gave a medium level of agreement on whether they were consulted in the compilation of health and safety plans; and participation in the formulation of health and safety policies (mean=3.33 and 3.00). From the findings, it may be inferred that workers were not too involved, if at all involved, in the planning and formulation of health and safety documentation. There was consensus among both management and workers in this regard. Therefore, there is a need for more collaboration between workers and management to improve health and safety standards.

Analysis of composite means of constructs

The composite means of the constructs Health and Safety Policies and Workers Involvement are shown in Table 4. A comparison of the composite means between management and construction workers was done to identify differences in responses:

Table 4: Summary of Composite Mean Values

Management					**Construction Workers**			
	Mean	SD	Inter.	Rank	Mean	SD	Inter	Rank
Health and Safety Policies	4.00	0.68	H	1	3.83	0.87	H	2
Workers Involvement	3.76	0.71	H	2	3.94	1.03	H	1

Furthermore, an independent t-test was conducted in Table 5 to determine the statistical significance of the differences in the composite means between managers and workers in Table 4. Independent t-test is used to determine whether two sample means, which are assumed to come from two different groups, are statistically significant (Burnham, 2015; Field, 2017). The p-value is used to determine whether there is any statistical significance between the two means (Barnham, 2015). A statistical significance between the means suggests that either management or the construction workers had a higher agreement level of the measured construct. When using an independent t-test, the first step is to test the assumption of homogeneity. Levene's test (f-test) is used to test the assumptions of the homogeneity for equal variances (Pagano, 2004). Where there is no statistical significance between the means ($p>0.05$), the assumption is not violated and 'equal variance is assumed'; meaning that the first line is used to interpret the results. However, where there is a statistical significance, the assumption is violated ($p\leq0.05$) suggesting that equal variance is not assumed and the second line of interpretation is used.

Table 5: Independent Samples T-Test

		Levene f-test		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Dif.	Std. Err Dif.	95% Confidence Interval of the Difference	
									Lower	Upper
Health and Safety Policies	Equal Var. A	2.359	.128	1.046	92	.298	.172	.164	-.154	.497
	Equal Var. N/A			.956	46.080	.344	.172	.179	-.190	.533
Workers Involvement	Equal Var. A	12.021	.001	-.964	92	.337	-.176	.182	-.538	.186
	Equal Var. N/A			-.845	42.271	.403	-.176	.208	-.596	.244

Health and Safety Policies

Comparatively, there was a high level of agreement among managers (mean=4.00, SD=.68) and construction workers (mean=3.83, SD=.87) regarding the availability health and safety policies on-site. There was no statistical significance between the means t (92) =1.05, p=.298; suggesting that both management and construction workers overall shared the same views on the availability of Health and Safety Policies on site. Overall, the requirements for health and safety policies on site were still not satisfactory. In most instances (Table 3), it seemed as though construction workers were excluded in the administration of health and safety and only involved in the execution and implementation aspects.

Workers Involvement

Overall, both management (mean=3.76, SD=.71) and the construction workers (mean=3.94, SD=1.03) highly agreed that workers were involved in workplace health and safety-related matters. The differences between the means were not statistically significant, t (42.27) = -.845, p=.403; suggesting both groups shared the same views. There is still a need for more workers' involvement and management to encourage workers' involvement despite similarities in mean scores in key areas of health and safety.

Spearman's Correlation

Spearman's rank-order correlation (rho/rs) was used to measure the strength and direction of association/relationship between the constructs: Health and Safety Policies and Workers' Involvement.

Table 6: Spearman's Correlation:

Management (N=64)		
	H&S Policies	Workers Involvement
Health and Safety Policies	1.000	.599**
	.	.000
Workers Involvement	.599**	1.000
	.000	.

Construction Workers (N=30)		
	H&S Policies	Workers Involvement
Health and Safety Policies	1.000	.671**
	.	.000
Workers Involvement	.671**	1.000
	.000	.
**. Correlation is significant at the 0.01 level (2-tailed).		
*. Correlation is significant at the 0.05 level (2-tailed).		

Managements' response

The correlation between Health and Safety Policies and Worker Involvement was statistically significant, suggesting that the availability and implementation of 'H&S Policies' increased knowledge on site, and also, increased the Workers' Involvement in health and safety related measures on site ($r=.599$, $p<0.000$). The findings indicated a strong positive correlation between H&S Policies and Workers' Involvement.

Construction Workers response

The correlation between H&S Policies and Workers Involvement was positive and statistically significant ($r=.671$, $p<0.000$). The strong correlation suggested that an increase in H&S Policies on-site increased Workers Involvement. The findings were similar to those provided by management.

Discussion and Conclusion

This study investigated the involvement of construction workers in the formulation and implementation of construction health and safety policies on construction sites. Based on the findings of this study, health and safety policies were made available on-site, even though, the respondents agreed they were still not sufficient. An increased level of compliance with the health and safety policies could significantly improve the involvement of workers' health and safety issues on site. Fragmentation was further noted between management within construction companies and the construction workers since both respondents did not agree on some issues. There is need for more education on health and safety policy as a mediator and the need for integration among management and workers in order for contractors to realise the benefits of policies and to engender full commitment towards implementation and compliance. However, the expectation would have been that both management and construction workers within construction companies possessed enough knowledge in order to improve their level of compliance and to improve construction workers wellbeing. Management in construction companies need to involve workers in the implementation and formulation of health and safety policies. They should also empower workers to be the key personnel advocating policy instead of relying on them. This in-turn could improve health and safety and assist management to make informed decisions since workers are physically involved in the execution of activities on-site.

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Evaluating the role of leadership within Construction SMEs, for improving health and safety performance

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Abstract

The construction industry is complex, dynamic and viewed as a high hazard industry. Official accident and ill-health data from HSE demonstrates conclusively that the health and safety performance of the construction sector is still below the all-industry average. Small and Medium-Sized Enterprises (SMEs) are vital to the technical development and sustainability of the UK construction supply chain. However, construction SMEs are also a significant high-risk factor for accidents and incidents. The greatest power for change being with leaders as they have the most influence. This research aims to evaluate the critical success factors, drivers and decision-making practices of leadership, which lead to positive health and safety improvements with the Construction SME sector. A qualitative research method using a focus group process was adopted and considered one critical stakeholder's group. The main themes were leadership, safety management and systems, health and safety culture and performance improvements. Data was reviewed and analysed within an encompassing 4 P structure of Partnership, Process, Performance and Pressures. The initial positive findings from “Partnerships” relating to communication through action, visibility and relationship trust and closely linked to “Pressures” through financial constraints, market conditions and understanding the business.

Keywords: Leadership, Safety Management System, Safety Performance, Construction, SME.

Introduction

The principles of promoting the construction industry's health and safety performance align with the main recommendations of the Farmer Review (2016). His report, explicitly undertaken for the Construction Leadership Council, highlighted adverse industry matters of structural fragmentation, workforce size, collective stakeholder leadership fragmentation and poor image, which has restricted the development of the construction industry within the UK. There is a growing dependency upon and influence of SMEs, and the part that they play within the construction industry supply chain. The development of the UK construction industry has led to a “Construction Labour Model” (Farmer, 2016) that is significantly reliant upon an SME supply chain. In 2018 the construction SME sector had more than 1 million organisations with an expected growth expected to be 3% per year (Department of Business, Energy and Industrial Strategy, 2018 New stats to be released 18th Oct 2019 Therefore, by having such a significant quantity of UK construction organisations within the SME sector, this creates an overall business vulnerability for the construction industry. Previous research undertaken with SMEs identified that SMEs take a different approach to risk and have a different perspective on dealing with extreme events than large organisations (Sullivan-Taylor and Branicki, 2011).

Therefore, by considering existing skills, knowledge and behaviours of entrepreneur directors, owners and front line supervising leaders of construction SMEs, consideration of best industry practice and innovation could create an altered approach for health and safety performance improvement. Stogdill (1950) defined leadership as “the process (act) of influencing the activities of an organised group in its efforts toward goal setting and goal achievement," created an important distinction that went beyond merely defining leadership solely within the individual.

Theories have been developed to categorise and identify causal determinates of the effectiveness of leadership, such as their traits (Fiedler 1978), behavioural styles (Flieshman et. al 1973), dyadic relationships (Graen, 1976) and subordinate perceptions (Hollander and Julian 1969; Lord 1998), transformational acts (Bass, 1985). These theories have developed and relate to those of transformational theory (relationship theory) (Sashkin, 2004) and transactional theory (management theory) (Bryant, 2003). The purpose of developing leadership or structure is to a way of providing models that can be developed and implemented for the growth of essential leaders (Bray, Campbell and Grant, 1974; Glickman et al. 1968 in Fleishman and Mumford 1991). Kempster et al. (2011) views the role, purpose and practice of leadership going beyond vision, mission, shared goals, objectives and plans. Hunt and Conger (1999) link to a broader corporate social perspective in balancing the need of individuals, responsibility towards society and future generations and the sustainable need to generate profits.

The philosophy of implementing a health and safety management standard, such as ISO 45001, is the aim of providing a framework to reduce the impact of health and safety accidents in the organisation, irrespective of the size of the organisation or industry. This aids in providing greater independent assurance as to its leadership role and requirements (Roberts, 2016). The importance of focusing on the role of health and safety through leadership, within Construction SMEs, requires a greater understanding of the relationships between the leader and stakeholders (Partnerships) and the business environment (Pressures). The leader will have a perception of the external drivers (Performance) of health and safety for business sustainability (Process) and convey their vision and values through interaction and communication with employees and the broader stakeholder community. The elements of vision and values are significant within leadership theory, particularly transformational leadership theory, as these elements have been identified as encouraging trust as a universal significance between the leader and the follower (Gillespie and Mann, 2004).

Zohar and Luria (2005) recognise the vital importance of safety culture and leadership and provide a new perspective of leaders as a relevant role model within safety culture. The ability to influence others recognises the importance of a leader as a role model and create a strong belief in charismatic leaders (Cooper, 2005). Cooper also acknowledged that effective leadership is an essential feature for active safety culture because leaders determine the attitude of the organization's members regarding safety issues and their corresponding reactions. Burns (1978) identified that the theory of leadership is exercised when persons with certain motives and purposes mobilise resources to arouse and satisfy the followers' motivations and that our historical view of leaders is quite negative. The relationship between the leader and the follower is not about coercion and exploitation. The most powerful influences are human relations and engagement. Real leadership consists of leaders inducing followers to act for specific goals that represent the values and motivation of both leader and follower. The more senior the leader, the higher their potential influence can be for safety (Flin and Yule, 2004).

Skeepers and Mbohwa (2015) found that construction health and safety performance is affected by leadership behaviour, with improvement where there are strong foundations in communication, commitment and employee training. They go on to suggest that the sound principles of leadership are the same positive behaviours associated with safety management and are themselves generally progressive leadership behaviours. The management philosophy of Deming's Plan-DO-Check-Act cycle (1982) identifies employee engagement, teamwork and continuous improvement as being key behaviours for health and safety leadership.

A significant motivator for SMEs' leaders is the long-term financial development of the company. Therefore, a more defined link should be created between leadership, improved health and safety performance and the impact for company development The impact of which relates to a potential for the socio-economic development, for local areas, (Kheni et al. 2007) where construction SMEs attraction their workforce and work. A real opportunity for improving safety standards, within SMEs, may consider the innovative leader (Basu and Green, 1997) and entrepreneurial leader (Taylor and Branicki, 2011 b) as having the opportunity, beyond that of the resources associated with larger organisations, to improve health and safety performance.

Previous research for health and safety within construction SMEs had focused on Safety Management Practices and legislation (Unnikrishnan, et. al 2015) training (Holte et al. 2015), behavioural safety (Stiles, et. al 2012), safety culture (Agumba and Haupt, 2009) and politics and social culture (Kheni, Dainty, Gibb, 2007). Other research has considered leadership for health and safety SMEs; however, this was not in a construction context (Mirza and Nizma Isha, 2017). Therefore, a gap in the literature identifies an opportunity to focus on leadership's role in improving health and safety performance within construction SMEs.

Methodology

Qualitative study

A qualitative research study approach was applied to study leadership's best practice for health and safety within construction. The qualitative research approach would allow for a specific context to be analysed from a real-life, lived experience through a focus group. The focus group participants were chosen on a deliberative sampling basis and consisted of six elite, construction, health and safety professionals. A small number of participants were chosen for the focus group due to being more natural to host and manage. As the small group size can be viewed as a limitation, the justification was for the participants' to be comfortable and allow for an unhindered in-depth insight into their experience, which is better accomplished by a smaller group. A smaller group allows each participant more time to share their experience, gain understanding, and explore, in context, examples. The benefits are that all participants can develop intense or lengthy experiences, which aid discussion (Krueger and Casey, 2014). The participants work in construction, with between 3 and 40 years of experience, from SMEs to large, global-sized organisations and are predominantly based in Scotland.

By evaluating the professional lived experiences and opinions and comparing the different characteristics, an initial framework of possible cause and effect (Mathews and Ross, 2017) was developed in alignment with the qualitative research approach. As a focus group, the strategy considered the main themes in line with the literature review. The focus group was allowed to review the collected data for validity, add comments, or clarify their comments. Semi-structured questions were used to provide a conversational tone and allow the participants to use their own words (Longhurst, 2016).

Sampling

The purposive sampling focus group was of Health and Safety professionals. This group allowed the views from a wide range of experience, including the organisation's size and different construction industry sectors. This data source was to allow for a view of positive and negative leadership practices.

The rage of experience and variety of the size and type of construction sector provided various topics relevant to experience; however, much was made of contemporary examples allowing other participants to develop.

Data collection and analysis

The main features of a leader

The data collection consisted of providing questions based upon the fourth main themes identified within a literature review: Leadership, Safety Management, Health and Safety Culture and safety performance. A thematic analysis was then undertaken to identifying the relationship with Sodhi and Tang (2017) 4P conceptual framework (Pressure, Partnerships, Practices and Performance) relating to specific action parameters. Previously the benefits of using such a method allowed for the development between theory and practice (Goi, 2009). Their structure provides an inclusive methodology based upon broader literature themes which relate to each other for performance measurement:

1. Pressures (Planning and reacting to Industry and market: the work and economic environment).
2. Partnership (Leadership theory: relationship and motivation between the leader and the follower).
3. Practice (Behaviour process and practices related to health and safety, climate culture, management and controls) and the relationship of the first 3 Ps to
4. Performance (measures that define a baseline and allow for improvements).

Identifying other constraints such as pressures demanded upon a leader and the impact on the relationship with the follower provides a perspective of the impact of the 4Ps on beliefs, behaviour, and relationships for the construction SME leader's health and safety performance.

The first discussion topic related to the main features of "positive leadership". The traits (Fiedler, 1978), behaviours (Flieshman, 1973) and expectations of a positive or good leader explored.

The focus group provided examples of positive leaders and relationships they had experienced, with one participant discussing the relationship with the DuPont Bradly curve theory as a method of performance development of a maturing organisation.

Variation of health and safety leadership between an SME and Large Company

This discussion wished to explore what differences exist between the leadership of health and safety SMEs and Large (L) construction companies (Table 1). The identification of difference is essential to establish since health and safety legislation has limited progressive aspects and attracts all companies irrespective of the size of the organisation and the limited research for Leadership within Construction SMEs.

There were general elements of consensus and distinct differences between leadership for SMEs and Large construction companies, which also relate to health and safety, which can be applied to benefit performance improvement.

Table 1 - Variation of health and safety leadership between an SME and Large Company

Partnerships	Practices	Pressure	Performance
Their people, they care. (SME)	Pros- easy to communicate, easy to change (SME)	Go with standards set by e.g. client, main contractor, greatest influence in the supply chain. (SME)	Difficult to measure leadership. (SME and L)
Fear of enforcing positive practices up the chain/client. (L)	Communication-can be difficult to change. (L)	Financial pressures (SME)	Self-motivated (SME)
Provide or allow for empowerment down the line. (SME)	Complex process for large organisations (such as due diligence etc.) (L)	Values of others influence. (SME)	Desire to grow (SME)
Authority given to Health and Safety Managers. (SME)	Easier for large Orgs to influence H&S (positively/negatively)	Values of individuals brought onto the site. (SME)	Higher level of H&S Leadership (SME)
	Easier for SMEs to adapt. (but, sometimes happens through external pressure)	Timing of others constraints (deadlines and demands) (SME)	
	Be an Advocate of system (L)	Barriers/clashing cultures with others (SME)	
	Leadership, positive practices (SME easier to observe)	Limited and access to resources (SME)	

Identification and evaluation of external factors on health and safety leadership

This discussion topic was to review the complicated relationship between the leader and follower as they are influenced by other factors and not a binary function with influences outside the leader's control (Table 2), such as those that affect a whole industry. The discussion associated with this topic, centred around the combined areas of partnerships and pressures from stakeholders, predominantly from the more powerful section of the supply chain. Positive elements can be identified that external drivers can add value to an SME, such as support from the supply chain and working to higher standard requirements.

Table 2 - Identification and evaluation of external factors on health and safety leadership

Partnerships	Practices	Pressure	Performance
Build loyalty (lead to investment of time/money for training and support within the supply chain)	Ability to change to meet demands	Provision of continuity of work- Positive aspect	Reputation
Potential for government initiatives (e.g. asbestos removal creates work)	Should be considered with in a wider risk management context	Time pressure created by others	Negative driver for H&S Leadership action
Relationship with client	Greater potential for the use of technology	Sustainability of work	The size of the organisation and the ability to cope
Cultures created by Large Organisations	Beliefs	Penalties for SMEs	External influence on SMEs can add value
Redirect leadership through interventions of e.g. HSE (Fee for Intervention has changed relationships)	Behaviours	New systems guidelines for HSE prosecutions/fines	Professional body information (healthy working lives campaign (goals, aims accreditation)
Big organisations helping small organisations	Gain access to tender lists (ISO accreditation, leadership requirements)	Cost cutting practices greater influence on SMEs sustainability	Sense of achievement (IOSH merit of award)
Professional body support (health working lives campaign)		Current market conditions	Industry recognition
Third party Accreditation (ISO 45001)			Ability to access funds and grants for training and technical competency (vital for SMEs)
Education- Further and Higher education providers –level of H&S provision and recognition			

The impact of Leadership on Health and Safety Culture

Cooper (2001) detailed the importance of leadership as a useful trait for a positive organisational health and safety culture, as it helps define how members of the organisation will act when safety matters. Therefore, it was essential to obtain the perspective of leadership and the relationship as well as the elements that impact the SMEs health and safety culture (Table 3).

The most significant influence on health and safety is related to the practices of the leaders. These points of discussion are then closely linked to the organisation's comments for health and safety performance.

Table 3 -The impact of Leadership on Health and Safety Culture

Partnerships	Practices	Pressure	Performance
Maintain contract relationships through culture	Awareness of health and safety culture helps identify "why you are doing it"	Understands the business financial position	An evaluation of culture (Bradley curve theory)
Support by most senior person	Two-way communication (Good communicator)	What am I spending and why am I spending it	Understands what it is the business is trying to achieve
Credibility though Respect, Trust and being convincing	Credibility, ability to argue and convince		Safety is a value not a priority
Trust is earned – it needs to be a constant	Understands the business		Values need to change, lead by involvement
	Lead by example Visible action of most senior persons Engagement (buy-in)		Identifies standards

Findings and Discussion

Within the discussion associated with the main features, the discussion topics were spread across the four elements of Partnership, Practices, Pressures and Performance. However, the most central theme was associated with Partnership and the relationship between the Leaders and the follower predominantly front the follower's perspective. This theme suggested that respect, care, other people's view, approachable, and communication would be expected of a leader. These elements of leadership then related well to Performance, not in the number of responses but the emotive language use, vision, passion, drive and expectation. It would suggest that the follower is looking for a purpose to believe this is someone worth following.

With limited research associated with leadership within construction health and safety SMEs, it was essential to evaluate if there was suitable differentiation between the leaders of health and safety for SME and Large construction companies. The Pressure component identifies that there was potential more for leaders of an SME to consider due to the diverse roles are undertaken by the Director/Owner to address other areas other than solely construction practices. The second most prominent component was Practices. These became positive aspects for SMEs due to the shorter links in communication and potentially more natural change of direction and tactics with the often research identified problems for SMEs of financial pressures. A subsequent question was asked of SME leaders as entrepreneurs. All participants agreed there were significant elements of cross over, between aspects of an Entrepreneurship, to that of a leader. It was agreed that the Entrepreneur would be at the start-up stage of innovation for the company. Many adjectives were used to identify what an Entrepreneur was however, at some point, there would need to be a change, if the business was to grow as per the strategic principles of an SME. An Entrepreneur would need to exhibit or develop leadership skills to create motivation of the follower, through clear and appropriate communication. Only then would this allow the organisation to transform, develop and grow further. For improving performance, there would still be drive to grow the organisation; however, it is the limits of the leader’s knowledge and understanding that often prohibits the company’s growth due to the requirement of additional special skills associated with an entrepreneur (Taylor and Branicki 2011). Overall the opinion that the Entrepreneur could take a business only so far, and the next stage of development would be based upon leadership.

The relationship between a leader and the follower is not single-dimensional. External factors impact the relationship. Influencing external factors are associated with the external partnerships and stakeholders within the supply chain, as well as the effects of unplanned health and safety issues from the site and addressing change from clients and other contractors. Addressing the continuity creates additional external pressures by meeting demands of others' time scales, standards and quality were also identified as pressures, more so for SME contractors due to the limited resources, not so much the flexibility of resourcing tradesmen but their availability. Positive aspects were supported by large organisations, who allow access to resources such as training and health and safety guidance from their organisation. One participant's view was that “real health and safety leadership would be working to the aspiration of no accidents” and supported by another as “the real focus for health and safety leadership.”

An organisation's culture is a driving force for growth, development, and performance (Cordes, et al. 2011). The first response identified that leadership was significant to the organisation's culture and was attributable to the previous element discussed. Practices were identified to have the most significant impact on the culture with the influence on health and safety performance. Therefore, the leader’s awareness, credibility, leading by example, and visible actions to create trust and buy-in from the follower would again identify health and safety as a value (Reiche et al. 2017). The expectations and standards set by the leader create the culture and in turn, would have the most effect on health and safety performance.

Conclusions

One of the most significant findings from the focus group is that there is a difference between the leadership role within an SME compared to that of a large construction company. It requires additional skills, a broader understanding of soft skills such as communication and motivation, technical skills for construction and health and safety controls for the hazards encountered, and people skills for the followers' motivation. These skills are achievable within the setting of additional external pressures of the SME, including financial, economic climate, design and market changes. Of the framework elements, themes, all except the features of a leader, often exhibited a close relationship between two of the 4P's, clearly identifying the relationship which leadership has with the elements of the structural framework of Partners, Processes, Pressures and Performance and the potential permeability of health and safety performance improvement has for construction SMEs. With the inclusion of flexible access to continual personal development, leadership skills, and progressive, relevant health and safety performance improvement processes can improve the link between leadership and health and safety performance within construction SMEs. This research is limited by a narrow view of the leader-follower relationship within a localised Scottish perspective. It did not specifically identify any particular type of construction SME regarding the Owner/Director, the site supervision, or site operative. However, the data was from a precisely focused expert perspective on construction health and safety, and the discussion considered health and safety, to the organisation.

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