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Building Digital Competence: Advancing Data-Driven Culture in the Malaysian Construction Sector

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Abstract

The operationalisation of a data-driven culture is increasingly recognised as a transformative force for improving productivity and competitiveness within the construction industry. Despite advancements in digital technologies, the construction sector, particularly in Malaysia, has been slow to embrace this cultural shift. This study explores key attributes required for fostering a robust data-driven culture, focusing on leadership, literacy, democratisation, and analytics. A systematic literature review identified 33 critical indicators across these domains, validated through focus group discussions with industry practitioners. Subsequently, a structured questionnaire survey was administered to construction stakeholders in Malaysia. The results indicate that Digital Knowledge Expertise, Competency Measurement, Continuous Professional Development, Quality Assurance, and Financial Resource Allocation are the most influential drivers. Conversely, significant gaps were identified in areas such as external collaboration, predictive analytics, and digital tool proficiency. To address these gaps, the study proposes a conceptual framework that integrates four interrelated drivers and provides a structured pathway for advancing data driven practices in construction organisations. This framework offers practical implications for aligning leadership, capacity building, and data governance with national digital strategies. This study extends the current literature by providing a new perspective into the competencies required to institutionalise data driven transformation in developing construction sectors.

Keywords: Data, Construction, Data-Driven Culture, Developing countries, Digital Transformation

1. Introduction

In today's increasingly digitised world, data has emerged as a critical organisational resource, often likened to oil for its transformative potential in driving competitiveness and innovation (Anton, 2023). Across various sectors, data-driven cultures have become powerful catalysts for change, enabling organisations to establish analytics infrastructures that collect, assess, and effectively utilise user data (Kollwitz, 2018). A robust data-driven culture fosters collaboration within and beyond organisational boundaries, enhancing engagement, adaptability, and efficiency. It shifts decision-making processes from reliance on intuition and experience to informed strategies grounded in data (Chaudhuri, 2023).

The rapid advancement of information and communication technologies (ICTs) and the ongoing digital transformation across industries have accelerated the adoption of data-driven practices. In healthcare, for example, data culture facilitates knowledge management systems and information-sharing behaviors, improving patient care outcomes (Goncalves et al., 2024). Similarly, in retail, technologies such as Artificial Intelligence (AI), blockchain, and robotic process automation are transforming supply chains into more resilient, sustainable, and collaborative networks (Chen et al., 2024). The manufacturing sector has also seen significant operational improvements, with data-driven transformation enhancing efficiency and performance (Ghafoori et al., 2024). Furthermore, the integration of data culture into educational systems has fostered innovation and improved knowledge management (Eshbayev et al., 2023).

Yet, in many developing countries, including those with rapidly expanding construction sectors, digital transformation remains constrained. Limited financial resources, inadequate infrastructure, and a shortage of skilled professionals often hinder the implementation of advanced digital solutions. Additionally, resistance to change and a lack of awareness about the benefits of digital transformation contribute to slow adoption in these regions (Pittri et al., 2025).

Despite these challenges, certain countries have made notable progress. Malaysia, for instance, has demonstrated a proactive approach towards digital transformation in its construction sector.

Malaysian construction firms utilise an average of 6.9 digital technologies, surpassing the regional average by 50% and ranking second among six Asia-Pacific countries surveyed, including Japan, Singapore, and Australia. Notably, 23% of Malaysian construction firms' budgets are allocated to the implementation of new technologies, reflecting a significant commitment to modernising operations and enhancing competitiveness (CIDB, 2024). Among these technologies, Building Information Modelling (BIM) has gained the most traction in Malaysia and currently forms the primary vehicle through which data-driven practices are operationalised (CIDB, 2024).

However, despite this momentum, barriers common in other developing countries persist. Integration difficulties, fragmented processes, financing constraints, skill gaps, and risk aversion still slow the sector's full embrace of data-driven work practices (Tummalapudi et al., 2022; Akinyemi et al., 2018). The absence of an overarching framework for cultivating a data-driven culture leaves critical knowledge gaps (Bilal et al., 2016), perpetuating challenges such as weak strategic planning, poor communication, and limited cross-stakeholder collaboration (Yu et al., 2021; Lu et al., 2021).

Despite these challenges, fostering a data-driven culture in construction offers transformative potential. Research indicates that implementing data culture can lead to reduced workloads, greater reliability in estimating numerical data, increased assertiveness in decision-making, and enhanced controllability in project management (Bilal et al., 2016). The adoption of data science can also enhance transparency, communication, and the management of personnel and equipment, which are essential for the success of projects involving multiple stakeholders (Brodny and Tutak, 2025). Furthermore, integrating advanced data technologies with organisational culture enables employees to better understand tools and methods, identify opportunities, and share solutions within their organisations, ultimately driving innovation and improved outcomes (Bilal et al., 2016). Best practices for promoting a data-driven culture include the development of frameworks that focus on datafication, data production, data cultivation, and infrastructure, as well as the establishment of dedicated data science

departments (Hatoum et al., 2020; Hashim et al., 2024). Such approaches foster continuous improvement and provide organisations with a competitive edge in the construction industry.

While frameworks for data-driven practices in other industries provide valuable insights, they do not fully address the unique complexities of the construction sector, such as project diversity, stakeholder heterogeneity, and resistance to change. Recognizing these challenges, this study specifically focuses on the Malaysian construction industry, which presents both unique challenges and opportunities in adopting a data-driven culture. Malaysia is currently undergoing a significant shift through strategic national initiatives such as the Construction 4.0 Strategic Plan (2021–2025) and the National Construction Policy 2030 (NCP 2030), both of which aim to accelerate digital adoption across the construction value chain. These policies emphasize the integration of technologies like BIM, IoT, and big data analytics. However, limited research has empirically identified and prioritised the specific organisational attributes required to cultivate a data-driven culture that can support and sustain these transformations (Musarat et al., 2024). The central research question posed is: What are the key attributes that Malaysian construction organisations must possess to successfully adopt a data-driven culture? Consequently, the purpose of this paper is to identify the critical attributes of a data-driven culture in Malaysian construction organisations and to assess the relative importance of these attributes in fostering digital transformation and improving organisational performance.

Initially, a comprehensive literature review was conducted to identify key elements of data culture and their drivers, such as data analytics, data literacy, data democratisation, and data leadership (Hashim et al., 2024). Building on this theoretical foundation, a questionnaire survey targeting industry practitioners in Malaysia was carried out. The survey gathered insights from contracting firms, consultancy organisations, and client organisations on the operationalisation of a data-driven culture within the construction sector. This approach provided industry-wide perspectives on the relative importance of these practices, offering actionable recommendations for aligning the construction industry with global digital transformation trends while addressing localised challenges.

2. Key elements of data-driven culture in construction organisation

The concept of data-driven culture in this study refers to an organisational environment in which data is systematically collected, analysed, and embedded into decision-making processes across all levels, enabling more accurate, timely, and strategic actions (Acker and Clement, 2019). This definition provides the foundation for understanding how data culture supports digital transformation in the construction industry.

A separate study by Hashim et al. (2024) was initially conducted to identify the key elements of a data-driven culture specifically within the construction sector. A systematic literature review (SLR) was carried out to determine the essential attributes aligned with four primary domains of data culture: data leadership, data literacy, data democratisation, and data analytics. These domains, presented here as subsections, collectively form the core of a data-driven culture.

2.1 Data Leadership

Data leadership refers to the capacity of organisational leaders to integrate data-centric goals into strategic decision-making and operational management. It includes promoting digital expertise, ensuring quality assurance in digital activities, overseeing project progress, and aligning practices with legal frameworks (Akinyemi et al., 2018). Strong data leadership is essential for embedding data-informed strategies into an organisation's culture, thereby setting the foundation for digital transformation and improved project outcomes (Srinavin et al., 2021).

2.2. Data Literacy

Data literacy encompasses the skills and knowledge stakeholders need to effectively interpret, analyse, and utilise data across various organisational tasks. Critical elements within this domain include technology adaptability, digital knowledge transfer, proficiency with data tools, competency measurement, and continuous professional development (Lu, 2021; Xie et al., 2022). Cultivating these skills among construction professionals is crucial for maximising the benefits of data-driven decision-making practices.

2.3 Data Democratisation

Data democratisation involves establishing mechanisms that guarantee broad access to data, enabling seamless collaboration and robust data governance throughout the organisation. It highlights the importance of interoperability, collaboration between internal and external stakeholders, and the standardisation of data procedures (Honcharenko et. al., 2021) Effective data democratisation practices promote inclusive data use, enhance organisational transparency, and drive collaborative innovation (Eshbayev et. al., 2023).

2.4 Data Analytics

Data analytics consists of methods and techniques used to convert large, diverse datasets into strategic insights, facilitating informed decision-making. This domain comprises descriptive, diagnostic, predictive, and prescriptive analytics. Applying advanced analytics in construction enables organisations to anticipate outcomes, optimise performance, mitigate risks, and drive continuous improvement through evidence-based decisions (Wu et al., 2022).

The literature further identified five sub-attributes adapted from Arbury et al. (2017) and Acker and Clement (2019): datafication (turning construction processes into quantifiable data), infrastructure of data (technical ecosystems and funding to sustain data management), cultivation of data (training, skill development, and readiness for organisational change), culture of use (interoperability, collaboration, and standardised procedures for data exchange), and culture of production (systematic data gathering, extraction, and outcome-focused analytics). Additionally, data utilization, defined as the application of data-driven insights to inform decision-making, ensures that analytics outputs, such as cost forecasts or schedule optimizations, are actively integrated into project management practices to address issues like budget overruns or delayed deliveries (Bilal et al., 2016; Adekunle et al., 2022).

It is worth noting that these five sub-attributes are closely linked to the four primary domains, forming a cohesive framework that addresses key challenges in the construction industry. For example, datafication supports the Data Leadership domain by helping leaders convert fragmented processes such as manual progress tracking into structured data. Integrating sensor data from machinery into a central system, for instance, enables real time monitoring to reduce

downtime (Bilal et al., 2016; Hashim et al., 2024). This supports analytics adoption to resolve issues such as inaccurate reporting and resource misallocation. Similarly, cultivation of data aligns with Data Literacy by addressing digital skill gaps and resistance to new technologies. Training workers in tools such as BIM and VR reduces errors and improves site coordination (Chaudhuri, 2023; Xie et al., 2022). The culture of use, which promotes standardised practices and interoperability, underpins Data Democratisation by improving collaboration across stakeholders often hindered by incompatible tools or data formats (Honcharenko et al., 2021; Eshbayev et al., 2023). The infrastructure of data, also tied to Data Leadership, requires committed leadership to invest in digital systems and governance, which is key to overcoming underinvestment and inefficiencies from outdated platforms (Zulu et al., 2023; Srinavin et al., 2021). Lastly, the culture of production strengthens Data Analytics by enabling continuous data collection and proactive decision making through predictive dashboards and VR based simulations (Adekunle et al., 2022; Wu et al., 2022).

Building on these findings, a conceptual framework for operationalising a data-driven culture was developed, incorporating five key elements: a culture of production for systematic data generation and utilisation, a culture of use that integrates data into decision-making, data cultivation to enhance data collection and analysis practices, datafication to embed data-driven workflows into operations (e.g., digitizing material procurement processes to optimize supply chain efficiency), and robust data infrastructure (e.g., predictive maintenance schedules derived from IoT sensor data, are applied to improve operational decisions) to support technological needs for data sharing and analytics. The framework helps overcome common construction challenges such as fragmented collaboration and resistance to change. It provides a structured path for shifting from intuition-based to data-informed decision-making. By adopting these elements, construction organisations can foster innovation, improve productivity, and achieve digital transformation.

3. Implications for Digital Competitiveness in the Construction Industry

Building on a conceptual framework for operationalising a data-driven culture, specific indicators were identified to provide a deeper understanding of how various factors align with the broader goals of digital transformation and competitiveness. A systematic literature review (SLR) of 272 articles identified 41 potential indicators, which were refined to a final set of 33 through expert focus group discussions. These indicators were mapped to four main attributes and five sub-attributes of a data-driven culture.

In the context of construction, data-driven culture is structured around five key sub-attributes: datafication, infrastructure of data, cultivation of data, culture of use, and culture of production. Each sub-attribute encompasses unique but interconnected indicators. Datafication involves transforming construction processes into measurable metrics, including digital expertise, professionalism, adherence to codes of conduct, progress monitoring, risk mitigation, quality improvement, and legal compliance (Ghafoori et al., 2024; Tummalapudi et al., 2022). The infrastructure of data serves as the foundation for widespread data adoption, supported by robust cybersecurity measures, reliable digital platforms, and adequate funding to ensure seamless integration (Low et al., 2021; Srinavin et al., 2021). Cultivation of data emphasises building technical knowledge and fostering a willingness to adopt new tools, ensuring user-friendly learning experiences, enhancing competency through hands-on expertise, providing proactive training, and streamlining workflows in Engineering, Procurement, and Construction (EPC) settings (Rane and Narvel., 2022; Xie et al., 2022). Meanwhile, the culture of use focuses on translating data insights into actionable practices by ensuring data interoperability, developing compatible systems, adhering to collaborative modeling standards, and standardising data logging (Honcharenko et al., 2021; Acker et al., 2019). These practices are further reinforced by support from both internal and external stakeholders (Eshbayev et al., 2023; Lu, 2021). Lastly, the culture of production centers on systematic data collection and analysis, leveraging practices such as register-based statistics, detailed data gathering, BIM-driven information extraction, outcome forecasting, estimating, and applying prescriptive analytics for prevention and mitigation. Strategic control frameworks, including Total Data Quality Management (TDQM), which focuses on maintaining accurate and consistent data throughout a project, and Extract, Transform, Load (ETL) processes, which involve collecting

data from various sources, cleaning or adjusting it, and preparing it for analysis (Adekunle et al., 2022).

By defining and grouping these core components, construction organisations can develop digital infrastructure, improve workforce skills, encourage inclusive data use, and embed analytics-driven workflows into everyday practice. Taking this holistic approach that integrates technology with organisational processes positions the construction industry to significantly improve productivity, sustainability, and competitiveness. The detailed relationships between these indicators and their respective attributes are summarised in Table 1.

4. Methods

A systematic literature review (SLR) methodology was adopted to ensure a structured and transparent approach in reviewing relevant studies on data-driven culture in construction. The SLR followed guidelines by Osei-Kyei and Chan (2015), involving three main stages: (1) identification of studies, (2) selection of studies, and (3) examination and synthesis of findings. In the first stage, the Scopus database was chosen due to its comprehensive coverage and accuracy in construction management and engineering literature. The search strategy involved keywords such as “data-driven,” “data capability,” “data culture,” “big data,” “data analytics,” and “data mining” combined with “construction industry.” Searches were conducted across titles, abstracts, and keywords, yielding an initial 670 articles. In the second stage, articles were screened using predefined inclusion and exclusion criteria. Included articles were required to (a) focus specifically on data technology-driven practices in construction, (b) concepts, applications, or processes related to big data in construction, and (c) discuss the social aspects of data-driven activities. Articles outside the construction project management context or those addressing purely technical or statistical aspects were excluded. After rigorous screening, 136 articles remained for detailed content analysis. The third stage involved qualitative content analysis, categorizing key drivers of data-driven culture based on their characteristics and synthesizing arguments from selected literature. The identified categories included data analytics, data democratization, data literacy, and data leadership. More details on this process can be found in Hashim et al. (2024).

Following an extensive analysis of literature, an initial set of 41 indicators was refined through a preliminary focus group discussion with 15 practitioners, including four from contracting firms, nine from consultancy organisations, and two from client organisations, all with relevant experience in the construction industry. The discussion was conducted in February 2024, resulting in 33 final indicators across five sub-attributes of a data-driven culture. The reduction in the number of indicators was driven by the identification of overlapping terminologies and the consolidation of similar items to improve clarity and focus. For example, indicators such as Progress Monitoring and Information Coordination were combined into a single indicator, Project Progress Oversight, reflecting their shared emphasis on tracking and managing project activities. Similarly, Financial Criteria and Availability of Fund were merged under Financial Resource Allocation to streamline financial management attributes. Indicators deemed unsuitable or less applicable to the unique needs of construction organisations, such as redundant technical criteria, were excluded to maintain relevance. Furthermore, contextual refinements were made by integrating references to local practices, such as BIM ISO 19650, JKR BIM Guidelines, and other national policies, to ensure consistency with industry standards.

To explore the attributes for operationalising a data-driven culture in construction organisations, a quantitative approach was employed in the form of a structured questionnaire survey. This method allowed efficient data collection from a broad range of construction professionals (Aghimien et al., 2023). The questionnaire was divided into two sections: the first section collected background information about the respondents, while the second section assessed participants' perspectives on the extent to which the respondents consider the identified data-driven culture attributes as important for construction organisations. Responses were measured using a five-point Likert scale, from ‘not at all important’ to ‘very important’.

265 Table 1: The related attributes to data driven culture in construction

Attribute	Sub Attribute	Code	Indicator	Description	Examples of Authors
Data Leadership	Datafication (D)	D1	Digital Knowledge Expertise	Leading and applying digital practices such as BIM ISO 19650 and JKR BIM Guidelines.	Zhang et al., (2022); Srinavin et al. (2021)
		D2	Ethical Digital Management	Facilitating ethical conduct based on responsibilities and CIDB Malaysia Code of Ethics within digital project environments.	Ghafoori et al. (2024); Honcharenko et. al (2021)
		D3	Industry Standards Compliance	Promoting adherence to industry codes and practices, including those by PAM and BEM, to ensure regulatory and technical compliance.	Ayodele et. al (2021); Wu et al. (2022)
		D4	Project Progress Oversight	Directing digital project monitoring efforts through tools such as BIM JKR Guidelines, S-Curves, and Gantt Charts to ensure timely and accurate reporting	Tummalapudi et al. (2022); Lu and Zhang (2021)
		D5	Risk Analysis Proficiency	Leading structured risk assessments across construction phases using tools like Fish Bone Diagram, DTA, and HAZOP.	Ayodele et. al (2021); Turner et al. (2021)
		D6	Quality Assurance in Digital	Driving the application of digital quality standards, including ISO 9001:2015 and BIM JKR Guideline	Ayodele et. al (2021); Chen and Dai (2021)
		D7	Legal Framework Expertise	Guiding teams in interpreting and complying with legal frameworks such as UBBL 1984, CIPAA 2012, and OSHA 1994.	Srinavin et al. (2021); Akinyemi et al. (2018)
	Infrastructure of Data (ID)	ID1	Data Security Management	Implementing and maintaining secure digital environments by managing access control, identifying vulnerabilities, and mitigating risks in data systems, including PDA usage.	Honcharenko et. al (2021) Srinavin et al. (2021)
		ID2	Infrastructure Development	Establishing and optimising digital infrastructure by deploying tools such as BIM, virtual design, AR, and new modelling software.	Low et al. (2021) Lu (2021)
		ID3	Financial Resource Allocation	Managing financial expenditures and perform cost-benefit analyses to support infrastructure development and digital technology integration.	Pedro et al. (2022); Srinavin et al. (2021)
Data Literacy	Cultivation of Data (C)	C1	Digital Tools Proficiency	Applying and mastering digital tools such as BIM, AR, VR, BDA, IoT) across all construction phases to enhance productivity and decision-making.	Honcharenko et. al (2021); Lu (2021)
		C2	Technology Adaptability	Adapting to and integrating new digital technologies through structured learning e.g., training, workshops, and certifications (e.g., MyBIM CIDB).	Lu (2021) Srinavin et al. (2021)
		C3	Digital Knowledge Transfer	Facilitating and institutionalising knowledge transfer by embedding digital competencies within teams.	Tummalapudi et al. (2022); Lu (2021)
		C4	Competency Measurement	Evaluating and benchmarking digital skillsets using structured metrics like KPI reports and performance registers.	Lu (2021); Rane and Narvel (2022)
		C5	Real-Life Design Experience	Engaging in hands-on digital project delivery, including design and monitoring digital construction in real-life project scenarios.	Atuahene et. al (2022); Strom (2020)

		C6	Continuous Professional Development	Advancing digital literacy through ongoing education including formal academic training, workshops, seminars, and professional certifications.	Eshbayev et. al (2023); Alamil et al. (2019)
		C7	Coordination	Managing digital coordination strategies to align teams, streamline workflows, and ensure integrated project execution across stakeholders.	Xie et al. (2022); Lu and Zhang (2021)
Data Democratisation	Culture of Use (U)	U1	Data Interoperability	Managing digital data exchange across teams and platforms by aligning software types file formats, and Common Data Environment (CDE) protocols.	Eshbayev et. al (2023); Tummalapudi et al. (2022) Ayodele et. al (2021)
		U2	Cross-Organisation Compatibility	Ensuring seamless data integration among stakeholders using compatible formats (e.g., native and lightweight file formats).	Tummalapudi et al. (2022); Ayodele et. al (2021) Honcharenko et. al (2021)
		U3	Collaborative Modeling Standards	Standardising collaborative modeling practices by aligning workflows, model orientations, and annotation conventions across disciplines.	Ayodele et. al (2021); Honcharenko et. al (2021)
		U4	Internal Collaboration Support	Providing structured support within teams for preparing and exchanging digital data using tools like BIM, VR, AR)	Eshbayev et. al (2023); Dilakshan et al. (2021)
		U5	External Collaboration Support	Facilitating cross-organisational collaboration by coordinating external data contributions and model integration suing shared platform.	Lu (2021); Srinavin et al. (2021)
		U6	Data Standardisation	Implementing and maintaining standardised data practices, including compliance to CIDB Act 520, Eurocodes, and British Standards.	Anton et al. (2023); Yang and Talha (2021)
		U7	Building Model Exploration Skills	Applying digital modeling tools (e.g., BIM, AR, VR) for visualisation, modeling, and decision-making in building exploration.	Wu et al. (2022); Honcharenko et al. (2021)
		U8	Time Management for Tool Utilisation	Optimising time allocation for digital tool usage to ensure efficient integration of technologies such as BIM into project workflows.	Anton (2023); Honcharenko et al. (2021)
Data Analytics	Culture of Production (P)	P1	Data Visualisation	Translating construction data into visual formats such as histograms, pie charts, and dashboards to enhance clarity, communication, and collaboration.	Aleksandrova et al. (2019); Wu et al. (2022)
		P2	Detail data collection	Collecting and managing detailed project data throughout the project lifecycle using manual tools (e.g., checklists) and digital tools (e.g., BIM, drones, 4D scanning).	Eshbayev et al. (2022); Wu et al. (2022)
		P3	Selective Information Analysis	Extracting and prioritising relevant data for decision-making using manual or digital tools (e.g., FIND/QSELECT in BIM)	Wu et al. (2022); Lu (2021)
		P4	Performance	Forecasting project performance outcomes (e.g., cost, time,	Eshbayev et. al (2023);

			Prediction	budget) identifying risks using structured data models and analysis frameworks.	Nawi et al. (2021)
		P5	Predictive Analytics	Applying predictive data models using BIM and historical project data to anticipate deliverables and resource needs.	Patel and Patel (2020); Garyaev and Garyaeva (2019)
		P6	Risk Prevention Strategies	Analysing past project data and codes to proactively identify potential risks and develop pre-emptive mitigation strategies.	Honcharenko et al. (2021); Bilal et. al (2019)
		P7	Mitigation action	Developing and implementing response strategies for anticipated issues based on data-driven insights from predictive tools and scenario modeling.	Ayodele et. al (2021); Alaka et al. (2019)
		P8	Risk Control Procedures	Designing standardised procedures and control measures to mitigate risks using BIM models, guided templates, and compliance tracking tools.	Adekunle et al. (2022); Turner et al. (2021)

Convenience sampling was utilised to collect data based on the researcher's network and the convenient availability of participants in terms of time, location, access, and willingness to participate (Whitehead and Lopez, 2016). Initially, a set of 31 individuals was identified through the researcher's network and a snowballing approach. This convenience-based approach may introduce selection bias, as it tends to favour participants who are more digitally inclined and already within the researcher’s professional circle. Consequently, the sample may overrepresent individuals from organisations with higher digital maturity, potentially underrepresenting views from smaller firms or those with limited digital exposure. To ensure expert relevance, participants were not selected based solely on availability but were screened using a structured point-based system adapted from Hallowell and Gambatese (2010). Participants were required to attain a minimum of 11 points based on criteria such as professional experience in construction, a bachelor's degree or higher, professional body registration, involvement in digital data tasks, responsibility for a digital portfolio, publications on digital construction, and participation in relevant training. These criteria are widely recognised in construction studies as indicators of digital expertise (Hallowell and Hansen, 2010). The structured point-based screening system ensured that only participants with substantial expertise in digital construction were included, enhancing the reliability of the data.

From the initial pool of 31 potential experts, 18 individuals were certified as experts based on the aforementioned criteria and confirmed their willingness to participate in this survey. While the sample size may appear limited, it is appropriate for expert-based studies focusing on depth and relevance. The sample size of 18 experts was deemed sufficient to achieve data saturation, where further interviews were unlikely to yield significantly new perspectives on data-driven culture attributes (Whitehead and Lopez, 2016). Similar expert-driven studies in construction have employed sample sizes ranging from 10 to 20 participants (e.g., Kordi et al., 2022; Yin and Caldas, 2020). For example, Kordi et al. (2022) utilized 15 experts to explore practices of social sustainability, while Yin and Caldas (2020) employed 11 experts to investigate the issues and solutions for scaffolding in construction projects, demonstrating that small, expert-driven samples are effective for specialized research questions. Moreover, the selection process ensured representation from diverse disciplines of expertise, including construction project

management, digital technology and policy development, to prevent any potential biases towards specific attributes (Karakhan et al., 2020). In addition, the survey was conducted in a face-to-face guided format, allowed for real-time clarification of responses, reducing misinterpretation and increasing the validity of the findings, thereby compensating for the smaller sample size with high-quality, contextually rich data. The choice of 18 experts was also influenced by practical considerations, including the time-intensive nature of face-to-face questionnaires and the limited availability of highly qualified construction professionals, striking a balance between depth and feasibility (Yin and Caldas, 2020).

To evaluate the reliability and internal consistency of the Likert scale items, Cronbach's alpha was utilised. Cronbach's alpha is a statistical test that generates values between 0 and 1, where higher values indicate higher reliability. The data collection instrument in this study exhibited a Cronbach's alpha value of 0.847, indicating a high level of reliability.

The collected data was subjected to both descriptive and inferential statistical methods. The relative importance index method (RII) was used to determine the insight of participants on the data driven culture attributes. The RII was computed based on the following formula Tholibon et al. (2021);

$$Relative\ Importance\ Index = \frac{\sum w}{AN} = \frac{5n_5 + 4n_4 + 3n_3 + 2n_2 + 1n_1}{5N}$$

where *w* is the weighting given to each factor by the respondents, which ranges from 1 to 5; '1' being not at all important and '5' being very important. A is the highest weight; in this study it is 5; and N is the total number of samples. The RII should be a variable ranging from 0 to 1. The Intraclass Correlation Coefficient (ICC), a combination of interrater agreement (IRA) and interrater reliability (IRR) was adopted to determine the consistency and consensus of the experts' responses to data-driven culture attributes. As described in studies by Che Ibrahim et al. (2015), IRA signifies the degree of similarity in the level or magnitude of ratings provided by two or more raters, while IRR indicates the consistency in the pattern of ratings given by two or

more raters. An ICC value of 0 indicates a lack of agreement among respondents, whereas a value of 1 signifies perfect agreement.

During the administration of the face-to-face survey, researchers also took field notes to capture open-ended responses and comments from participants. These qualitative insights were manually thematically coded. Coding was conducted based on the underlying meaning and context of each comment, which were categorised according to the nature of the attribute and its associated sub-attribute (e.g., data leadership, literacy, democratisation, and analytics). To ensure reliability and reduce subjective interpretation, the coded themes were reviewed and cross-validated by multiple researchers within the project team. This triangulation process improved consistency in theme classification and contributed to the robustness of qualitative insights integrated into the discussion.

5. Results and analysis

Demographic details of the participants

The background information of the survey participants is presented in Table 2. Participants were categorised based on their discipline, position, and total points scored. The majority of the participants (61.1%) were from consulting organisations, followed by contractors (27.8%) and clients (11.1%). This distribution indicates a balanced representation of key stakeholders in the construction industry, ensuring a diverse range of perspectives on data-driven culture attributes. Concerning the roles of the participants, BIM-related positions dominated the study, with BIM Modellers accounting for the highest proportion (50%). This is followed by more specialised roles such as BIM Coordinators (11.1%), Lead Modellers (5.6%), and BIM Trainers (5.6%). The prominence of BIM-related positions highlights the focus on digital tools and methodologies within the construction industry.

Regarding their disciplines, civil engineering professionals comprised the largest group (more than 50%), followed by architecture, electrical engineering and project management. The inclusion of professionals from diverse disciplines, roles, and organisational types strengthens the validity and applicability of the findings. Furthermore, the high competency levels of the

participants, as evidenced by their point scores and qualifications, affirm the quality and reliability of the data collected in this study.

Table 2: The profile of respondents

Code	Organisation	Discipline	Position	Total Point
A-1	Contractor	Project Mngmt	Project Engineer	12
A-2	Contractor	Civil	Site Engineer	11
A-3	Contractor	Structural	BIM Modeller	12
A-4	Contractor	Eng. Services	BIM Modeller	11
A-5	Contractor	Civil	BIM Modeller	12
B-1	Consultant	Electrical	BIM Modeller	11
B-2	Consultant	Civil	BIM Modeller	12
B-3	Consultant	Civil	Lead Modeler	18
B-4	Consultant	Civil	BIM Trainer	40
B-5	Consultant	Civil	BIM Modeler and Coordinator	17
B-6	Consultant	Architect	Modeler	12
B-7	Consultant	Civil	BIM Modeller	11
B-8	Consultant	Civil	BIM Modeller	11
B-9	Consultant	Civil	BIM Modeller	14
B-10	Consultant	Architect	BIM Modeller	11
B-11	Consultant	Civil	BIM Coordinator	16
C-1	Client	Civil	BIM Coordinator	14
C-2	Client	Project Mngmt	Project Engineer	14

Note: The “Total Point” column reflects each respondent’s cumulative score based on predefined selection criteria (e.g., qualifications, professional body registration, digital portfolio, training, and publication).

Data Driven Culture Attributes

The analysis of survey responses in Table 3 highlights several critical insights about the relative importance of various data-driven culture attributes within the Malaysian construction sector. Among the four key attributes; Data Leadership, Data Literacy, Data Democratisation, and Data Analytics, the highest-ranked indicators predominantly fall under Data Leadership and Data Literacy, emphasising the importance of leadership and skill cultivation in driving data-driven practices. Indicators such as Digital Knowledge Expertise (RII = 0.989), Competency Measurement (RII = 0.989), and Continuous Professional Development (RII = 0.978) rank the highest overall, reflecting the industry's prioritisation of expertise, professional development, and quality assurance in digital practices. A radar chart of RII scores across the four key attributes (Figure 1) visually highlights Data Leadership and Data Literacy as the most critical domains driving data-driven transformation in the Malaysian construction sector.

However, the radar chart also reveals several low-performing indicators across different sub-attributes, including C1: Digital Tools Proficiency, C5: Real-Life Design Experience, D3: Industry Standards Compliance, U5: External Collaboration Support, P5: Predictive Analytics, and P8: Risk Control Procedures. These anomalies highlight key capability gaps that warrant further attention.

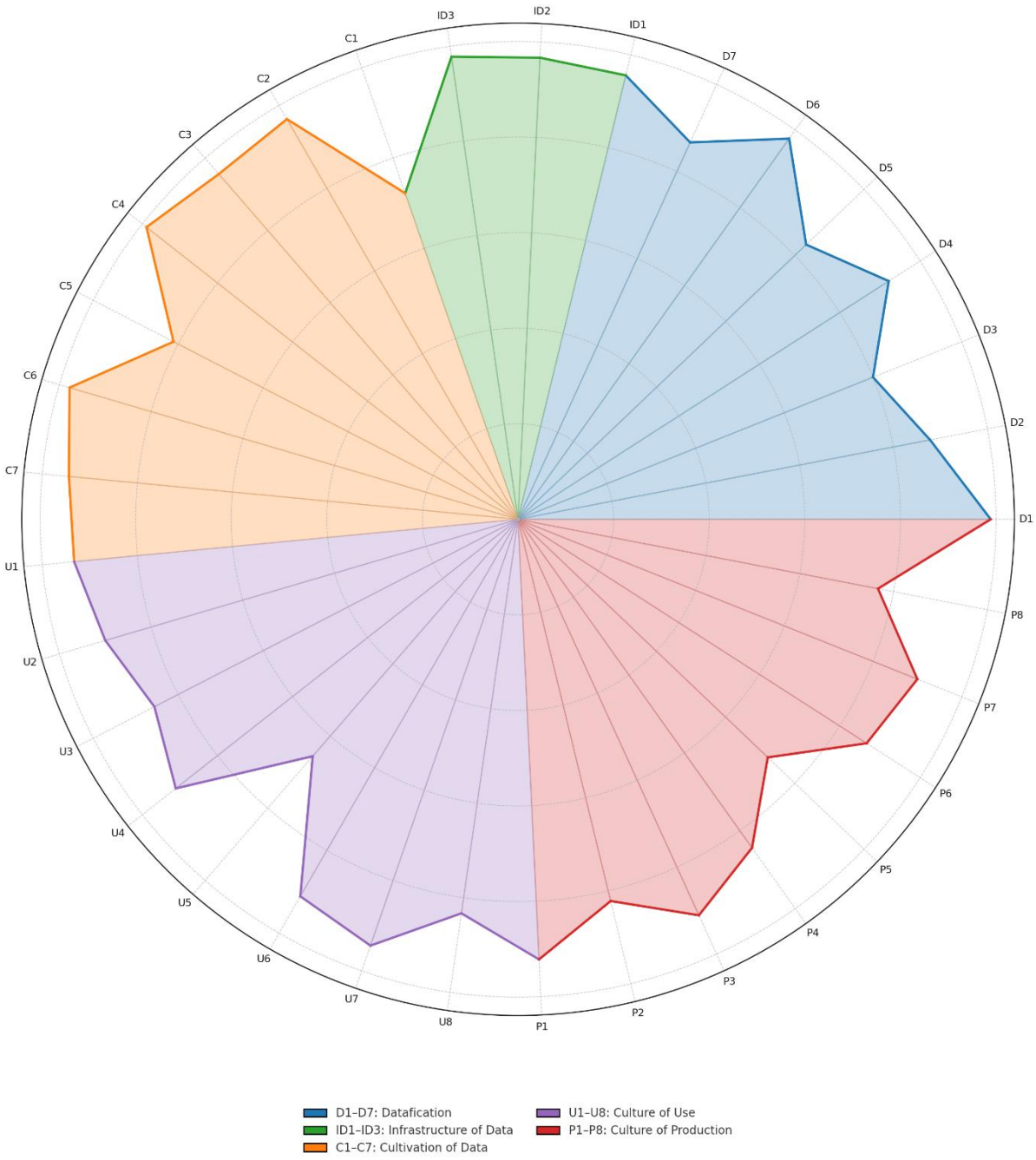

Figure 1: Radar Chart of RII by data driven attributes

Specific comments from practitioners further illustrate these priorities. For example, a project engineer remarked on the need to “understand digital practices such as BIM ISO 19650” (C-2), aligning with previous studies that highlight the significance of international standards for ensuring interoperability and effectiveness in construction digitisation (Bilal et al., 2019). Similarly, a lead modeller explained that it is crucial to “apply digital construction deliverables according to JKR BIM Guidelines” (B-3) because these national guidelines outline step-by-step procedures for implementing BIM tools effectively. Meanwhile, participants repeatedly emphasised the importance of competency to ensure that construction professionals can meet the demands of an increasingly digitalised industry. Several practitioners highlighted practical know-how, noting that personnel should “have experience and be familiar in digital application” (A-2) and that they must be able “to perform digital construction deliverables through in-house by” (A-5).

In the Data Leadership domain, critical enablers include Digital Knowledge Expertise and Quality Assurance in Digital, with Project Progress Oversight (RII = 0.922) and Legal Framework Expertise (RII = 0.867) emphasising the significance of oversight and legal knowledge in driving digital transformation. For instance, respondents recommended that “Gantt charts related to digital-based activities shall be established before project preliminary phases” (B-3) to better manage digital workflows, and they stressed “S-Curves for project oversight, following JKR BIM Guidelines” (B-4) as key tools for monitoring progress. These insights correspond well with Zulu et al. (2023), who emphasised structured leadership actions and systematic oversight mechanisms as critical factors driving successful digital

Table 3: Relative important index on the order of importance in the data driven attributes

Attribute	Sub Attribute	Code	Indicator	Σw	Relative Important Index (RII)	Ranking (based on each Sub Attribute)	Overall Ranking
Data Leadership (RII = 0.9168)	Datafication (D)	D1	Digital Knowledge Expertise	89	0.989	1	1
		D2	Ethical Digital Management	79	0.878	4	20
		D3	Industry Standards Compliance	72	0.800	7	29
		D4	Project Progress Oversight	83	0.922	3	14
		D5	Risk Analysis Proficiency	75	0.833	6	26
		D6	Quality Assurance in Digital	88	0.978	2	4
		D7	Legal Framework Expertise	78	0.867	5	22
	Infrastructure of Data (ID)	ID1	Data Security Management	86	0.956	3	9
		ID2	Infrastructure Development	87	0.967	2	7
		ID3	Financial Resource Allocation	88	0.978	1	5
Data Literacy (RII = 0.9096)	Cultivation of Data (C)	C1	Digital Tools Proficiency	65	0.722	6	32
		C2	Technology Adaptability	87	0.967	3	6
		C3	Digital Knowledge Transfer	86	0.956	4	8
		C4	Competency Measurement	89	0.989	1	2
		C5	Real-Life Design Experience	73	0.811	5	28
		C6	Continuous Professional Development	88	0.978	2	3
		C7	Coordination	85	0.944	3	11
Data Democratisation (RII = 0.8680)	Culture of Use (U)	U1	Data Interoperability	84	0.933	2	12
		U2	Cross-Organisation Compatibility	81	0.900	5	18
		U3	Collaborative Modeling Standards	77	0.856	6	23
		U4	Internal Collaboration Support	82	0.911	4	17
		U5	External Collaboration Support	59	0.656	8	33
		U6	Data Standardisation	82	0.911	3	15
		U7	Building Model Exploration Skills	85	0.944	1	10
		U8	Time Management for Tool Utilisation	75	0.833	7	25
Data Analytics (RII = 0.8443)	Culture of Production (P)	P1	Data Visualisation	83	0.922	1	13
		P2	Detail data collection	74	0.822	5	27
		P3	Selective Information Analysis	82	0.911	2	16
		P4	Performance Prediction	76	0.844	6	24
		P5	Predictive Analytics	65	0.722	8	31
		P6	Risk Prevention Strategies	78	0.867	4	21
		P7	Mitigation action	81	0.900	3	19
		P8	Risk Control Procedures	69	0.767	7	30

adoption. However, challenges remain, particularly in regulatory support. Respondents pointed out that "there is no legal/regulation/act from the Malaysian government to justify the mandatory use of BIM" (B-9), urging policymakers to "obligate rules/regulations related to BIM licensing" for effective implementation (C-1). The notably lower ranking of industry compliance further indicates that adherence to established standards is insufficient, revealing significant opportunities for improvement in regulatory frameworks and standardised compliance practices. For example, a BIM Modeller commented that practitioners often "just follow Superintending Officer (SO) organisation's procedure" (B-10) rather than aligning with widely recognised codes or specifications. Moreover, smaller firms reportedly adopt ISO standards "only if prompted by top management" (A-4), indicating that institutional incentives are essential for fostering broader compliance. The limited regulatory support and inconsistent adherence to established standards identified in this study align with findings by Pittri et al. (2025), who highlighted similar institutional and regulatory gaps that hinder widespread adoption and compliance with digital practices in the construction sector.

Within Data Literacy, experts highly rated Technology Adaptability (RII = 0.967) and Digital Knowledge Transfer (RII = 0.956), recognising the necessity of adaptive learning and effective knowledge dissemination. In contrast, Digital Tools Proficiency (RII = 0.722) was notably less emphasised, highlighting an evident skills gap. This lower emphasis on digital proficiency suggests the presence of barriers such as inadequate access to specialised training programs or software resources. For example, one BIM Modeller emphasised that "To run the software, the player shall have a certificate, at least from Autodesk" (B-2) while another respondent stressed the importance of regular updates on "new technologies and software versions to maintain industry relevance" (A-2). This finding corroborates the view presented by Hyatt (2021), who identified similar gaps in skill competencies and advocated structured training and development programs as key factors enhancing organisational data literacy.

In Data Democratisation, the findings highlight a blend of strengths and challenges. Indicators such as Building Model Exploration Skills (RII = 0.944) and Data Interoperability (RII = 0.933) are highly regarded, emphasising the industry's competency in utilising advanced modeling

and cloud-based data-sharing tools. However, External Collaboration Support (RII = 0.656) ranks the lowest among all indicators, signaling critical challenges in fostering effective collaboration across external stakeholders. This anomaly might be linked to regulatory gaps in Malaysia, specifically the absence of mandatory regulations for using a Common Data Environment (CDE), limiting effective external stakeholder collaboration. In contrast, Internal Collaboration Support (RII = 0.911) demonstrates relatively strong performance, suggesting that while organisations are adept at internal teamwork, the lack of seamless external partnerships may hinder broader data-sharing and cross-organisation compatibility. Specific practitioner feedback further illustrates these challenges. For instance, one respondent noted, “External stakeholders create positive rivalry culture in the use of BIM” (A-1) indicating potential competitiveness rather than cohesive collaboration. Another emphasised the necessity of standardised data environments, commenting, “Need one cloud for all stakeholders to see the data, such as a Common Data Environment (CDE)” (B-2). This challenge resonates with findings by Hwabamungu and Shepherd (2024), who emphasised that fragmented stakeholder interactions significantly hinder broader digital transformations in construction. In addition, concerns were raised about outdated tools in smaller firms and challenges related to differing data languages complicating integration efforts.

In the Data Analytics attribute, Data Visualisation (RII = 0.922) emerges as the most important indicator, highlighting the industry's emphasis on presenting data insights effectively. However, other indicators, such as Predictive Analytics (RII = 0.722) and Risk Control Procedures (RII = 0.767), rank lower, reflecting a lag in the adoption of advanced analytics and risk management practices. This suggests that while organisations are comfortable with basic data interpretation, they are less equipped with capabilities for proactive, predictive, and preventive measures. For example, one BIM Modeller commented, “BIM software produces various dimensions of design outputs, such as material lists, placements, and drawings, which are then translated into interactive visual tools like histograms and pie charts to facilitate communication and collaboration” (A-5). The BIM Modeller and Coordinator further emphasised, “The lack of automated predictive tools for clash analysis limits proactive risk identification, leaving smaller firms to rely on manual methods using spreadsheets like Excel.” (B-5). These observations

align with existing research by Pittri et al. (2025), who documented similar trends of limited predictive analytics adoption due to resource constraints and knowledge gaps.

To measure the level of agreement among respondents, the Intraclass Correlation Coefficient (ICC) was calculated. The analysis indicated an IRR value of 0.847 and an IRA value of 0.775, both of which exceed the threshold ICC value of 0.70 (LeBreton & Senter, 2008). These results demonstrate a high level of consistency and strong consensus among practitioners, quantifying the reliability of the study. The findings confirm that the practitioners consistently perceived and rated the data-driven culture attributes for construction organisations.

6. Discussion

This section consolidates and interprets the key findings from the empirical analysis, drawing on practitioner insights and existing literature to explain the implications of these attributes.

6.1 Data Leadership: Strategic Alignment and Policy Integration

The prominence of indicators such as Digital Knowledge Expertise, Quality Assurance in Digital, and Financial Resource Allocation highlights the crucial role of leadership in advancing data-driven practices. Data leadership is a foundational pillar among the four critical drivers (analytics, literacy, and democratisation) essential for achieving digital competitiveness (Hashim et al., 2024). By establishing clear processes and policies that support the production, use, and continuous cultivation of data, leaders secure genuine buy-in across the organisation, enabling them to integrate datafication practices and robust data infrastructure into everyday operations. Operationally, this involves fostering strong staff engagement by upskilling existing personnel, potentially via reverse mentoring, or selectively recruiting externally for advanced digital skills (Gledson et al., 2023). In Malaysia, strategic leadership has been strengthened significantly by governmental initiatives, including the National Construction Policy (NCP) 2030 and mandatory BIM adoption for public projects exceeding RM10 million. These policies create clear regulatory incentives, pushing organisations towards standardised and structured digital adoption (CIDB, 2024). To further facilitate this leadership transformation, organisations are encouraged to cultivate an ecosystem of innovation by promoting collaborative internal teams,

providing platforms and spaces for idea sharing, and partnering strategically with supply chains to distribute innovation risks (Morgan and Papadonikolaki, 2021). Case studies such as Gamuda Berhad and the Pan Borneo Highway further exemplify successful leadership-led integration of BIM, drones, and cloud analytics, effectively embedding data-driven decisions into operational frameworks (CIDB, 2025). Business leaders' proactive efforts in improving their digital competencies through external and internal networks, fostering bidirectional trust, and empowering staff are vital to promoting and sustaining a robust data sharing culture across industry supply chains (Gledson et al., 2023).

6.2 Data Literacy: Addressing Skill Gaps and Enhancing Competency

Data literacy attributes, notably Competency Measurement and Continuous Professional Development, received high prioritisation, reflecting the industry's recognition of ongoing professional growth and structured skill enhancement. This highlights the shift from passive data awareness to an applied understanding of how to interpret, utilise, and transform data into operational insight. A cornerstone of this approach lies in effectively translating day-to-day activities into actionable insights, leveraging digital knowledge to interpret and capitalise on data. To operationalise this, professionals must demonstrate proficiency across multiple standards and guidelines such as BIM ISO 19650, BIM JKR Standard and Guidelines, BIM Specification Parameter, BIM: JKR Data Management Manual, JKR: JKR Template User Manual, and BIM: JKR Green Rating Application Manual. These frameworks not only set performance benchmarks but also guide the structured cultivation of digital literacy within construction environments. Integrating such frameworks into organisational practice allows for more precise identification of skill gaps through Competency Measurement and facilitates targeted capacity-building via CPD programmes.

However, notable gaps persist, particularly evident in the lower-ranked Digital Tools Proficiency indicator. A 2023 industry report indicated that only 24% of contractors possess high knowledge of IoT, and fewer than 10% are proficient in advanced technologies like 3D printing (CREAM, 2022). This gap is further magnified in developing economies, where data analytics and cybersecurity capabilities are notably underdeveloped (Adepoju and Aigbavboa,

2020). These statistics highlight the critical need for structured, targeted training initiatives, such as CIDB's myBIM certification and the Skills Competency Training Programmes, to bolster workforce capabilities.

In addition to technical proficiency, recent findings show that employee characteristics including social behaviours can also predict digital literacy outcomes in construction organisations (Zulu et al., 2023). This suggests that human resource strategies must consider behavioural and attitudinal factors, not just technical qualifications. As emphasised by Wang and Krish (2019), fostering data literacy not only enhances operational efficiency but also ensures technology amplifies human expertise technological capabilities to achieve optimal outcomes

Moreover, digital technologies, encompassing data collection tools, decision-oriented systems, collaborative platforms, and security-focused solutions, are increasingly utilised to enhance quality assurance processes within the construction industry (Ghansah and Edwards, 2024). To support these applications, the development of a robust and adaptable data infrastructure becomes essential. Such infrastructure, when conceptualised as a complex adaptive system, enables seamless integration across workflows while supporting the pillars of a strong data culture - production, use, and continuous cultivation (Brous et al., 2019).

6.3 Data Democratisation: Enhancing Collaboration and Standardisation

Data democratisation continues to be a critical yet underdeveloped dimension of Malaysia's digital construction transformation. While internal collaboration practices appear relatively mature, external collaboration support remains a key weakness, exposing underlying fragmentation across the industry. This challenge is symptomatic of broader structural limitations, including siloed workflows, limited trust, and inconsistent adoption of CDEs project stakeholders (CREAM, 2022).

Efforts to address these gaps are increasingly supported by strategic public-private initiatives.

For instance, CIDB's partnership with platforms like PlanRadar exemplifies targeted interventions aimed at improving accessibility to collaborative, cloud-based tools that promote interoperability and real-time data sharing across organisations (Graham, 2024). However, democratising data access and use requires more than digital tools, demanding a cultural shift toward openness, transparency, and shared responsibility, as cultural inertia remains one of the most enduring obstacles to digital integration in construction (Kane et al., 2015; Samuelson and Stehn, 2023). To overcome these challenges, industry leaders must actively foster environments of trust and knowledge exchange. This includes establishing cross-functional collaboration forums, encouraging shared innovation ownership with the supply chain, and considering third-party facilitation for training and integration support (Morgan & Papadonikolaki, 2021).

6.4 Data Analytics: From Visualisation to Advanced Predictive Insights

Data analytics in the construction industry remains unevenly developed, with a strong emphasis on data visualisation but limited progress in advanced applications such as predictive analytics and risk control procedures. This preference reflects early-stage adoption, where visual dashboards and descriptive metrics are more commonly applied, while tools like AI-driven models and blockchain-enabled platforms remain underutilised (Chen et al., 2024). In Malaysia, this trend is consistent across firms, where implementation of analytics solutions is constrained by insufficient data literacy, lack of investment in upskilling, and workflow resistance (Madanayake and Çıdık, 2019; Ngo et al., 2020).

Despite growing recognition of BIM and big data's transformative potential, many organisations struggle to operationalise these tools effectively. Even with access to large volumes of data, the ability to convert insights into meaningful project improvements is often hindered by fragmented data ecosystems, poor data quality, and entrenched cultural barriers (Tummalapudi et al., 2022). Moreover, contractors, SMEs, and start-ups frequently face a steep learning curve and lack the internal resources needed to capitalise on Industry 4.0 technologies such as IoT, cloud-based analytics, and blockchain applications (Atuahene et al., 2022).

Real-world examples such as Gamuda's integration of digital twin technology illustrate the substantial benefits of advanced analytics in enhancing forecasting, cost control, and risk management (CIDB, 2025). However, these examples remain outliers in an industry that is still grappling with foundational capability gaps. Recent studies have thus advocated for the use of digital readiness and analytics capability assessment tools to help organisations benchmark their strengths and identify priority areas for investment (Ngo et al., 2020). To close this divide, industry-wide adoption of targeted training, accessible analytics platforms, and leadership commitment to cultural change is essential. As Upadhyay and Kumar (2020) emphasise, the successful integration of big data analytics relies not only on technical infrastructure but also on the presence of a supportive, data-informed organisational culture that empowers staff to use data proactively and strategically.

7. Conceptual Framework for Advancing Data-Driven Culture

Building on the analysis and discussion of the four main attributes; data leadership, data literacy, data democratisation, and data analytics, this section presents a consolidated conceptual framework (see Figure 2) for advancing data-driven culture in the Malaysian construction sector. The framework synthesises key findings from the empirical data, practitioner perspectives, and national digitalisation strategies. It positions these four attributes as interdependent pillars that must be strategically aligned to foster a high-performing, digitally competent, and future-ready construction industry. The framework not only addresses current gaps but also provides a structured pathway for operationalising data culture through leadership, literacy development, standardisation, and analytics integration (Tummalapudi et al., 2022).

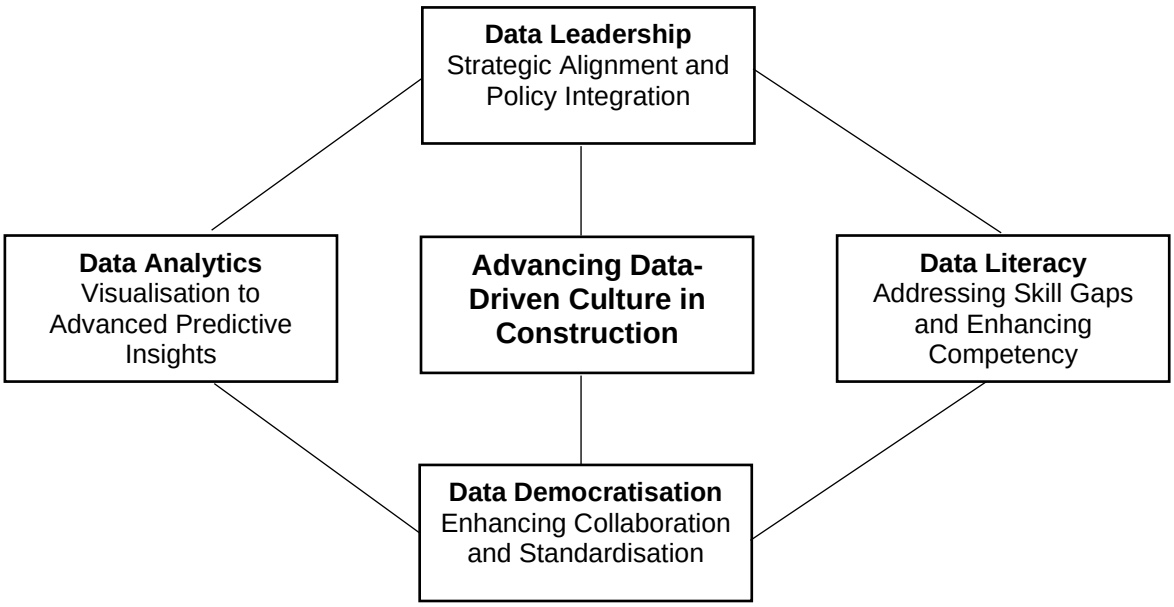

Figure 2: Conceptual Framework for Advancing Data-Driven Culture for Malaysian Construction

Data leadership functions as the strategic enabler, providing direction through policy alignment, resource mobilisation, and institutional governance. It is essential for championing innovation, establishing ethical practices, and aligning digital standards with national regulatory initiatives such as BIM mandates (CIDB, 2024). Data literacy focuses on building workforce capacity by enhancing the ability of construction professionals to engage with digital tools and interpret data-driven insights. Structured training and continuous professional development are critical for improving operational outcomes and increasing digital confidence across the sector (Adepoju and Aigbavboa, 2020; Zulu et al., 2023). Data democratisation emphasises collaboration and standardisation by promoting transparency, shared data environments, and interoperable systems. These practices reduce fragmentation and foster inclusive innovation among project stakeholders (Morgan and Papadonikolaki, 2021). Data analytics, although less mature in implementation, plays a critical role in transforming raw information into predictive insights that support real-time decision-making, performance forecasting, and risk mitigation (Ngo et al., 2020; Tan et al., 2023). When underpinned by a strong data culture, analytics contributes significantly to productivity, communication, and competitive advantage (Hashim et al., 2024; Reyes-Veras et al., 2023).

As Malaysia's construction industry advances its digital transformation through initiatives such as the National Construction Plan (NCP) 2030 and the CIDB's Construction 4.0 roadmap, success increasingly depends not only on technology adoption but also on deep cultural transformation. Shifting mindsets from intuition-based to data-informed decision making is crucial. For instance, adopting predictive analytics to anticipate project delays or cost overruns requires moving beyond traditional experience-based judgments. Fostering collaboration is equally critical, particularly in overcoming siloed operations across architects, consultants, and contractors. Encouraging open data sharing through platforms like CDEs can align workflows and reduce rework.

Despite these advances, Malaysia continues to face significant cultural barriers including resistance to change, low digital literacy, and fragmented coordination (Musarat, et al., 2024). Addressing these requires strong leadership commitment to position data as a strategic asset through investments in digital infrastructure, policy enforcement, and competency development. Embedding data literacy across all organisational levels helps reduce pushback against tools such as BIM, virtual reality (VR), or IoT-based platforms. In the Malaysian context, a study by Tanko et al. (2024) revealed that while BIM is still in the early stages of implementation, professionals identified its potential for reducing construction waste and improving productivity, particularly through applications such as quantity take-off, 3D coordination for clash detection, and site utilisation planning. However, widespread uptake is hindered by cultural challenges, including ambiguous guidelines, low trust, and insufficient training. Comparable regional experiences illustrate the transformative potential of cultural change. The L&T Group, a major construction firm in Asia, achieved a 25% improvement in equipment fuel efficiency, a 15% increase in labour productivity, and a 10% boost in machinery utilisation by aligning executive leadership, workforce upskilling, and standardised data practices (Subrahmanyan and Jalona, 2020). Similarly, a Singaporean construction firm reported significant gains in project delivery performance, productivity, and stakeholder satisfaction by engaging stakeholders at all levels, supported by clear leadership communication, continuous professional development, and structured collaboration (Ngo et al.,

2020). Together, these cases demonstrate that sustained leadership commitment, skill development, and collaborative data practices can deliver measurable benefits.

These examples highlight the tangible value of embedding a data-centric culture in construction. For Malaysian firms, replicating such outcomes involves prioritising training, formalising data governance protocols, and ensuring accountability at the leadership level. Aligning with the aspirations of NCP 2030, such cultural adaptations are essential to overcome persistent industry issues like disconnected workflows and underutilised digital tools, while positioning Malaysia as a regional leader in data-driven construction transformation.

8. Conclusions

This study highlights the essential attributes required for cultivating a robust data-driven culture within the Malaysian construction industry, particularly amidst the growing adoption of BIM and Industry 4.0 technologies. Based on a structured face-to-face survey involving 18 practitioners, the findings highlight the critical importance of Digital Knowledge Expertise, Competency Measurement, Continuous Professional Development, Quality Assurance in Digital, and Financial Resource Allocation. These attributes are pivotal for enhancing leadership, advancing workforce skills, and aligning strategic resources. Effective data leadership, characterised by well-defined processes and policies, serves as a central driver in enabling Datafication and establishing a robust Infrastructure of Data to translate routine construction activities into actionable insights. Complementing this is Data Literacy, a distinct attribute that includes the Cultivation of Data, enabling the identification of skill gaps and guiding targeted capacity-building initiatives. It ensures the workforce remains proficient in emerging tools and methodologies while fostering a culture of continuous learning and adaptability within the organisation.

While foundational systems and skills are relatively important, the findings reveal persistent gaps in External Collaboration Support, Predictive Analytics, and Digital Tools Proficiency. Addressing these challenges requires a concerted effort to enhance collaboration mechanisms, adopt advanced analytics technologies, and standardise practices across organisations. By

strategically integrating leadership, workforce competencies, and technical infrastructure, construction organisations can foster a resilient ecosystem that supports both the Culture of Use, enabling seamless data accessibility and collaboration, and the Culture of Production, driving the generation and application of actionable insights. This holistic approach reflects the need for well-trained human capital, transparent quality standards, and adequately allocated financial resources to converge in supporting robust digital initiatives. Notably, the conceptual framework developed in this study consolidates these elements into four interrelated drivers: data leadership, data literacy, data democratisation, and data analytics. Each offers structured pathways for guiding digital transformation efforts in the construction sector. The framework highlights that a strong data culture must be institutionally supported, competency led, inclusively governed, and analytically enabled.

While this study provides valuable insights, several limitations merit acknowledgement. First, the use of convenience sampling may introduce bias and limit the generalisability of the findings; however, this is mitigated by a rigorous expert selection process based on stringent qualification criteria. Future studies are encouraged to adopt stratified random sampling or engage larger, more diverse participant pools to validate and extend these findings at scale. Second, the scope of the research is confined to the Malaysian construction industry; future studies in other countries with similar or different digital mandates are needed to assess the generalisability of these findings. Third, the study primarily captures individual-level perspectives, leaving industry or project-based outcomes unexplored. Future research could adopt a multi-layered approach to explore the operationalisation of data-driven competencies at portfolio, program, project, and task levels. Moreover, longitudinal studies could examine how data culture maturity evolves over time across different organisational scales.

Despite these limitations, the study provides significant practical implications. It highlights the growing need for digital competence and structured frameworks to guide the transformation of traditional construction environments into data-informed, future-ready ecosystems. For practitioners and policymakers alike, the findings offer guidance on aligning workforce development with national digital agendas, such as the Construction 4.0 roadmap and the

National Construction Policy 2030. Thus, it contributes to the global discourse on data culture and provides a foundational model for advancing digital capability within complex project-driven sectors.

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