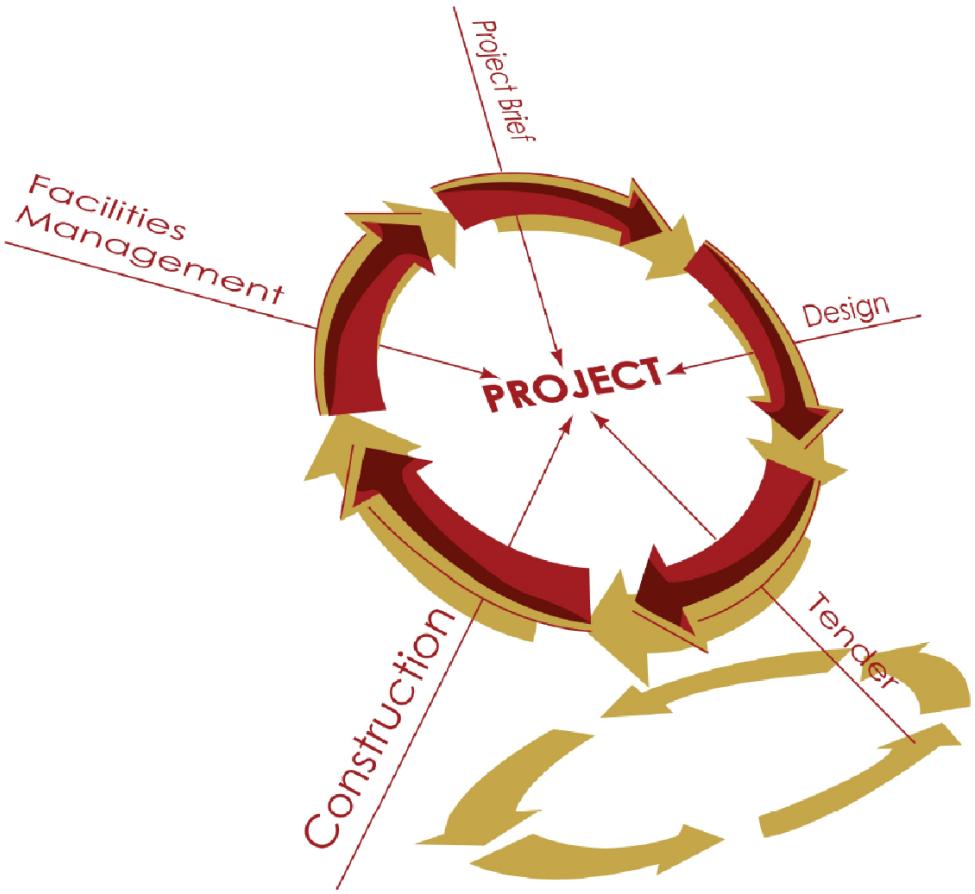
MCRJ SPECIAL ISSUE Volume 26 | No. 3 | 2025 eISSN 2590 - 4140

Malaysian Construction Research Journal

CONSTRUCTION INDUSTRY CONGRESS (CIC) 2024



CREAM CONSTRUCTION RESEARCH INSTITUTE OF MALAYSIA
CIDB MALAYSIA

MALAYSIAN CONSTRUCTION RESEARCH JOURNAL (MCRJ)

SPECIAL ISSUE Vol. 26 | No. 3 | 2025

CONSTRUCTION INDUSTRY CONGRESS (CIC) 2024

The Malaysian Construction Research Journal is indexed in
Scopus Elsevier, ASEAN Citation Index (ACI) and MyJurnal

eISSN No.: 2590 – 4140

Construction Research Institute of Malaysia (CREAM)
Level 14, CIDB 520, The MET Corporate Towers,
No. 20, Jalan Dutamas 2,
50480 Wilayah Persekutuan,
Kuala Lumpur, MALAYSIA.

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Introduction

This special issue focuses on transforming the construction industry through innovation, safety, and sustainability. The construction industry is undergoing a pivotal transformation driven by rapid technological progress, evolving regulatory frameworks, and an increasing focus on environmental responsibility, workplace safety, and operational efficiency. This special issue presents a diverse collection of research articles that collectively explore the evolving landscape of the construction sector across various domains, geographies, and methodological perspectives. From the bustling urban centers of Malaysia and Indonesia to conservation sites like South Africa's Kruger National Park and the high-rise developments in China, the articles in this issue reflect the global and multifaceted nature of construction challenges and innovations.

A key theme running throughout this compilation is occupational safety and regulatory compliance, particularly in high-risk environments such as high-rise construction projects. Articles examining causes of accidents, the role of clients in Prevention Through Design (PtD), and the application of digital tools like Building Information Modelling (BIM) to manage safety violations highlight the pressing need for robust safety management frameworks and proactive design-based interventions.

Technological integration features prominently, with several contributions investigating the adoption and implementation of advanced tools and systems—including BIM, artificial intelligence (AI), blockchain, and the Internet of Things (IoT). These studies underscore the critical success factors, challenges, and emerging best practices associated with digital transformation, especially in developing economies and infrastructure projects.

Sustainability emerges as another cornerstone of this issue, explored through the stabilization of organic soils with recycled materials, the influence of building envelopes on energy efficiency, thermal comfort in certified green buildings, and material handling practices that balance efficiency with environmental responsibility. Such research signals a growing recognition of construction's environmental footprint and the need for greener building practices.

The issue also sheds light on process optimization and project management within the sector. Topics such as lean construction implementation, data-driven culture, scheduling integration, and the execution of term contracts point to the evolving strategies needed for improving project delivery outcomes and resource management.

By bringing together empirical studies, case analyses, and literature reviews, this special issue offers a comprehensive view of contemporary trends and enduring challenges in the construction industry. It serves as a valuable resource for academics, practitioners, and policymakers seeking to foster a safer, smarter, and more sustainable built environment.

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Editorial

Welcome from the Editors

Welcome to this special issue in Malaysian Construction Research Journal (MCRJ) for the Construction Industry Congress (CIC2024). We would like to express our sincere gratitude to our contributing authors, reviewers, organisers and readers.

This special issue in MCRJ for CIC2024 contains twenty (20) exciting papers covering the theme of "Building Resilience and Sustainability". It is hoped that the readers would greatly benefit from the scientific content and quality of papers published in this issue:

A brief introduction of each article is given hereunder:

Ku Adenan Ku Ismail et al. evaluated the causes of construction accidents through the application of a structured questionnaire to come out with a structured framework that can enhance the safety regulations in high-rise construction projects in Malaysia. The statistical techniques used to evaluate the data obtained are Relative Importance Index (RII) and Average Index (AVI), while Cronbach's alpha is used to measure the significant between three different groups of respondents (namely contractor, consultant and client) the reliability and validity of the study. The top five of the causes of accidents in high-rise construction project are failure to comply with safety regulations, lack of safety working procedure, no safety and health management practice or standard operating procedures, not providing safe working conditions, and inappropriate construction methods. The enforcement of the law must be strengthened to ensure full compliance by all parties, thereby facilitating the provision of a safe working environment within the construction sector. The top five of the causes of accidents in high-rise construction projects are failure to comply with safety regulations, lack of safety working procedure, no safety and health management practice or standard operating procedures, not providing safe working conditions, and inappropriate construction method. The enforcement of the law must be strengthened to ensure full compliance by all parties, thereby facilitating the provision of a safe working environment within the construction sector.

Ting et al. examined the implementation of Lean Construction among G7 Contractors in Malaysia, focusing on awareness, challenges, and key measures for improvement. Lean Construction, derived from Lean Manufacturing, offers a systematic approach to enhancing efficiency and minimizing waste. However, its adoption remains limited. Based on survey responses from 122 construction professionals, it was found that while there is a strong understanding of efficiency-driven Lean principles, gaps persist in client-focused concepts. The highest-ranked barriers include Lack of Awareness and Lack of Top Management Support. Essential countermeasures for successful adoption include Management Leadership and Investment in Technologies. The study highlights how Lean Construction can drive greater efficiency and sustainability in Malaysia's construction sector.

Ayah Almsedeen et al. presented a study on stabilizing organic soil using concrete waste and gypsum by-products. The optimal mix (10% CW + 10% G) resulted in a 1108% increase in unconfined compressive strength after 28 days. Triaxial tests showed enhanced shear strength, cohesion, and internal friction angle. The research highlights the potential of these industrial wastes as sustainable alternatives to traditional stabilizers for improving the geotechnical performance of organic soils.

Syahirah Kamarul et al. explored safety management practices within the Malaysian construction industry, particularly focusing on infrastructure construction, and highlight the importance of adhering to safety protocols. Despite its significant contribution to the country's economic development, the lack of systematic implementation of safety measures in construction management can result in accidents, potentially hindering the nation's economic progress. The research seeks to establish safety management as a crucial element influencing project performance and success in construction endeavors, with a specific emphasis on infrastructure projects in Malaysia. Additionally, efforts will be made to enhance awareness regarding the importance of safety management in construction projects. Data collected through questionnaires and a case study conducted at the MRT Line 2 Construction Site.

Lungie Maseko et al. looked at the Critical Success Factors (CSF) that may influence the success of implementing term contracts at the Kruger National Park (KNP). In practice the KNP has utilized term contracts, which have resulted in failure to achieve project objectives and uncreased contractual disputes. By interviewing the 15 project managers in the park, the study found that planning, communication, stakeholder involvement, project manager's competence and project characteristics, are the CSF for the implementation of term contracts. It also identified various measures for process success, including traditional metrics (time, cost and quality), along with the contemporary factors (safety, minimum site disputes and environmental impact). Project managers highlighted a lack of monitoring tools during the implementation of these contracts, particularly in terms of assessing performance against the established objectives for empowering local contractors. These results are to improve procurement, contract and operational management capabilities, preventing future occurrences.

Siti Kartini et al. investigated energy sustainability in tropical climates, where buildings consume substantial energy due to air conditioning. Construction materials significantly affect heat exchange and energy dissipation, making early design decisions crucial for sustainable building practices. Kartini's study explores how Building Information Modelling (BIM) can evaluate the energy-saving potential of different wall materials in academic buildings at Universiti Malaysia Sabah's Faculty of Engineering. The study compares four wall materials: Insulated Concrete Forms (ICF), Vacuum Insulated Panels (VIP), Aerated Concrete, and Polyurethane (PU) foam insulation. Using BIM and energy analysis software, the study modeled current energy consumption patterns and assessed the materials' energy performance. The findings reveal that VIP walls have the lowest Energy Use Intensity (EUI) and U-value, offering the best insulation and energy efficiency. VIP walls led to a 23.6% reduction in cooling load and energy consumption compared to traditional brick walls, resulting in significant savings of 113 kWh/m² of electrical energy. This study highlights the potential of BIM in optimizing building designs for energy efficiency, promoting sustainability by reducing energy consumption and improving overall building performance.

Muhammad Tarique Lakhiar et al. assessed thermal comfort and indoor environmental quality (IEQ) in a GreenRE-certified building in Malaysia. The study utilized a cross-sectional survey over 15 days, evaluating thermal sensation, temperature acceptability, airflow, and humidity among 63 respondents. Findings show that 57.1% of participants reported stable comfort, while 30.2% desired increased airflow, and 23.8% found the indoor air slightly dry. The study also analysed compliance with GreenRE certification, concluding that while the building meets energy efficiency and temperature acceptability standards, improvements in airflow and humidity control are needed to enhance occupant satisfaction.

Hafnidar A. Rani et al. reviewed key themes including case studies, barriers, and readiness, emphasizing training and policy support on BIM implementation in Indonesia. The study highlighted financial and regulatory challenges, recommending national standards and collaboration. It also focused on government training subsidies and the need for cross-sector cooperation to support SMEs and ensure structured, sustainable BIM adoption across the industry.

Tamiru Mengst Habtu and Walied A. Elsaigh presented a comprehensive bibliometric review of BIM applications in road infrastructure management, analysing publications from 2010 to August 2024 using Scopus data and the PRISMA protocol. Employing VOSviewer and Biblioshiny, this study identifies leading publications, collaborative networks, and key themes, revealing growing interest in BIM alongside geographical limitations. The study underscores knowledge gaps and future directions, emphasizing the integration of BIM with emerging technologies, regional adoption challenges in developing countries, and the need for international collaboration to drive sustainable and practical solutions.

Mohd Khairul Amri Ramly et al. explored the Critical Success Factors (CSFs) for effective Transfer of Technology (TOT) in Malaysia's digital construction industry. Despite the rise in TOT activities, there is no consensus on measuring its effectiveness, particularly among industry-academia collaborators. Using a systematic literature review with the PRISMA technique, 31 articles were selected from an initial 309, and analysed using NVIVO software. The study identified seven main themes—Politics, Economics, Social, Technology, Policies, Legal, and Environment—comprising 39 subthemes as key success factors for TOT. The findings aim to fill knowledge gaps, guide future research, and help construction organizations navigate digital transformation, achieve sustainable success, and create better business opportunities leading to economic growth. Future research should focus on measuring CSFs to enhance the existing literature on TOT.

Siti Amirah Ahmad et al. investigated the key factors influencing blockchain adoption in Malaysia’s construction sector. Using semi-structured interviews with 21 industry professionals through face-to-face and online modes, the study employs thematic analysis to extract insights. The findings identify five critical factors shaping blockchain integration: Social, Educational, Technical, Political, and Financial. Key challenges include low awareness, a lack of skilled professionals, and insufficient government support. The research provides a framework for policymakers, industry practitioners, and researchers to understand and address barriers to blockchain adoption. By tackling these factors, Malaysia's construction industry can move towards greater efficiency, cost savings, and sustainable material handling practices, reinforcing the sector’s long-term resilience.

Mohamad Irwan P. Harahap et al. investigated the integration of Building Information Modeling (BIM) to mitigate safety violations in high-rise construction projects in Malaysia. The study employs a mixed-methods approach, combining a questionnaire survey of construction professionals and an analysis of BIM's potential to address safety challenges. The survey identifies common safety issues and explores how BIM can enhance safety through improved planning, visualization, and real-time monitoring. The findings highlight significant barriers to BIM adoption, including legal and contractual considerations, limited awareness, and resistance to change. To address these challenges, a strategic framework for successful BIM integration is proposed, emphasizing regulatory support, continuous education, stakeholder collaboration, and incentives for BIM adoption.

Faisal Sheikh Khalid et al. examined the use of steel and polypropylene (PP) fibers in concrete to improve tensile strength and reduce cracking, particularly in non-structural and low-reliability structural elements like slabs and walls. Concrete mixes with 0%, 0.5%, 1.0%, and 1.5% of each fiber type were tested. Results showed that fiber inclusion enhanced both compressive and splitting tensile strength, with the best performance seen in the mix containing 1.0% PP and 1.5% steel fibers. This mix achieved a 35.7% increase in compressive strength and a 58.8% improvement in splitting tensile strength compared to the control. The study concludes that combining steel and PP fibers in concrete creates stronger, more crack-resistant composites, making hybrid fiber reinforcement an effective alternative to traditional methods in structural and non-structural applications.

Nur Nilam Sari Md Yusoff et al. established a structured framework that supports clients in adopting a proactive approach to safety, emphasizing early risk management and collaboration among project teams. The framework offers practical solutions to enhance workplace safety, sustainability, and project efficiency by aligning client responsibilities with regulatory requirements. This shift from reactive to preventive safety management is essential in reducing workplace accidents and strengthening compliance with industry regulations.

Azahar Mohd Yasin explored the use of Internet-of-Things (IoT) technologies to enhance safety on smart campuses, emphasizing their potential to improve campus planning and administration. Despite these benefits, challenges in decision-making have hindered IoT adoption. To understand the factors, risks, and challenges affecting implementation, the study conducted semi-structured interviews with 20 safety personnel from private and government universities experienced in occupational health and safety. Thematic analysis of the data revealed five key themes each for influencing factors (competency, financial, technology, infrastructure, management), risks (management, technology, safety competency, financial, infrastructure), and challenges (management, competency, system, human, financial). These findings offer practical guidance for decision-makers and university administrators to strategically plan IoT integration, prioritize resources, and address critical issues in implementing IoT for improved campus safety.

Hashim et al. suggested the sub-attribute of datafication comprises seven indicators which are: (i) D1 - knowledge and expertise; (ii) D2 - professionalism; (iii) D3 - code of conduct; (iv) D4 - progress monitoring; (v) D5 - risk; (vi) D6 - quality; and (vii) D7 - legal. Next, the second sub-attribute of a data-driven culture in the construction digital industry, referred to as infrastructure of data, consists of three indicators as follows: (i) ID1 - data security; (ii) ID2 - availability of infrastructure; and (iii) ID3 - availability of fund. The third sub-attribute,

cultivation of data, has seven indicators, which are: (i) C1 - technical knowledge; (ii) C2 - willingness to adapt into new technology; (iii) C3 - ease of learning experience; (iv) C4 - competency; (v) C5 - experience; (vi) C6 - training; and (vii) C7 - coordination. Another sub-attribute of a data-driven culture in the construction industry is termed the culture of use, which comprises eight specified indicators: (i) U1 - data interoperability; (ii) U2 - compatibility with other organization; and (iii) U3 - collaborative work processes and modeling standards; (iv) U4 - internal support; (v) U5 - external support; (vi) U6 - data standardization; (vii) U7 - building model reading and exploration; and (viii) U8 - availability of time to use. The last sub-attribute, referred to as the culture of production, has eight indications. These indications are identified as the specified terms which are: (i) P1 - register-based statistic; (ii) P2 - detail data collection; (iii) P3 - information extraction; (iv) P4 - outcome expectations; (v) P5 - data estimating; (vi) P6 - prevention; (vii) P7 - mitigation action; and (viii) P8 - control strategy.

Xiong Ping et al. explored the critical challenge of material handling (MH) inefficiencies in China's rapidly expanding high-rise construction sector. This study addresses the research gap by identifying key success factors (SFs) through semi-structured interviews with 30 industry professionals and thematic analysis. Findings categorize SFs into four critical themes: education, awareness and research, utilization of advanced technology, and market drivers. Enhanced training programs, increased awareness of sustainable MH practices, and integration of digital and automation technologies are essential for improving efficiency. Additionally, stakeholder collaboration and government policies play a crucial role in fostering an environment conducive to MH optimization. The study aligns with China's Construction Industry Modernization Guidelines (2020–2035) and provides a framework for local governments, policymakers, and industry professionals to optimize MH practices in CHRB.

Syahirah Mat Sahizol Raduan et al. highlighted the critical role of the Building Information Modelling Execution Plan (BEP) in fostering communication and collaboration among project stakeholders by defining roles, responsibilities, and deliverables. However, inconsistencies in BEP usage due to a lack of standardisation pose challenges in ensuring alignment with project goals. This study examines the existing BEP elements and identifies challenges in its implementation within Malaysian construction projects. Through qualitative document analysis of 14 BEP documents, findings reveal significant variations in BEP structure and content across organisations. The study highlights the need for standardisation to enhance BEP practices, improve BIM implementation, and support government efforts in advancing BIM adoption in Malaysia.

Patrose Leshinka et al. explored how Artificial Intelligence (AI) can transform occupational health and safety in the construction industry. The study utilized an exploratory research approach combining qualitative and quantitative methods, with data collected from Building Information Modeling (BIM) and analyzed using the HSE Nation AI tool. The AI tool identified 16 distinct hazards, including falls, heavy machinery risks, and chemical exposure, which were categorized using a color-coded risk assessment matrix. High-risk areas were prioritized for safety interventions, and after implementing control measures, reassessments showed significant risk reduction. The integration of AI into BIM enabled enhanced visualization and real-time communication of safety risks, fostering proactive hazard management. The research concludes that AI integration improves hazard detection, risk assessment, and communication, providing a data-driven safety approach hence leading to safer and more efficient construction projects.

Lim et al. developed an integrated planning and scheduling framework to enhance construction project control for contractors. Using a qualitative case study approach, the research explored planning and scheduling practices through semi-structured interviews, document reviews, and observations. Findings revealed that Scope, Schedule, and Cost are the primary knowledge areas influencing schedule development, with other project management areas indirectly integrated. The proposed framework follows the Input, Tool and Technique, Output (ITTO) model, incorporating eleven inputs, sixteen techniques, and twenty-three project data points to improve task sequencing and resource allocation. Validation by industry experts confirmed its practical applicability in streamlining project planning and execution. This structured approach bridges theoretical project management concepts with industry practices, enabling contractors to systematically develop feasible schedules, enhance project monitoring, and optimize resource utilization, ultimately improving construction project efficiency.

CAUSES OF ACCIDENTS IN HIGH-RISE CONSTRUCTION PROJECTS AND THE APPLICATION OF SAFETY REGULATIONS IN THE MALAYSIAN CONSTRUCTION INDUSTRY

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Abstract
The increase in the number of construction projects also contributes to the high accident rate. Accidents in the construction industry will affect the construction project, such as increasing project costs, quality non-conformance, and schedule overruns. The main causes of accidents on construction sites, according to the ranking, are working at height, unsafe working practices, failure of structure, incorrect work procedures, and not wearing personal protective equipment. The statistics are based on the accident reports made by contractors. The causes of construction accidents are assessed by using a questionnaire in order to develop a structured framework that can enhance safety regulations. The significant relation and reliability between group contractor, consultant and client are measured using RII and Cronbach's alpha. The top five causes of accidents in high-rise construction projects are failure to comply with safety regulations, lack of safety working procedures, no safety and health management practices or standard operating procedures, not providing safe working conditions, and inappropriate construction methods. The enforcement of the law must be strengthened to ensure full compliance by all parties, thereby facilitating the provision of a safe working environment within the construction sector.

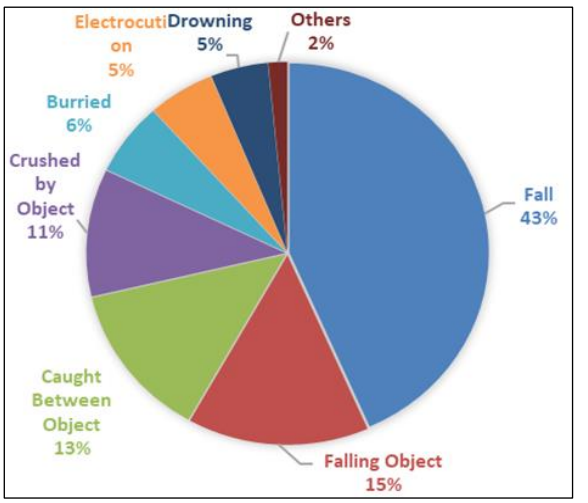
Keywords: *Safety Regulations; Causes of Construction Accidents; Questionnaire Survey; High Rise Construction Projects*

INTRODUCTION

Construction contributes to significant growth in the Malaysian economy and also contributes to the high rate of accidents. Accidents in the construction industry will affect the construction project, such as increasing project costs, defects and delays (Izatul et al., 2024). DOSH stated that 1143 cases of construction accidents in Malaysia from 2015 to 2019 (DOSH, 2020).

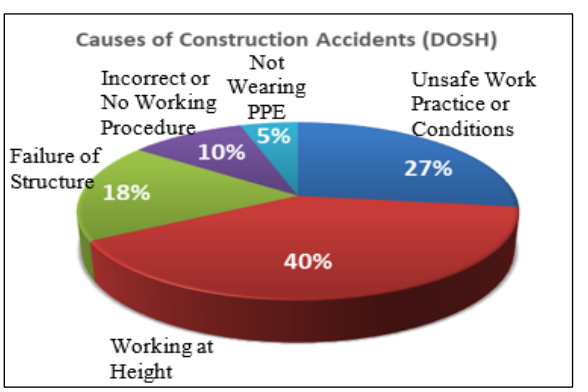
DOSH's statistic as shown on Figure 1 indicate that construction accidents are due to fell from height place (43%), falling object (15%) caught from an object (13%), crushed by an object (11%), buried (6%) electrocution (5%) drowning (5%) and others such as fire & harmful chemicals (2%) (DOSH, 2020). DOSH reported as shown on Figure 2 that the causes of construction accidents are due to working at height (40%), unsafe work practice or conditions (27%), failure of structure (18%), incorrect or no working procedure (10%) and not wearing PPE (5%) (DOSH, 2020). The statistics obtained from DOSH are based on the accident reports made by the contractor or project owner. The actual number of accidents and near-misses at construction sites may be higher (SOCSO, 2014).

The objective of the study is to identify and rank the root cause of accidents in each stage of construction projects.



(Source: DOSH, 2020)

Figure 1. Percentage of Fatalities Based on The Types of Accidents in Construction Industry in Malaysia



(Source: DOSH, 2020)

Figure 2. Causes of Construction Accidents in Malaysia

METHODOLOGY

Questionnaire Survey Questions

To get details of the causes of accidents in high-rise construction projects, a questionnaire survey has been conducted. The survey involved high-rise construction projects and included all parties involved, such as contractors, consultants, and clients. The survey will have nine sections, namely background of respondents, safety awareness, causes of accidents, type of accidents, impact of accidents, benefits of improving safety and health, preventive measures, enhancement of safety regulations, and open-ended questions.

Target Respondents

This study targeted personnel at the professional level in construction companies, such as the general manager, project manager, site engineer, quantity surveyor, safety officer, and other professionals involved in construction projects. The study also targeted staff from

contractor companies, including sub-contractors of various sizes, from G5 to G7 grade contractors. This study will also involve consultants, clients, and other professionals involved in projects.

A questionnaire survey was used to analyse the cause of construction accidents in high-rise construction projects. The RII is used to determine which factors have a huge impact on the cause of construction accidents in high-rise construction projects. The ranked factors are classified into classes of impact from very low to very high by using AVI (Idris, 2018). The RII and AVI value is determined by using the formula as shown in Table 1 (Kometa et al., 1994). The reliability and validity of data are determined by using Cronbach's alpha.

Table 1. The Formula Used to Calculate RII and AVI

Relative Importance Index (RII)	$RII = \frac{\sum W}{A \times N}$
Average Index (AVI)	$AVI = \frac{\sum(\beta \times n)}{N}$

RESULTS AND DISCUSSION

One hundred eighty questionnaires were sent to the construction field in order to get the reaction. The respondents were engineers, architects, quantity surveyors, engineers and HSE officers with experience between 5 to 15 years.

Top Five Causes of Accidents in High-Rise Buildings

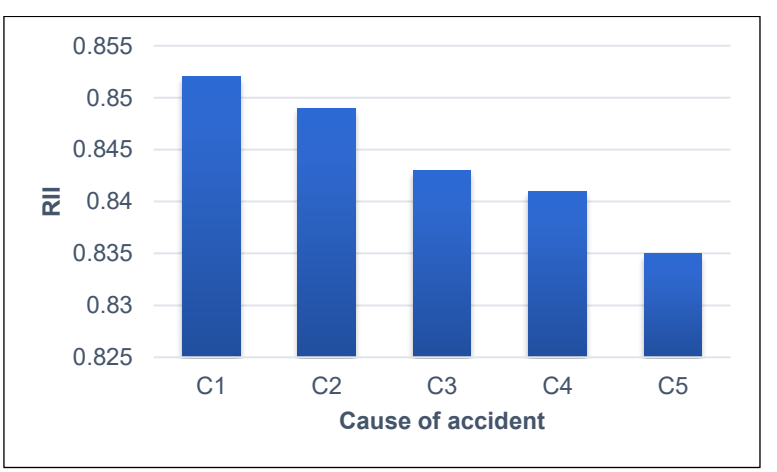


Figure 3. Top Five (5) Causes of Accidents in High-Rise Buildings

Table 2. Top Five (5) Causes of Accidents in High-Rise Building

Rank	Cause of Accident	RII	Cause of Construction Accident
1	C1	0.852	Failure to comply with Safety Regulations such as OSHA 1994 and FMA 1967
2	C2	0.849	Lack of safety working procedure
3	C3	0.843	No Safety and Health Management Practice or Standard Operating Procedures
4	C4	0.841	Not providing safe working conditions
5	C5	0.835	Inappropriate construction method

Based on the survey, the top five causes of accidents in high-rise buildings are failure to comply with safety regulations such as OSHA 1994 and FMA 1967, lack of safety working procedures, no safety and health management practices or standard operating procedures, not providing safe working conditions and inappropriate construction methods (Figure 3 and Table 2).

Rank #1 - Failure to Comply with Safety Regulations such as OSHA 1994 and FMA 1967 (RII = 0.852, AVI = 4.258)

It is the responsibility of all parties involved in construction to comply with the safety acts such as OSHA 1994 and FMA 1967 (OSHA, 1994). This study found that most of the accidents that occur in high-rise construction projects are due to non-compliance with this act. Therefore, it is important to ensure all parties involved in the construction, especially contractors, are adhering to the safety regulations, guidelines and procedures as detailed out in OSHA 1994 and FMA 1967. Failure of any construction practitioners to comply with these acts is not only an offense but will also pose a high risk of accidents on construction sites (DOSH, 1983).

Rank #2 - Lack of Safety Working Procedure (RII = 0.849, AVI = 4.247)

The survey shows that the second top cause of accidents in high-rise construction projects is the lack of safety working procedures. Every contractor shall submit safety working procedures in detail, including method statement, materials to be used, machinery to be used, and other important safety procedures to be followed. This safety procedure shall be approved by the consultant and shall be followed by the contractor during construction (DOSH, 2007). Therefore, the construction practitioner needs to ensure that the safety working procedures are sufficient and approved for implementation.

Rank #3 - No Safety and Health Management Practice or Standard Operating Procedures (RII = 0.843, AVI = 4.216)

According to the survey, the third leading cause of accidents in high-rise construction projects is the lack of safety and health management practices or standard operation procedures. The top management from all parties involved in construction must ensure that construction practitioners follow the safety and health management practice or the standard operation procedures OSHA 1994. It is the responsibility of the top management of each organisation to ensure that procedures are in place in the company's SOPs. This will give a high level of commitment from the top management to the lower levels.

Rank #4 - Not Providing Safe Working Conditions (RII = 0.841, AVI = 4.247)

According to the survey, the fourth leading cause of accidents in high-rise construction projects is the failure to provide safe working conditions. The construction practitioner needs to ensure that the working conditions at the construction site are safe by following the safety guidelines such as providing safety signage, providing appropriate safety gears such as safety helmet, safety vest, safety shoe, safety glove, ear plug, goggle and safety harness and adhere to all guidelines and procedures for high-rise construction project (OSHA, 1994).

Rank #5 - Inappropriate Construction Method (RII = 0.835, AVI = 4.175)

The survey shows that the fifth top cause of accidents is inappropriate construction methods. The contractor must ensure that the construction methods are safe for people's health and well-being. This includes a construction method for a temporary structure, such as the installation of scaffolding, formwork, and the use of heavy machinery. Safe construction methods must be considered from the design stage, construction stage and then at the maintenance stage. Safe construction methods must be refined starting from design, preparation of method statement and close monitoring during construction (OSHA, 1994).

Causes of Construction Accidents Based on the Questionnaire Survey's Respondents and Interview

A total of 134 respondents from all levels of the Malaysian construction industry were recruited for the questionnaire survey, representing a representative sample of the entire industry. It was determined that 55 contractors from 3 separate G7 contractors working on three different projects were selected to respond to the questionnaires. The number of consultants chosen from the directory is 35, all of them are registered with the Board of Engineers Malaysia, with 34 respondents coming from the developer sector. With 64 respondents, most respondents had more than 15 years of expertise in a comparable field. According to the results, 33% of respondents had 5-10 years of industry experience, while 14.9% of respondents had 25 years of industry experience (Figure 4). There are three major types of business respondents: 42% from contractors, 26% from engineering consultants, and 23% from developers, with a total number of respondents of 134 (Figure 7).

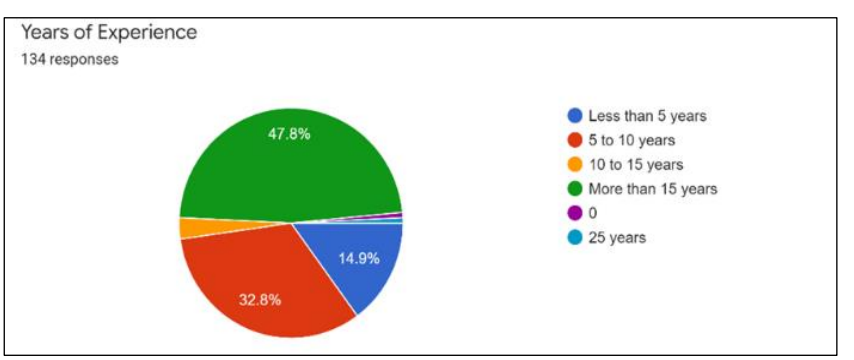


Figure 4. Background of The Respondents (Years of Experience)

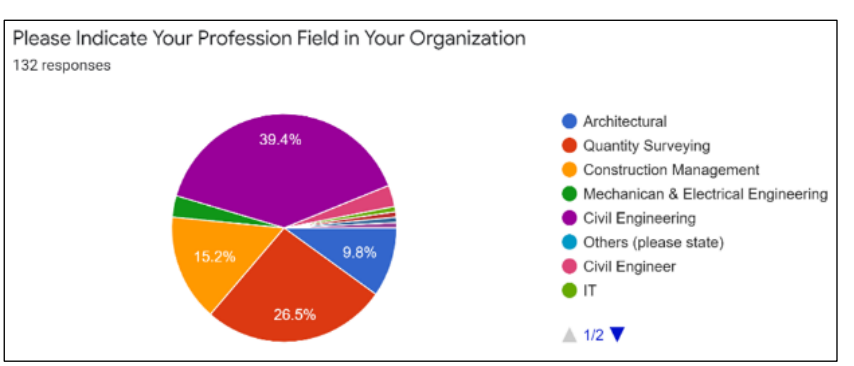


Figure 5. Background of The Respondents (Profession Fields)

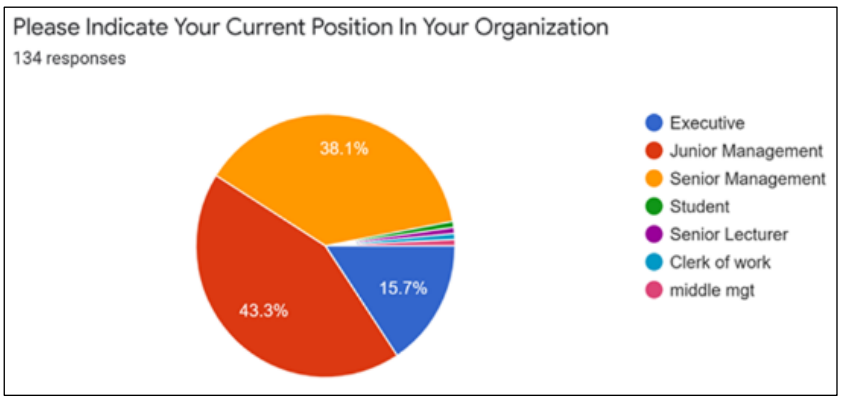


Figure 6. Background of The Respondents (Current Position)

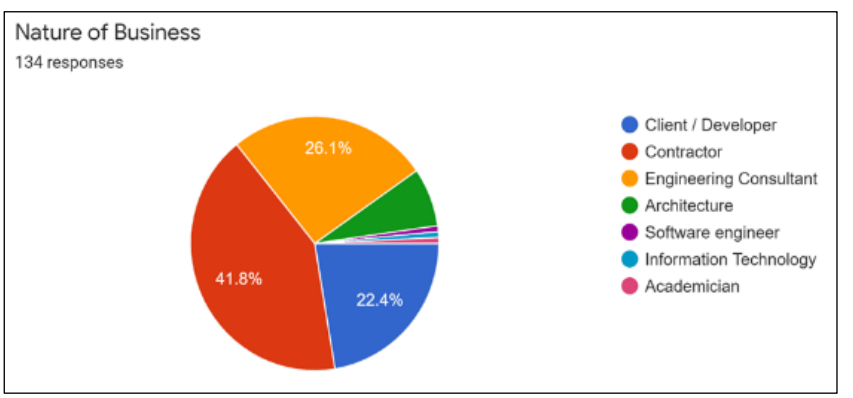


Figure 7. Background of The Respondents (Nature of Business)

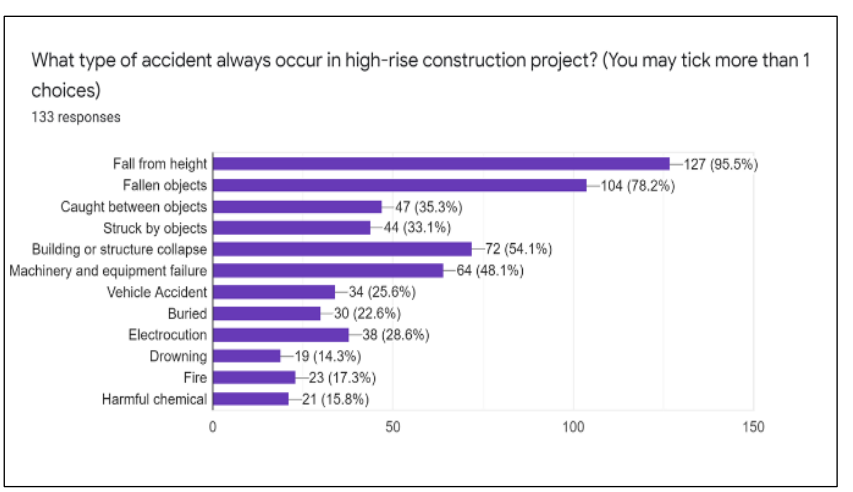


Figure 8. Type of Construction Accident

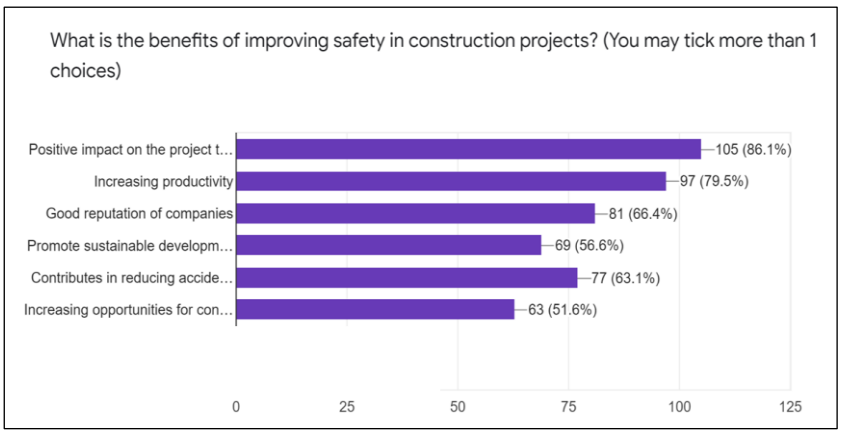


Figure 9. Benefits of Improving Safety

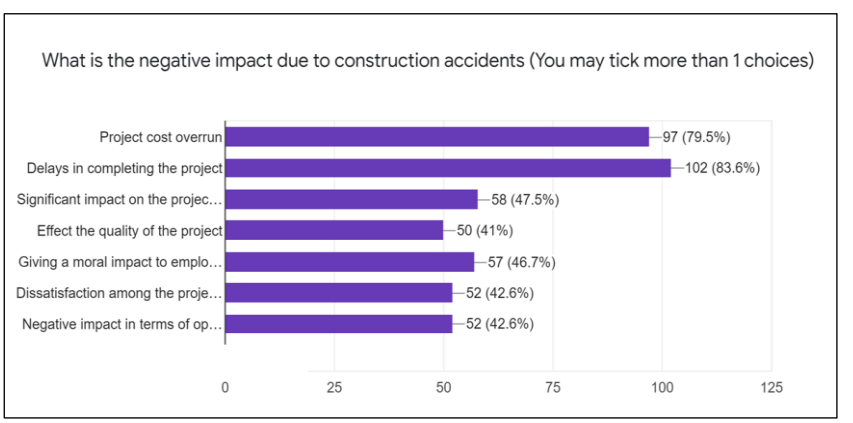


Figure 10. Negative Impact Due to Construction Accidents

CONCLUSION

The detailed causes of accidents in high-rise construction projects were obtained through a questionnaire survey. The survey involved high-rise construction projects and included all parties involved, such as contractors, consultants and clients. The survey has nine sections, namely background of respondents, safety awareness, causes of accidents, type of accidents, impact of accidents, benefits of improving safety and health, preventive measures, enhancement of safety regulations and open-ended questions. The identified factors in the survey were grouped under the following categories: (a) safety awareness, (b) Causes of construction accidents, and (c) Type of construction accident. The questionnaire was distributed among three different groups: executives, senior management, and junior management. The data obtained are then ranked according to their RII value. The ranking is necessary to determine which factors have a huge impact on the cause of construction accidents in high-rise construction projects.

Based on the survey, the top five causes of accidents in high-rise construction projects are failure to comply with safety regulations such as OSHA 1994 and FMA 1967, lack of safety working procedures, no safety and health management practices or standard operating procedures, not providing safe working conditions, and inappropriate construction methods.

Under Section 15 of OSHA 1994, employers and contractors who fail to provide a safe and healthy working environment for their employees can be charged under this section, which carries a maximum sentence of an RM50,000 fine, two years in jail, or both. The enforcement of this law must be strengthened to ensure full compliance by all parties, thereby facilitating the provision of a safe working environment within the construction sector.

ACKNOWLEDGEMENTS

The author thanks Yayasan UTP for supporting this research under the Grant Yayasan UTP Fundamental Research Grant (Reference: YUTP-FRG 1/2022 (015-LC0-405).

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AWARENESS, CHALLENGES AND MEASURES FOR LEAN CONSTRUCTION IMPLEMENTATION AMONGST MALAYSIAN GRADE 7 (G7) CONTRACTORS

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Abstract
Lean Construction, derived from Lean Manufacturing, offers a systematic approach to minimising waste, improving process efficiency, and enhancing project delivery for the construction sector. However, its adoption remains limited in Malaysia. This study examines the implementation of Lean Construction practices among Grade 7 (G7) Contractors, focusing on the awareness and challenges towards the concept and strategies for improvement. A quantitative survey was conducted, and 122 construction personnel from G7 contractors' firms responded. Findings reveal a rather strong awareness of Lean principles among respondents, especially regarding operational efficiency and waste reduction benefits. However, knowledge gaps persist in client-centred principles such as Value Identification and Value Stream Identification, which are crucial for aligning projects with customer needs. Top barriers to the implementation of Lean Construction techniques include insufficient awareness of the actual practices, lack of top management support and limited commitment from project teams. Strong management leadership and investment in modern technologies emerge as the most critical factors for facilitating Lean Construction implementation. Additionally, raising awareness through education and training, empowering construction personnel, and conducting pilot projects are essential for successfully integrating Lean techniques into projects. Given the persistent challenges in the construction sector, including dealing with inefficiencies, project delays, cost overruns and material wastages, this study offers critical insights into the role of Lean Construction in addressing these issues. By identifying key barriers and effective implementation strategies, the findings contribute to a deeper understanding of how Lean principles can enhance productivity and promote a more sustainable construction industry in Malaysia.

Keywords: *Lean Construction; Awareness; Challenges; Measures; G7 Contractors*

INTRODUCTION

Lean construction, as defined by the Lean Construction Institute (2024), is a project delivery approach rooted in production management, which includes introducing a new framework for designing and building capital facilities. This approach, adapted from Lean manufacturing principles, transforms construction processes by rethinking how work is conducted throughout project delivery. Lean construction applies the core goals of Lean manufacturing, that is, maximising value and minimising waste, to specific methodologies in construction project execution. It can also be seen as a continuous improvement strategy in the construction process, aimed at reducing resource waste and enhancing project value for the customer (Morshidi, Othman, Bohari and Rais, 2022; Marhani, Othman and Ismail, 2012). Consequently, Lean construction can be described as a methodology focused on minimising waste while producing high-quality end products (Morshidi et al., 2022; Ahmed, Hossain, and Haq, 2021; Reinbold, Riediger and Pollack, 2018).

There are five (5) Lean principles for organisational waste elimination, and these principles are known as the strategic approach to the phrase "Lean thinking" (Akanbi, Oyedolapo and Goulding, 2019). The following Table 1 shows the five principles of lean construction techniques.

Table 1. The Five Principles of Lean Construction Techniques

Code	Lean Principles	Description	References
LP1	Value Identification	Provide a precise definition of what generates value from the client's point of view. The concept of value in construction is assessed based on the customer's viewpoint, namely by determining value from the customer's point of view.	(Verma, 2023; Nifla and Reshma, 2019; Akanbi et al., 2019)
LP2	Value Stream Identification	Thoroughly identify each stage in the value stream that effectively delivers what the customer values while eliminating any elements that do not contribute value to the consumer. A value stream encompasses all the phases that create value in the process of designing, producing, and delivering a product. To ensure an efficient delivery process in a construction project, it is crucial to minimise all nonvalue-adding operations, which refer to activities that do not provide any value to the client.	(Verma, 2023; Nifla and Reshma, 2019; Akanbi et al., 2019)
LP3	Flow	Implement measures to guarantee an uninterrupted flow within the value stream. It is important to acknowledge that each of these flows has its own distinct characteristics and should be appropriately controlled.	(Verma, 2023; Nifla and Reshma, 2019; Akanbi et al., 2019)
LP4	Allowing Customer Pull	This requires just-in-time production of exactly what the consumer requires. At the strategic level, pull is the requirement to be able to deliver the product to the client as soon as the customer requires it. Pull refers to the capability of promptly delivering the product to the consumer.	(Verma, 2023; Nifla and Reshma, 2019; Akanbi et al., 2019)
LP5	Pursuing Perfection	Always strive for perfection by delivering what the consumer wants and expects through continuous removal of waste. Through process improvement to deal with the challenges in the construction.	(Verma, 2023; Nifla and Reshma, 2019; Akanbi et al., 2019)

(Source: Akanbi et al., 2019)

Lean construction aims to eliminate waste and enhance efficiency to optimise project delivery, significantly impacting construction schedules and overall project performance (Ahmed et al., 2021). The Lean construction approach seeks to address critical issues in the industry, such as delays, cost overruns, and quality deficiencies, which have long plagued construction projects (Othman, Zainal, Kasim and Abdul Rahim, 2023). One of the key benefits of Lean construction is its ability to ensure timely project delivery, providing clients with greater reliability (Ahmed et al., 2021). Additionally, Lean construction has been shown to increase workforce efficiency, facilitate improved coordination and communication, and reduce the incidence of defects and rework (Bajjou and Chafi, 2019). Research has also highlighted that Lean practices positively influence worker productivity and job site safety, demonstrating a link between Lean thinking and improved safety performance (Marhani et al., 2021). Furthermore, lean construction's emphasis on minimising waste and maximising resource efficiency supports environmental sustainability objectives (Francis and Thomas, 2020).

Although Lean construction has the potential to bring about significant benefits, the construction industry has many barriers when it comes to implementing it on a large scale (Othman et al., 2023; Ahmed et al., 2021; Marhani et al., 2021). Previous research on Lean construction has highlighted both the significant benefits and challenges associated with its implementation in the construction industry. Studies like those conducted by Xing, Hao, Qian, Tam and Sikora et al. (2021) and Litika, Jelodar, Vishnupriya, Rotimi and Vilasini (2022) emphasise the difficulties in adopting Lean construction methods, such as resistance to change, lack of stakeholder willingness to adopt Lean methodologies, and challenges in transitioning from traditional construction methods to Lean practices. These studies also point out the initial financial impact, with contractors potentially seeing reduced profits when first implementing Lean construction techniques (Graces, Forcael and Osorio, 2025). Furthermore, in Malaysia, the integration of Lean and Building Information Modelling (Lean-BIM) faced barriers like insufficient training, awareness, and empowerment from senior management, limiting its widespread adoption (Aziz and Zainon, 2022). The research underscores the need for targeted interventions, including training and leadership support, to enable the successful adoption of Lean practices in the construction industry (Albalkhy, Sweis and Lafhai, 2021).

In the Malaysian context, studies by Marhani, Abdul Haris, Muhammad Rooshdi, Adillah and Shaza (2023) and Arif, Azmi and Jaapar (2019) show that tools such as teamwork, daily hurdle meetings, and 5S are widely adopted in the industry, with teamwork and Total Quality Management (TQM) as part of Lean tools are particularly effective in reducing waste and improving environmental performance. Research by Ansah and Sooroshian (2017) and Yahya, Musli, Badrul, Mahmod and Abdullah (2023) identified 30 Lean tools, including the Last Planner System and Value Stream Mapping, as suitable for the Malaysian construction sector. While these studies demonstrate the potential of Lean construction to improve project efficiency and quality, they also highlight ongoing challenges, including resistance from stakeholders and a lack of comprehensive understanding or commitment (Pérez, Avila and Sanchez, 2024). Overall, while the benefits of Lean construction are evident, the implementation barriers remain significant, and overcoming these requires targeted strategies such as leadership support, training, and tailored Lean practices (Aslam. Baffoe-Twum, Muhammad and Ulhaq, 2024).

Despite the well-documented benefits of Lean Construction, including improved efficiency, waste reduction, and enhanced project performance, its widespread implementation remains limited due to persistent barriers such as resistance to change, lack of stakeholder commitment, and inadequate training. While previous studies have explored lean tools and their potential applications in the Malaysian construction industry, there is a gap in the study of how key countermeasures, such as leadership support, targeted education, and technological integration, can address these barriers effectively. Additionally, limited research has examined the interrelationship between awareness, challenges, and strategic interventions necessary for successful Lean adoption among Malaysia's G7 contractors.

This study aims to bridge this gap by providing empirical insights into the current state of Lean Construction implementation, identifying critical obstacles, and proposing tailored strategies to enhance its adoption in the Malaysian construction sector. It is crucial to identify and analyse these factors to better understand the current level of awareness and knowledge of Lean construction among professionals in G7 Contractors, as well as the barriers hindering any broader adoption.

Research Aim and Objectives

This study focuses on evaluating the implementation of Lean Construction among G7 Contractors in Malaysia. The research objectives are as follows:

i. To investigate the current level of awareness and understanding of Lean construction among professionals amongst G7 Contractors.
ii. To identify the potential barriers to the implementation of Lean construction amongst G7 Contractors.
iii. To identify the measures to empower Lean construction implementation amongst G7 Contractors.

RESEARCH METHODOLOGY

The research methodology is summarised in Figure 1 and further described below:

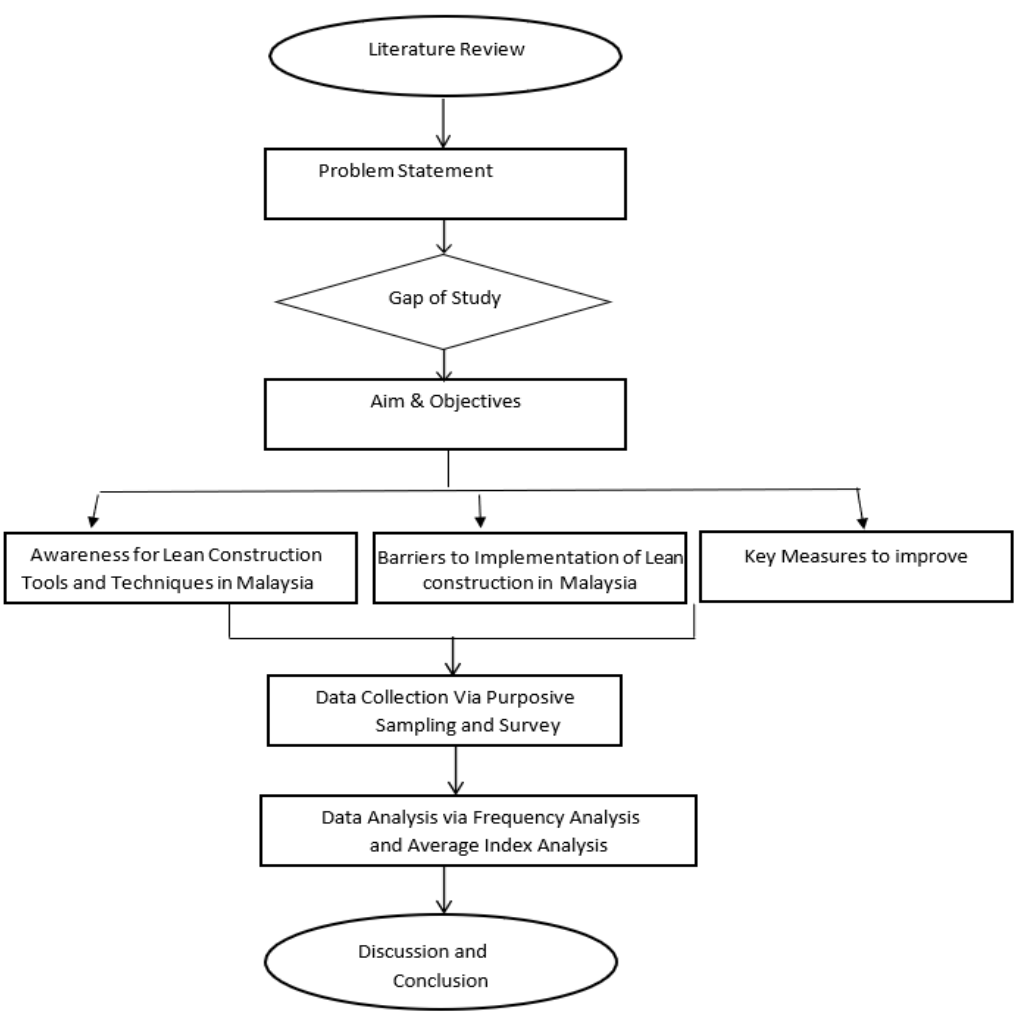

Figure 1. Research Method Flowchart

The quantitative research method is selected for this study due to its effectiveness in addressing the research objectives and providing reliable, generalisable results. Previous studies on Lean construction, such as those by Bajjou and Chafi (2019), Sarhan, Olanipekun, and Xia (2016), and Othman et al. (2023), have successfully employed this approach. The quantitative method using a questionnaire survey is chosen because it allows for the collection of a wide range of responses, enabling the research to cover a large number of respondents and ensuring greater generalisability of the findings (Shang and Pheng, 2014; Sarhan et al., 2016; Tezel, Koskela, and Aziz, 2018 as cited in Bajjou and Chafi, 2019). Additionally, this approach ensures the repeatability and validity of the results, providing valuable insights into the prevalence and distribution of key issues and patterns relevant to Lean construction in the Malaysian context.

Research Population and Research Sampling

The population refers to a group of individuals who share specific characteristics that the researcher wants to investigate (Morshidi et al., 2022). In other words, the term "population" refers to the community or group identified by the researcher. As for this study, the targeted population will be Grade 7 (G7) Contractors in Malaysia is 5680 (CIDB, 2018). The sample size for this study is 360 respondents determined by applying the formula of sample size (Charan and Biswas, 2013, as cited in Morshidi et al., 2022) as shown below:

$$\frac{\frac{Z^2 + p\,(1 - p)}{e^2}}{1 + \frac{(Z^2 + p\,(1 - p)}{e^2\,N}} \qquad (1)$$

Where Z is the Z-Score, p is the population proportion, e is the error, N is the total population.

Data Collection

The selected respondents are construction-related personnel from G7 contractor firms, each with a minimum of 5 years of site experience and a record of completed projects. Since it is preferable that respondents have prior knowledge of or experience with Lean Construction, it is expected the sample size will further be reduced. A total of 500 questionnaires were distributed via email, phone, and social media platforms, resulting in 122 completed responses, achieving a return rate of 24.5%. As noted by Gamil, Al-Sarafi, and Najeh (2022), a response rate of 14.1% is considered satisfactory in similar research contexts, indicating that this study's response rate is well above the acceptable threshold.

Purposive and snowball sampling methods were employed. Purposive and snowball sampling methods were selected because they enable the targeted identification of participants with relevant expertise. Purposive sampling ensures that only individuals with substantial site experience and familiarity with Lean Construction are included, enhancing the reliability of the findings. Meanwhile, snowball sampling helps reach additional qualified participants through referrals, ensures a well-informed respondent pool, and ensures the relevance and

quality of data collected (Taherhoost, 2016). Additionally, snowball sampling facilitates access to a specialised population by leveraging participants' networks to identify similarly qualified individuals.

The survey questionnaire is divided into four (4) sections:

- Section A captures respondent background information, including gender, age, highest qualification, years of service in the construction industry, and job title.
- Section B consists of closed-ended questions where respondents use a Likert scale to indicate their level of knowledge of Lean construction principles. Respondents may select one of three options: "Not familiar with," "Familiar with but not currently implemented," or "Familiar with and implemented".
- Section C presents closed-ended questions where respondents evaluate barriers to implementing Lean construction in the construction industry using a Likert scale. Eight barriers, identified from previous research, are assessed on a scale ranging from "Strongly Disagree" to "Strongly Agree."
- Section D includes closed-ended questions for respondents to evaluate proposed measures for strengthening Lean construction implementation in the construction industry. Seven measures, sourced from prior studies, are rated on the same Likert scale ranging from "Strongly Disagree" to "Strongly Agree."

Data Analysis

The data were analysed using SPSS for Social Science and Microsoft Excel by applying the frequency analysis method. Frequency analysis is a vital aspect of statistics that focuses on the frequency of a certain event; it involves creating a thorough frequency table and representing the data in a bar chart or a pie chart (Oosterbaan, 2021 and Morshidi et al., 2022). Moreover, frequency analysis is used to analyse respondents' backgrounds in research because it provides a clear picture of the distribution of demographic factors such as age, gender, education level, and years of experience.

In addition, descriptive analysis, specifically average index analysis, will be opted to achieve the objectives of the study. Furthermore, average index analysis is chosen because it provides a short overview of complex data, making it simple to analyse and compare. Its advantages include simplifying data presentation, facilitating trend detection, allowing for comparisons and highlighting discrepancies or patterns in data, all of which improve the analysis and comprehension of research findings.

The following is the equation for average index analysis for every variable (Chandrasekar and Kumar, 2014):

$$\text{Average Index} = \frac{\Sigma 1X^1 + 2X^2 + 3X^3 + 4X^4 + 5X^5}{\Sigma X^1 + X^2 + X^3 + X^4 + X^5} \quad (2)$$

Where; X^1 is the number of respondents for Strongly Disagree, X^2 is the number of respondents for Disagree, X^3 is the number of respondents for Neutral, X^4 is the number of respondents who Agree, X^5 is the number of respondents who strongly agree.

This study uses an evaluation table similar to Morshidi et al. (2022) to establish the average index analysis (AI) results. Table 2 shows the Average Index Analysis evaluation table.

Table 2. Average Index Analysis (A.I) Evaluation Table

Average Index	Evaluation
1.00 < Average Index < 1.50	Very Poor
1.50 < Average Index < 2.50	Poor
2.50 < Average Index < 3.50	Moderate
3.50 < Average Index < 4.50	High
4.50 < Average Index < 5.00	Very High

RESULTS AND DISCUSSION

Level of Awareness

The analysis of Lean Construction principles among 122 professionals in G7 contractors' firms in Malaysia provides a comprehensive understanding of the perception and implementation of these principles within the construction industry. Table 3 presents the findings in terms of the level of awareness and understanding of Lean Construction Principles through average indexes, evaluation levels, and rankings for each Lean Construction principle, offering valuable insights into their prioritisation and application.

Table 3. Level of Awareness and Understanding of Lean Construction Principles

Code	Level of Awareness and Understanding	Average Index (A.I)	Level of Evaluation	Rank
LP1	Value Identification: Respondent's awareness and understanding of the concept of identifying what generates value from the client's point of view in construction projects.	4.16	High	5
LP2(i)	Value Stream Identification: Respondent's awareness and understanding of the phases that create value in the process of designing, producing, and delivering a construction product.	4.17	High	4
LP2(ii)	Value Stream Identification: Respondent's awareness and understanding of the importance of minimising nonvalue-adding operations in construction projects.	4.26	High	1
LP3	Flow: Respondent's awareness and understanding of the concept of ensuring an uninterrupted flow within the value stream in construction projects.	4.18	High	3
LP4	Allowing Customer Pull: Respondent's awareness and understanding of the concept of 'pull' in Lean Construction and its importance in promptly delivering products to clients.	4.01	High	6
LP5(i)	Pursuing Perfection: Respondent's familiarity with the principle of continuously striving for perfection in construction projects.	4.18	High	3
LP5(ii)	Pursuing Perfection: Respondent's engagement in continuous process improvement activities to remove waste and meet client expectations.	4.19	High	2

The principle of minimising non-value-adding operations (LP2(ii)) ranked highest in the Value Stream Identification process, achieving an average index of 4.26. This finding reflects a strong understanding among respondents and substantial recognition of the importance of waste reduction in enhancing efficiency within construction projects. Respondents extensively involved in project management and operational roles tend to prioritise waste reduction due to its direct impact on critical project outcomes, such as cost savings and timely completion.

However, the emphasis on reducing non-value-adding operations is not an isolated effort but is intrinsically connected with other Lean principles, particularly Flow (LP3) and Continuous Improvement (LP5(i) and LP5(ii)). Respondents ranked Continuous Improvement (LP5(i)) and Striving for Perfection (LP5(ii)) second and third, with average indexes of 4.19 and 4.18, respectively. This interconnection highlights the holistic nature of Lean principles, where each support and reinforces the others. Continuous Improvement (LP5(i)) represents a sustained commitment to regularly evaluate and refine processes to remove inefficiencies, while Striving for Perfection (LP5(ii)) extends this by advocating for an ongoing pursuit of excellence, aiming to eliminate any non-value-adding elements. The Lean philosophy advocates for a shift away from conventional construction practices towards a culture that prioritises ongoing improvement, where every process is consistently assessed and improved. The synergy between these principles underscores that waste reduction is not a one-time goal but an iterative, continuous journey requiring consistent improvement and vigilance.

In addition, failure to eliminate waste can impede the smooth flow in the value stream, LP3 (also ranked third), resulting in delays and inefficiencies. The dedication to continuous improvement is highly connected to sustaining uninterrupted flow (LP3). A constant emphasis on improving workflows reinforces the concept of flow by identifying and removing obstacles, decreasing the time it takes to complete a process, and guaranteeing smooth transitions between various stages of construction. This alignment signifies that respondents comprehend the importance of maintaining a continuous flow by not only sustaining operational momentum but also actively improving processes to eliminate inefficiencies that may hinder this flow.

The principle of Value Stream Identification, LP2(i), ranked fourth with an average index of 4.17, underscores the importance of identifying and aligning construction phases that create value. While respondents acknowledge its significance, effective implementation remains a challenge, likely due to the complexity of mapping value-adding phases in the dynamic and unpredictable construction industry. This relatively lower ranking, compared to other Lean principles, highlights a notable gap in understanding and application. Addressing this gap is crucial, as challenges in implementing Value Stream Identification can undermine the overall effectiveness of Lean Construction, given its foundational role in streamlining processes and eliminating inefficiencies.

Value Identification (LP1), which ranked fifth with an average index of 4.16, reflects the respondents' recognition of the importance of aligning construction processes with client priorities. This principle ensures that all aspects of a project are geared towards delivering maximum value to the client, making it central to Lean practices. However, the lower ranking indicates a need for improvement in its application, as insufficient emphasis on understanding

and prioritising client needs can lead to inefficiencies and diminished project outcomes. This deficiency can also impact the successful implementation of related principles, such as Allowing Customer Pull (LP4), which relies on a thorough understanding of client demands.

The findings highlight a strong emphasis on waste reduction and operational efficiency among Malaysia's G7 Contractors, as evidenced by the highest ranking of Minimising Non-Value-Adding Activities (LP2(ii)). This suggests that respondents recognise the direct impact of waste elimination on cost savings, project timelines, and overall efficiency. However, while this principle is a cornerstone of Lean Construction, its effectiveness is not independent but rather deeply interconnected with other Lean principles. The close ranking of Continuous Improvement (LP5(i)) and Striving for Perfection (LP5(ii)) underscores the industry's need to refine processes and sustain efficiency over time. This reinforces the iterative nature of Lean Construction, where ongoing evaluation and process enhancements are crucial to long-term success.

Despite the strong awareness of efficiency-driven principles, the lower ranking of Value Stream Identification (LP2(i)) and Value Identification (LP1) reveals a gap in understanding client-driven Lean principles. This limitation is significant, as identifying and aligning value streams is fundamental to optimising processes and ensuring that construction activities are aligned with client priorities. The challenge likely stems from the complexity of mapping value-adding phases in a dynamic and less predictable industry like construction, which may contribute to inefficiencies and hinder Lean adoption. Similarly, the lower emphasis on Value Identification suggests a potential disconnect between project execution and client expectations, which can undermine the overall success of Lean implementation.

These results indicate that while G7 Contractors have a good fundamental understanding of Lean Construction, gaps remain in integrating operational efficiency with client-centric principles. Without addressing these gaps, the full potential of Lean practices cannot be realised, as efficiency alone does not ensure value delivery. A more balanced approach, incorporating both waste reduction and client engagement, is essential for a sustainable Lean transformation in Malaysia's construction sector. Achieving this requires a cultural shift towards continuous learning, deeper client involvement, and a commitment to excellence. By fostering a holistic understanding of Lean principles and their interdependencies, the industry can enhance efficiency, overcome challenges, and deliver greater value to clients.

Barriers to Implementation

Table 4 presents the barriers to the Implementation of Lean Construction, emphasising the average indexes, level of evaluation, and rank of each barrier.

With reference to Table 4, the results indicate the 122 respondents' degree of agreement regarding the barriers to the implementation of Lean construction. Lack of Lean Awareness and Understanding, BR1, has received the highest ranking with an average index of 4.41. The second highest ranked is followed by Lack of Support from Top Management, BR3. with an average index of 4.39. Meanwhile, the third highest average index is the Lack of Commitment of the Project Team, BR4, and Inadequate Strategic Planning, BR7, with an average index of 4.39. The fourth highest average index is resistance to changing the existing culture due to

comfortableness with the traditional method, BR5, with an average index of 4.36. Lastly, the fifth highest ranked goes to Lack of Standardisation, BR8, with an average index of 4.31.

Table 4. Barriers to The Implementation of Lean Construction

Code	Barriers to Implementation	Average Index (AI)	Level of Evaluation	Rank
BR1	Lack of Lean Awareness and Understanding	4.41	High	1
BR2	Implementation Cost	4.11	High	6
BR3	Lack of Support from Top Management	4.39	High	2
BR4	Lack of Commitment of Project Team	4.37	High	3
BR5	Resistance to change in the existing culture is due to comfortableness with traditional methods	4.36	High	4
BR6	The Nature of the Construction Industry differs from that of the manufacturing industry	4.00	High	7
BR7	Inadequate Strategic Planning	4.37	High	3
BR8	Lack of Standardisation	4.31	High	5

Ranked the highest with an average index of 4.41, BR1 highlights the fundamental barrier to Lean Construction, a widespread lack of overall awareness and comprehension of Lean concepts. According to Sarhan and Fox (2013) and Bajjou and Chafi (2018), effective Lean implementation necessitates a thorough understanding of its principles within organisations. Without this foundational knowledge, Lean Construction practices and benefits remain underutilised and underrated. The lack of awareness is often reflective of broader issues in organisational culture and knowledge management, which must be addressed through training and education initiatives. BR3, with an average index of 4.39, ranks as the second-highest barrier. Top management support is vital to overcoming other challenges, as leadership plays a crucial role in promoting Lean principles, allocating resources, and fostering a supportive environment. Aziz and Hafez (2013) emphasise that effective leadership is integral to establishing and sustaining Lean Construction. Without this support, efforts to address barriers like BR1 (awareness) and BR7 (strategic planning) are likely to falter, as the momentum for Lean adoption must originate from leadership.

Sharing the third rank with an average index of 4.39, BR4 and BR7 highlight the importance of team dedication and strategic planning. BR4 focuses on the lack of commitment from project teams, emphasising the need for teamwork, involvement, and a shared purpose among members. Commitment is closely tied to awareness (BR1) and leadership support (BR3), as it requires a cultural and organisational framework that fosters Lean adoption. Similarly, BR7 underscores the necessity of structured strategic planning for successful Lean implementation. Effective planning ensures that Lean principles are systematically and sustainably integrated into processes. This barrier is interconnected with BR1 (awareness) and BR3 (leadership), as strategic initiatives require a clear understanding of Lean principles and robust leadership to guide their execution.

Ranked fourth with an average index of 4.36, BR5 highlights resistance to cultural change as a significant obstacle. This barrier arises from a preference for traditional methods over new Lean practices. Resistance is exacerbated by insufficient awareness (BR1) and lack of leadership support (BR3). Overcoming this challenge requires a cultural transformation that promotes the adoption of Lean principles through education, leadership, and a clear demonstration of the benefits of Lean Construction. With an average index of 4.31, BR8 ranks

fifth among the barriers. The absence of standardised processes hinders the consistent application of Lean tools and methods, reducing efficiency and predictability. Standardisation requires leadership (BR3) and strategic planning (BR7) to establish consistent practices across projects. Additionally, addressing BR1 (awareness) is essential, as a thorough understanding of Lean concepts is necessary to implement and maintain standardised processes effectively.

The findings highlight critical barriers that hinder the successful implementation of Lean Construction among G7 Contractors in Malaysia. The most significant challenge is the lack of full Lean Principles awareness (BR1), which corresponds with the results in Level of Awareness. This underscores a fundamental issue as without a proper understanding of Lean principles, industry stakeholders struggle to recognise its value, leading to resistance and ineffective application. This lack of awareness is not just a knowledge gap but a systemic issue that affects decision-making, project execution, and long-term strategic planning. Equally crucial is the lack of top management support (BR3), which ranks as the second-highest barrier. Leadership plays a pivotal role in driving Lean adoption, influencing company culture, and ensuring resource allocation for Lean Construction initiatives. Without strong leadership commitment, awareness campaigns, strategic planning efforts, and team engagement (BR4) are likely to fail. This highlights the need for a top-down approach, where management not only supports but actively champions Lean Construction.

The findings also reveal that team commitment (BR4) and inadequate strategic planning (BR7) are closely interrelated. A lack of structured planning can lead to fragmented implementation, where Lean tools and techniques are applied inconsistently. Without clear direction and well-defined goals, project teams may remain disengaged, reinforcing resistance to change (BR5). The preference for traditional construction methods suggests a cultural reluctance to embrace innovation, which can be attributed to both insufficient training and fear of operational disruptions. Moreover, the absence of standardised processes (BR8) further weakens Lean adoption, as inconsistency in application reduces its effectiveness. Standardisation is a critical factor in Lean success, ensuring that best practices are consistently followed across projects. This challenge is exacerbated by the lack of leadership support (BR3) and insufficient strategic planning (BR7), reinforcing the interconnected nature of these barriers.

Overall, these findings indicate that Lean Construction cannot be successfully implemented through isolated interventions. Instead, a comprehensive approach is required—one that integrates leadership commitment, structured education, strategic planning, and cultural transformation. Without addressing these barriers in a cohesive manner, the industry risks stagnation, with Lean Construction remaining an underutilised concept rather than a transformative solution for efficiency and sustainability. These results emphasise the need for an industry-wide shift, where organisations actively invest in training, leadership development, and policy reforms to create an environment conducive to Lean adoption.

The following section focuses on measures to enhance the implementation of Lean Construction in Malaysia's construction industry to address the identified barriers. These measures aim to strengthen the understanding, adoption, and integration of Lean principles, enabling the industry to overcome challenges and achieve sustainable improvements.

Key Measures to Enhance Lean Construction Implementation

Table 5 presents the opinions of 122 respondents on potential measures to enhance the implementation of Lean Construction. The findings include the average indexes, evaluation levels, and rankings for each of the seven identified measures.

Table 5. Key Measures to Empower Lean Construction Implementation in Malaysia Construction Industry

Code	Key Measures	Average Index (AI)	Level of Evaluation	Rank
CM1	Sufficient awareness, education, and training empower the implementation of lean construction.	4.53	Very High	2
CM2	Management Leadership, Commitment and Involvement play a vital role in empowering Lean construction implementation.	4.61	Very High	1
CM3	An appropriate level of empowerment for various construction players is essential to empowering lean construction implementation.	4.41	High	3
CM4	Ensuring that the construction process is compatible with Lean Construction and performing "Trial and Error" is critical in enhancing the empowerment of Lean construction implementation.	4.31	High	5
CM5	The implementation of a pilot project is crucial to facilitating and empowering lean construction implementation.	4.36	High	4
CM6	It is vital to adapt the modifications of Lean tools to specific projects in order to empower Lean construction implementation.	4.36	High	4
CM7	Investment in Technologies contributes to facilitating and empowering Lean construction implementation.	4.61	Very High	1

Ranked the highest with an average index of 4.61, Management Leadership, Commitment, and Involvement, CM2, this measure underscores the critical role of strong leadership in driving Lean Construction initiatives. Effective management involvement ensures the allocation of resources, the establishment of a supportive culture, and the prioritisation of Lean practices within organisations. Without robust leadership, other measures risk losing momentum, as leadership is essential for countering the identified barriers and sustaining Lean Construction efforts.

Also, achieving an average index of 4.61 Investment in Technologies, CM7 highlights the importance of adopting modern technologies to streamline processes and improve efficiency. Technological advancements can significantly enhance Lean practices by reducing waste, improving time management, and optimising workflows. However, this countermeasure's success relies on the leadership outlined in CM2 to allocate resources and guide technological investments in alignment with Lean principles. With an average index of 4.53, Sufficient Awareness, Education, and Training, CM1 addresses the necessity of raising awareness and providing education and training on Lean Construction. This countermeasure directly tackles the barrier of limited awareness (BR1) and ensures that all construction players understand Lean principles. Management leadership CM2 plays a crucial role in initiating and supporting educational programs, while increased awareness enhances the overall capacity of the workforce to implement Lean practices effectively.

Ranked fourth with an average index of 4.41, Empowerment of Construction Players CM3 focuses on empowering construction professionals by granting them the necessary authority, responsibility, and accountability to implement Lean practices. Empowerment

complements CM1 by ensuring trained professionals can take ownership of their roles and make meaningful contributions. Effective empowerment also requires management support (CM2) to create and sustain enabling environments. Tied with an average index of 4.36, Pilot Projects, CM5, and Lean Tool Adaptation, CM6, emphasise practical application. CM5 promotes testing Lean practices through pilot projects to identify challenges and refine strategies, while CM6 advocates tailoring Lean tools to fit specific project contexts. These two measures are interrelated, as insights from pilot projects inform the necessary adaptations to Lean tools, ensuring their effectiveness in diverse environments.

The findings underscore the critical role of leadership commitment in driving Lean Construction adoption, as it serves as the foundation for all other Lean measures. Effective leadership is essential for allocating resources, fostering a supportive culture, and prioritising Lean practices within organisations. This commitment ensures that Lean principles are embedded into the organisational culture and cascaded throughout the entire workforce. However, leadership alone is not sufficient; it must be complemented by comprehensive training programs to ensure that all levels of construction professionals understand Lean principles and can apply them effectively. The study also highlights the importance of empowering construction professionals at all levels to take ownership of Lean practices. Empowerment ensures that even well-trained personnel can implement Lean successfully by granting them the autonomy and responsibility necessary to make decisions and drive change. Without this level of involvement, Lean initiatives may be undermined by rigid organisational structures and a lack of accountability, suggesting that Lean adoption should be an organisation-wide effort, not just a policy-level initiative.

Despite the emphasis on leadership and training, the study reveals that organisations may not be fully capitalising on the potential of pilot projects and the adaptation of Lean tools in real-world contexts. Pilot projects serve as a crucial mechanism for testing and refining Lean practices, allowing for practical application and the identification of challenges specific to each project. The relatively lower ranking of these measures suggests that while organisations acknowledge the importance of leadership and training, they may be overlooking the need for structured, ongoing learning and adaptation in practice. This gap highlights the need for a more iterative approach to Lean implementation, where feedback from practical testing informs continuous improvement.

Overall, the findings emphasise that successful Lean Construction implementation requires a comprehensive and integrated approach. Leadership must drive investment; training must develop capability; empowerment must ensure active participation; and pilot projects must refine methodologies. The interdependence of these factors suggests that focusing on one aspect in isolation is unlikely to yield significant improvements. Instead, a balanced strategy that combines leadership commitment, training, empowerment, and real-world testing is essential to ensure that Lean principles translate into tangible efficiency gains in Malaysia's construction sector.

CONCLUSION

In conclusion, this study successfully investigates the adoption of Lean construction practices among G7 Contractors in Malaysia, with a focus on understanding the level of awareness, challenges, and strategies for improvement. The findings indicate that while

professionals in G7 Contractor firms have a foundational understanding of Lean principles, particularly regarding waste reduction and continuous improvement, the practical application of these principles remains a significant challenge. One key difficulty identified is the alignment of construction processes with client values, which hinders the full realisation of Lean's potential. The study further identifies several critical barriers to the adoption of lean construction, including limited awareness, insufficient management support, resistance to change, and a lack of standardisation. These barriers are deeply interrelated and must be addressed through a multifaceted approach. The research recommends a combination of strong leadership commitment, comprehensive training, and investment in supportive technologies to overcome these obstacles. Additionally, strategies such as pilot projects and continuous feedback loops are proposed to refine Lean practices over time, ensuring their effective integration into project workflows. These findings offer valuable insights for industry stakeholders, including G7 Contractor Companies in Malaysia, on how to overcome the challenges of Lean adoption and improve project performance.

This study is evident in Lean Construction's potential to drive operational efficiency and long-term growth within Malaysia's construction industry. By addressing the barriers identified and implementing the recommended measures, such as enhanced leadership, training, empowerment, and the use of pilot projects, the industry can streamline operations, reduce waste, and enhance project outcomes. This, in turn, has the potential to boost productivity and contribute to more cost-effective, timely, and high-quality construction projects.

Beyond the construction sector, the findings underscore the broader impact of Lean Construction on national development. As a key driver of economic growth, the construction industry can evolve to meet modern demands for efficiency and sustainability by embedding Lean principles in everyday practices. This can enhance Malaysia's competitiveness in the global market, attract investment, and promote innovation while contributing to national goals of sustainable economic growth and improved public welfare. Lean Construction's emphasis on client engagement and value delivery aligns with several Sustainable Development Goals (SDGs), particularly SDG9 (Industry, Innovation, and Infrastructure) and SDG12 (Responsible Consumption and Production), reinforcing its relevance for Malaysia's long-term development.

By providing a detailed analysis of the awareness and understanding of Lean Construction among G7 Contractors, it highlights critical knowledge gaps and emphasises the need for targeted educational programs. The study also contributes actionable strategies for overcoming the barriers to Lean implementation, which will help industry professionals navigate the transition to Lean practices. Moreover, the findings are highly applicable to Malaysian construction professionals and policymakers, offering a roadmap for successful Lean adoption. In conclusion, this study not only advances academic understanding of Lean Construction in Malaysia but also provides practical insights that can help drive the broader adoption and effectiveness of Lean practices in the construction industry. By addressing key barriers and promoting strategies for improvement, this research paves the way for a more resilient, efficient, and sustainable construction sector in Malaysia, contributing to the country's economic growth and sustainability objectives.

However, it is noted that the limitation of the research lies in the potential for selection bias, as purposive and snowball sampling relies on the researcher's judgment and participant referrals, which may not fully represent the broader population of construction professionals. Additionally, the sample may be skewed toward individuals who are already aware of or engaged with Lean Construction, limiting the generalisability of the findings. Furthermore, snowball sampling may result in a homogenous group of respondents with similar perspectives, reducing diversity in viewpoints. A way forward for this research is to expand the sample size and diversity by incorporating a more randomised or stratified sampling approach to enhance representativeness. Future studies could also adopt a mixed-method approach, combining qualitative insights from in-depth interviews with quantitative survey data to provide a more comprehensive understanding of the adoption of Lean Construction. Finally, comparative studies across different countries or construction sectors could offer valuable insights into best practices and context-specific challenges, further strengthening the applicability of Lean Construction principles in Malaysia.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Universiti Malaysia Sarawak with Grant No. INT/F02/UPJ/86238/2023 for the funding and support in the execution of this research and paper.

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SUSTAINABLE STABILISATION OF ORGANIC SOILS USING GYPSUM AND CONCRETE WASTE

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Abstract
Organic soils, with their low bearing capacity and high compressibility, present significant challenges in geotechnical engineering. This study investigated the stabilisation of organic soil using a novel combination of construction and demolition waste concrete waste (CW) and by-product gypsum waste (G). Unconfined Compressive Strength (UCS) tests and Consolidated Undrained (CIU) triaxial compression tests were conducted to examine strength parameters and stress-strain behaviour under various conditions. The optimal mix of 10% CW and 10% G showed a 1108% strength increase after 28 days, while CIU triaxial tests demonstrated substantial improvements in shear strength and stiffness and reduced axial strain at failure. Test results revealed that higher confining pressure and longer curing times enhanced soil strength and reduced axial strain at failure. The combination of CW and G improved effective cohesion and friction angle, indicating better inter-particle bonding and mechanical performance. These findings highlight the potential of CW and G as sustainable, effective stabilisers for organic soil. The stabilisation increased the cohesion from 5–10 kPa to 20–30 kPa and enhanced the internal friction angle from 25° to 35–40°. This exhibits the effectiveness of CW and G in enhancing shear strength and mechanical properties, offering a greener alternative to traditional stabilisers in foundation design and construction.

Keywords: *Consolidated Undrained Compression Test; Sustainable Soil Stabilisers; Organic Soil Stabilisation, Construction and Demolition Waste; Soil Mechanics; Triaxial Testing*

INTRODUCTION

In the last decades, it became clear that structural damage depends not only on the behaviour of the superstructure but also on the subsoil beneath it; the integrity and longevity of building structures are intrinsically linked to the stability of their foundation soils (Akbar Firoozi and Asghar Firoozi, 2024). Organic soils, in particular, pose a significant challenge in the construction and infrastructure sectors. Due to its low compressibility, the excessive deformation of peat also poses a challenge in engineering practice, not only during construction but also in the long term (Zainorabidin et al., 2019). Traditional methods in soil stabilisation have relied heavily on cement and lime, raising environmental concerns due to their large carbon footprint and resource depletion. As the construction industry increasingly seeks sustainable alternatives, this has led to a growing interest in non-traditional methods, particularly those derived from construction and demolition waste and waste by-products, which align with circular economy principles.

Several industrial by-products, such as Cement kiln dust (CKD) and fly ash (FA), have been used as alternative stabilisers to improve soil strength while promoting sustainable construction practices. Previous studies have indicated that CKD could work as a proper soil stabiliser for clayey soils as a result of containing reactive calcium compounds that enhance soil cohesion and reduce compressibility. Silica fume, as a by-product of the production of elemental silicon or alloys containing silicon production, is a viable soil stabiliser that fills micro-voids and generates denser mixtures, improving the stabilised soil's structural

properties. Similarly, fly ash, sourced from coal combustion, exhibits pozzolanic properties contributing to long-term strength development in stabilised soils. These materials have been widely studied for their effectiveness in soil stabilisation; however, further comprehensive research is necessary to evaluate their performance alongside emerging stabilisers such as gypsum and concrete waste, particularly in undrained soil conditions.

Concrete and gypsum waste have emerged as promising materials among potential waste-based stabilisers. These materials are efficient in enhancing the mechanical properties of soils. As gypsum contains calcium sulfate, dihydrate has been found to enhance soil strength through cementitious and pozzolanic reactions, improving long-term durability (Abdolvand and Sadeghiamirshahidi, 2024). Concrete waste, conversely, preserves unreacted cement particles that contribute to strength enhancement and soil stabilisation through particle bonding (Kaptan, Cunha, and Aguiar, 2024). Both materials demonstrated the effectiveness of chemical reactions that hardened the soil through hydration and pozzolanic reactions (Kaptan et al., 2024);(Wu et al., 2024). Understanding their effectiveness in stabilising organic soils requires a comprehensive mechanical investigation, starting with unconfined compressive strength (UCS) testing to determine optimum mix proportions, followed by detailed triaxial testing to evaluate behaviour under more complex stress conditions.

The unconfined compressive strength (UCS) of stabilised organic soil specimens prepared in the laboratory is widely recognised as an important indicator for evaluating the efficiency of soil stabilisation methods (Mohammadinia et al., 2019). However, when the soil is exposed to rapid loading conditions, such as construction loads, it may be subjected to substantially great confining pressure. The existence of groundwater and the drainage condition make the UCS not indicative of the actual in-site behaviour (Luis et al., 2019). Many researchers indicated that soil specimens under undrained load conditions developed minimal deformation prior to peak strength compared to drained test specimens, which makes the undrained condition more crucial (Luis et al., 2019).

The Consolidated Isotropic Undrained (CIU) triaxial test provides crucial insights into the stress-strain behaviour, pore pressure response, and strength parameters of stabilised soils under conditions that simulate field scenarios. The ability to control specimen drainage and measure pore water pressures are advantages over simpler techniques like direct shear and UCS testing (Anon, 1990). Limited research has been conducted on the combined application of gypsum and concrete waste as soil stabilisers, particularly regarding their effects on soil behaviour under undrained loading conditions.

This study employs a systematic two-phase approach to investigate the effectiveness of gypsum and concrete waste as sustainable soil stabilisers. The first phase utilises UCS testing to identify the effectiveness of the materials in enhancing the behaviour of organic soil and determine the optimal mixture proportions by evaluating strength development across various additive combinations. The second phase employs consolidated isotopically undrained (CIU) triaxial testing on the optimised mixture to provide deeper insights into stress-strain behaviour, stiffness characteristics, and strength parameters under conditions that better simulate field scenarios. Key parameters investigated include stress-strain relationships, axial strain at failure, and effective strength parameters, providing a comprehensive understanding of the stabilised soil's mechanical behaviour.

MATERIALS AND METHODOLOGY

This section describes the materials utilised and the methodology followed to assess the effectiveness of gypsum and concrete waste in stabilising organic soil. The soil properties, additives, sample preparation, and testing procedures are covered in detail in the following subsections.

Soils and Binders

The soil sample was extracted from Gebeng, Pahang, Malaysia, at a depth of 1.5 m below ground level to ensure the exclusion of topsoil and non-representative samples. Natural disturbed soil was collected, where the organic soil is the foundation of this industrial area. Organic soil forms in wetland environments where the slow decomposition of submerged plant materials occurs due to anaerobic conditions, leading to their accumulation over time. In literature, many researchers have investigated the engineering properties of organic soil and revealed that shear strength is low, indicating that the soil lacks sufficient bearing capacity for structures (Almsedeen, Muhammad, and Ishak, 2024);(Zainorabidin and Wijeyesekera, 2008). Table 1 summarises the soil characteristics. X-ray diffraction (XRD) analysis of a representative soil sample provided mineralogical composition and oxide distribution, as shown in Table 2. The primary elements identified were C (41.8%), O (35.8%), Al_2O_3 (7.38%), and SiO_2 (10.4%), with the additional presence of CaO, Fe_2O_3, MgO, and SO_3.

Table 1. Engineering Properties of Organic Soil

Properties	Method	Value / Measure
Moisture Content (%)	BS 1377 Part 2: 1990	137
Organic Content (%)	ASTM D 2974-87	57.7
Specific Gravity	BS 1377: Part 2: 1990	1.6
Liquid Limit (%)	BS 1377-2: 1990	113
Plastic Limit (%)	BS 1377-2: 1990	88.8
Plasticity Index	BS 1377-4: 1990	24.0
Maximum Dry Density (g/cm³)	BS 1377-4: 1990	0.69
Optimum Moisture Content (%)	BS 1377-4: 1990	60.78
pH	BS 1377-1990	3.7
UCS (kPa)	BS 1377-7: 1975	36

Table 2. Mineralogical Composition of Organic Soil, CW and G

Elements / Minerals	Mass (%)		
	Organic Soil	CW	G
C	41.8	18.1	8.59
O	35.8	47.0	52.5
Ca	0.08	17.3	13.8
Si	4.67	15.0	0.17
Al_2O_3	7.38	-	0.72
SiO_2	10.4	39.8	0.37
CaO	0.12	30.4	19.7
Fe_2O_3	2.87	1.30	0.26
MgO	0.17	-	8.87
SO_3	0.43	-	21.4

Additives and Mixture Design

The additive used in this study is a combination of concrete waste (CW) and Mg-rich gypsum waste (G), sourced from construction and demolition activities and by-products of industrial waste, respectively. CW gradation has a maximum particle size of 2 mm (No. 10 standard ASTM sieve), and G possesses a fine content passing through a 45 μm sieve. The particles of each binder were inspected using SEM images, as shown in Figure 1. It is seen that the CW particles are spherical, and the Mg-G is mainly an elongated shape.

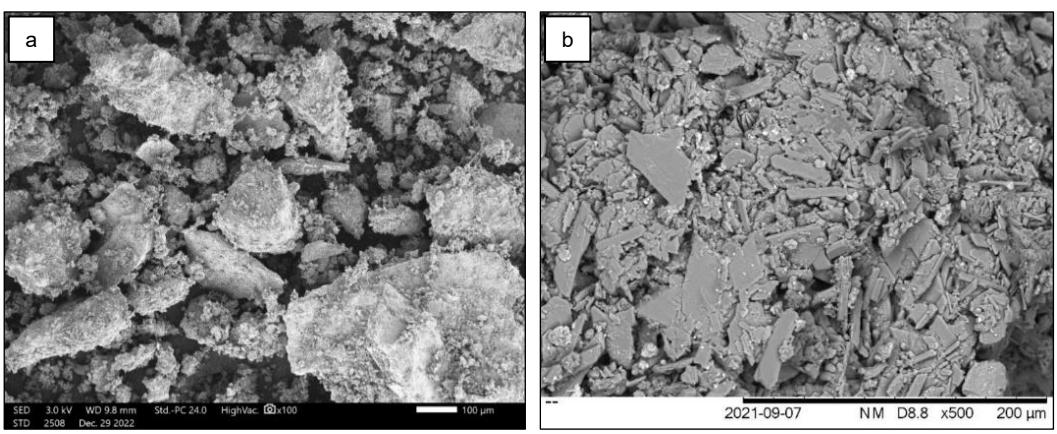


Figure 1. SEM Image for a) CW b) G

Gypsum and concrete waste are environmentally safe under controlled applications as soil stabilisers. Gypsum is commonly used in agriculture and soil treatment, improving soil structure and drainage without introducing harmful contaminants (Pu, Zhu and Huo, 2021). Similarly, concrete waste is an inactive material with negligible leaching effects when used for soil improvement (Awn and Abbas, 2022). Studies demonstrate that combining pozzolanic materials and calcium-rich additives enhances soil strength without significantly amending groundwater (Li et al., 2023).

The mix proportions ranged from 5% to 15% for each stabiliser by dry weight of the soil, resulting in three combinations. Each mix was assessed for its effectiveness in enhancing the mechanical properties of the organic soil through UCS testing. Table 3 shows the mixture combinations.

Table 3. Mixture Combinations

Mix ID	CW%	G%
S1	5	15
S2	10	10
S3	15	5

Sample Preparation

After the soil sample was oven-dried, it was passed through a sieve with a 2 mm opening. The dry additive's materials powder was combined first with oven-dried soil; then, the mixture was mixed with water with an electrical blender for 7 min to obtain a uniform slurry. The final mixture specimens were cast into moulds with 38 mm diameter and 76 mm length. After

compacting, the top surface was cut off, and the sample was wrapped using plastic wrap to prevent water loss during the curing period. By controlling the weight of OS-CG and water added to the mould, a consistent density was achieved for specimens after preparation. The sample was prepared using maximum dry density and optimum water content following BS 1377: Part 4: 1990 to ensure consistency with standard compaction standards.

Specimen Curing

Previous studies focusing on soil stabilisation by mixing with additives have indicated that strength is enhanced when time-dependent cementitious reactions develop (Wu et al., 2021). Hence, in this study, the air-curing method was used; therefore, the specimens used in scheduled tests were kept in an airtight container over the curing process in a room environment.

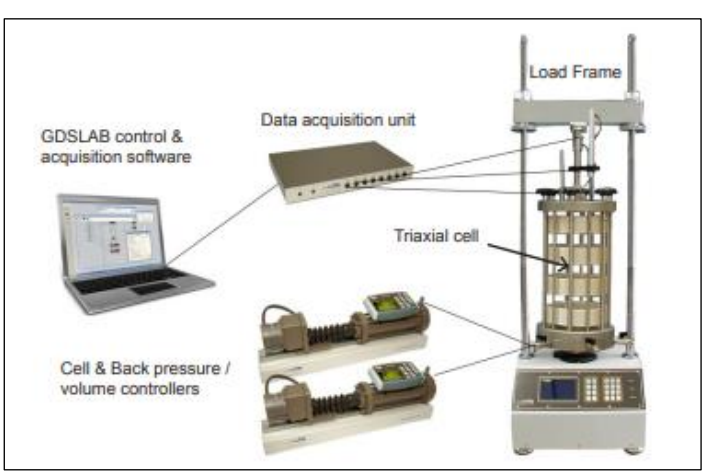
Testing Procedures

The following sections describe the testing procedures used to assess the mechanical properties of the stabilised soil, beginning with the unconfined compressive strength (UCS) test, which serves as a fundamental index of soil stabilisation effectiveness.

Unconfined Compressive Strength Test

The Unconfined Compressive Strength (UCS) was performed following the British standard BS1377: Part 7: 1990. It is a vital indication for assessing the efficiency of soil stabilisation methods. UCS has been widely considered a credible and simple experimental method in several research studies focused on soil stabilisation. The results were recorded at curing periods of 0, 7, and 28 days for all mixed ratios.

Triaxial device: The automatic triaxial shear device was purchased from GDS Instruments, UK. It consisted of a Load Frame, Data acquisition unit, GDSLAB control and acquisition software, Cell, and back pressure/volume controllers. Figure 2 presents a complete system diagram.



(Source: Rees, 2013)

Figure 2. GDS Triaxial Automated System

Consolidated Undrained (CU) Triaxial Test

The samples were left in curing for 28 days to gain most of the strength expected at the mature age since the UCS results indicated in previous tests show a high enhancement of strength at 28 days. The Consolidated Isotopically Undrained (CIU) triaxial tests were conducted on both untreated and treated organic soil samples following BS 1377: Part 7: 1990. The testing procedure consists of 3 stages: saturation, consolidation, and shearing. Before testing, the pumps utilised to exert the confining and back pressures were purified to ensure no air was entrapped in the system. The cell and back pressures were increased linearly in all specimens until they reached a minimum Skempton's B-value of 0.95. After the saturation period, the B-test was conducted on the specimen to confirm the saturation level. The B parameter is defined in Equation:

$$B = \Delta u / \Delta \sigma' c \quad (1)$$

Where: Δu is the resultant pore pressure increment due to the confining pressure increment Δσ'c around the specimen.

Then, the specimens were consolidated at three various confining pressures: 50, 100 and 200 Kpa. Once the consolidation was finalised, the specimens were sheared under undrained conditions at constant strain rates until they reached approximately 20% axial strain. The deviator stress and pore pressure were measured during the shearing.

RESULTS AND DATA INTERPRETATION

The UCS test was utilised to investigate the effectiveness of the improved additive and identify optimal mixture proportions by evaluating strength development across various additive combinations.

UCS Results

Strength Development with Different Mixture Ratios

UCS was conducted for each sample to evaluate its shear strength. The UCS test identified the optimal mix design for organic soil stabilisation using CG (5-15% CW and 5-15% G) of total dry weight. Figure 3 presents the UCS results for different combinations cured for 28 days. The control sample (S0) exhibited low strength at 36 kPa. As can be seen, a significant enhancement was observed as adding CG to the organic soil increased UCS. Table 4 provides the UCS growth rate (SGI) for various mixture compositions.

$$SGI\ (\%) = [(UCS(S1,2,3) - UCS(S0))/UCS(S0)] \times 100 \quad (2)$$

Table 5 shows the UCS growth rate for the mixture combinations. For example, with combination S1, the UCS growth rate reached 491.6% after 28 days of curing. In contrast, with combination S2, the growth rates were significantly higher, reaching 1108%. This indicates that the ratios of CW and G influence the efficiency, indicating the mixture combination has different levels to achieve pozzolanic reaction, rapid strength gains, particle packing, and effective stabilisation interactions. Different SGI values at a constant 20% stabiliser content suggest that the CW: G ratio is the key to effective stabilisation.

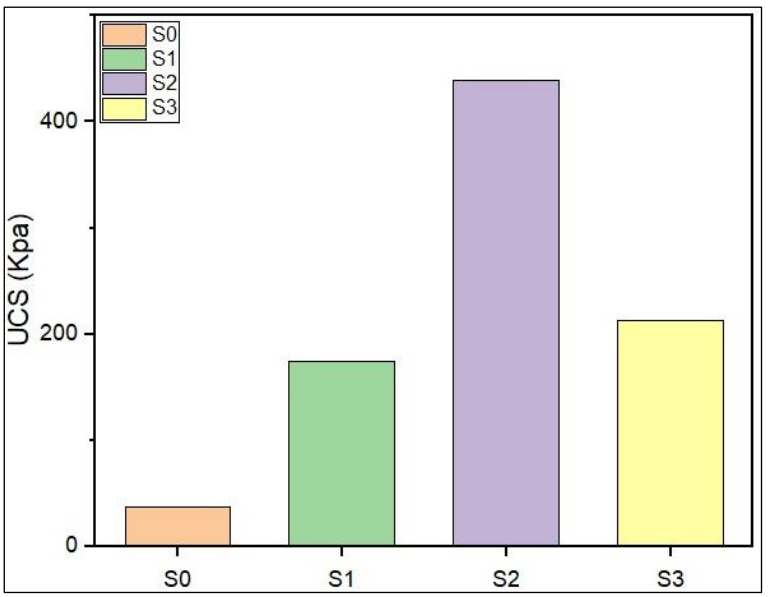


Figure 3. UCS of S0, S1, S2, S3 at 28 Days of Curing

Table 4. UCS and SGI Values

Soil Mixture Composition	UCS (Kpa)	SGI (%)
S1	213	492
S2	435	1108
S3	175	386.1

Effect of Curing Time on Soil Strength

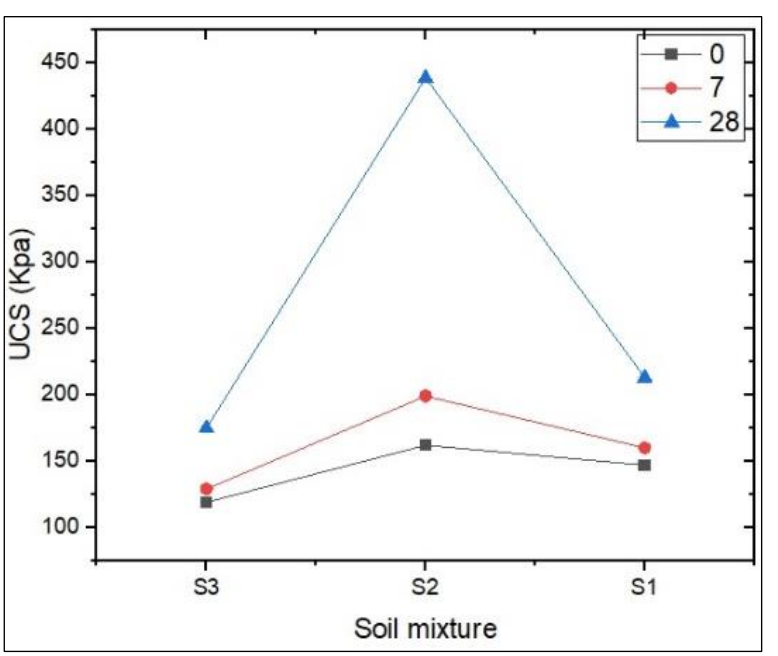


Figure 4. UCS at Various Curing Periods for S1, S2, and S3

The differences in stabilised soil's UCS at various curing periods are shown in Figure 4. The strengths of the stabilised soil cured at 0, 7, and 28 days were 5.65 MPa, 7.28 MPa, 8.49 MPa, and 9.11 MPa, respectively, for S2. This pattern informed that the UCS of stabilised soil increased as the curing period increased. Due to the minimal hydration product development during the early curing phases, soil particle interactions are relatively weak, resulting in lower strength. However, as the curing period increases, the unreacted active chemicals in the stabiliser are activated further, forming additional hydrates. These materials progressively expand and fill soil pores, resulting in an intense structure that increases soil strength.

This study indicated an increase in UCS for organic soil stabilised with 10% concrete waste (CW) and 10% gypsum (G) from 36 Kpa to 435 Kpa after 28 days of curing. This finding aligns with previous studies indicating alternate stabilisers are effective. Mohammadi & Boroomand (2021) demonstrated the beneficial impacts of gypsum in soil stabilisation by using recycled gypsum (bassanite) with cement and lime to improve UCS from 37 kPa to 603 kPa (Mohammadi and Boroomand, 2021). Similar findings were made by (Sharma and Sharma, 2020) and (Anon n.d.), who discovered that using construction demolition waste (CDW) in soil stabilisation considerably enhanced UCS, confirming CDW's feasibility as a stabiliser.

Optimisation and Analysis

The strength results from UCS were used to identify the optimal mix ratio. The S2 mixture, combining 10% CW and 10% G, was recognised as the optimum mixture combination. Due to a balanced pozzolanic reaction and sufficient particle packing, this optimum mixture exhibits the highest strength enhancement. This optimum mixture can be tested using the CU triaxial test for a comprehensive understanding of stress-strain behaviour and effective strength parameters.

CIU Results

Stress-Strain Behaviour Under Undrained Conditions

The stress-strain curves of natural organic soil (S0) and the optimum mixture of stabilised organic soil (S2) under undrained shear conditions are shown in Figure 5. S0 specimens displayed behaviour distinguished by a gradual increase in stress up to max peak strength at high strain. This indicates that the soil gains strength as it deforms, which means a ductile failure mechanism. All specimens reached max deviator stress at an axial strain of more than 18%. Meanwhile, the S2 displays a strain-softening tendency, transitioning from ductile to brittle behaviour. As seen in the figure, stabilisation induced brittle behaviour and a significant increase in deviator strength after 28 days. The results show that initial confining pressure significantly impacted the stress-strain curves. Higher confining pressure generally leads to higher peak strength. The effect of the confining pressure in S2 was higher than in S0.

Additionally, the stress-strain curves show the stiffness characteristics of the soil specimens, a significant factor for monitoring ground settlement during loading, which demonstrated substantial modification following stabilisation. The stiffness, indicated by the slope of the initial portion of the curve in the elastic region, is lower for S0 at all confining

pressures (50, 100, and 200) kPa. These results suggest that S1 deforms more promptly under stress, indicating a lower deformation resistance. In contrast, S2 exhibited steeper slopes in the elastic region, indicating higher stiffness and resistance to deformation. The increased confining pressures enhanced the stiffness of both samples, but S2 consistently behaved better than S1, which can be attributed to the improved material composition due to stabilisation. These findings imply that S2 exhibits enhanced structural integrity, increasing its capacity to support heavier loads with less deformation.

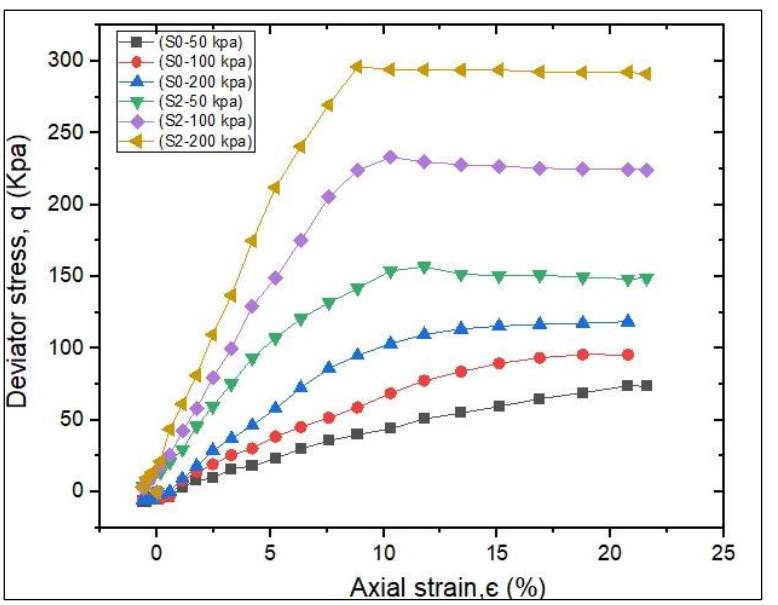


Figure 5. Stress-Strain Curve for S0, S2

Axial Strain at Failure

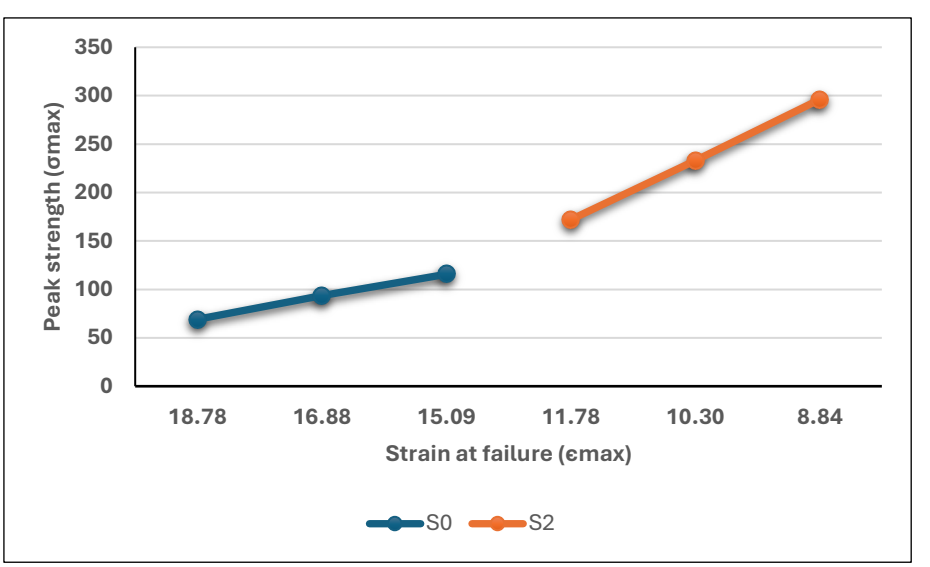


Figure 6. The Relationship Between σ_{max} and ϵ_{max}

Strain at failure (ϵmax) is defined as the axial strain corresponding to peak strength (σmax) or the starting point when σmax is maintained across a wide range of strains. S0 reached failure at an approximately high axial strain of (18-20) %; the failure point was less distinct because of the ductile and continuous strain hardening behaviour. In contrast, S2 reached failure at a lower axial strain compared to S1, with a range (of 8-10) % axial strain; the axial strain at failure significantly decreased with increasing confining pressure, showing values of approximately 10%, 9% and 8% for confining pressures of 50 Kpa, 100 Kpa, and 200 Kpa, respectively. The σmax versus ϵmax relationship is plotted in Figure 6, in which a positive linear relation was noticed between σmax and ϵmax.

Meanwhile, S2 generally had smaller ϵmax values under higher confining pressure. The correlation between confining pressure and axial strain is plotted in Figure 7, as a linear correlation and predictable pattern were observed between them in samples, indicating a uniform distribution of stresses throughout the soil structure. Furthermore, the stabilised soil exhibited a gradual failure without rapid strength reduction characteristics.

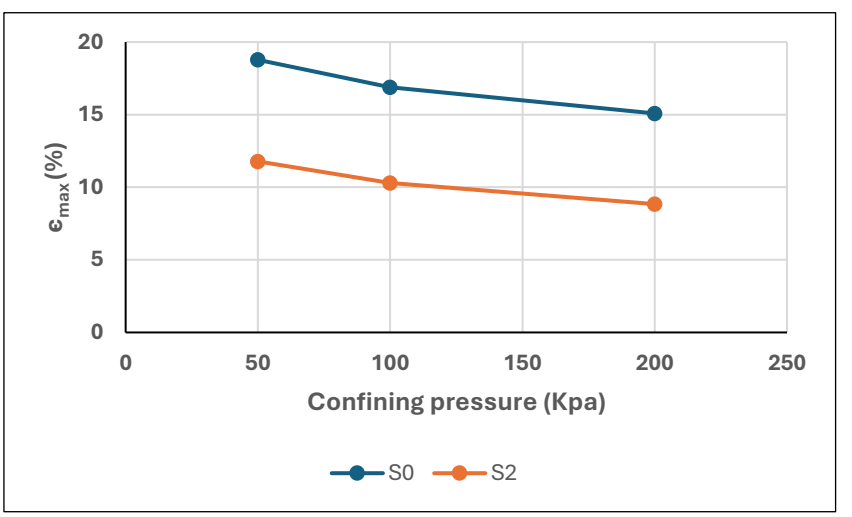


Figure 7. Effects of Initial Confining Pressure on ϵ_{max}

Effective Strength Parameters

Figure 8 and Figure 9 present the shear stress versus normal stress during the CIU tests administered by S0 and S2. The results were utilised to establish the effective strength parameters. Comparative Mohr-Coulomb failure criteria analysis showed significant improvements in mechanical characteristics. The unstabilised soil failed due to a limited effective stress range (3.7–107 kPa) and minor cohesive resistance. On the other hand, the stabilised soil exhibited a significant improvement in engineering performance, with an increased effective stress range (20 - 130 kPa) and improved failure characteristics. Peak strength grew by approximately 120 %, indicating substantial microstructural modifications.

Additionally, there is an enhancement in the effective cohesion and internal friction angle; unstabilised soil exhibited an effective friction angle (φ') of approximately 25° and effective cohesion (c') of 5-10 kPa, whereas stabilised soil exhibited a significantly improved effective friction angle (φ') of 35-40° and effective cohesion (c') of 20-30 kPa. Notably, enhanced

effective cohesion (c') indicates stronger inter-particle bonding, which results in inherent soil strength and resistance to shear deformation. The improved effective friction angle (φ') enhanced particle interlocking and load transfer capabilities, transforming soil mechanical behaviour by improving slope stability, load-bearing capacity, and resilience against deformation at confining pressures of 50, 100, and 200 kPa.

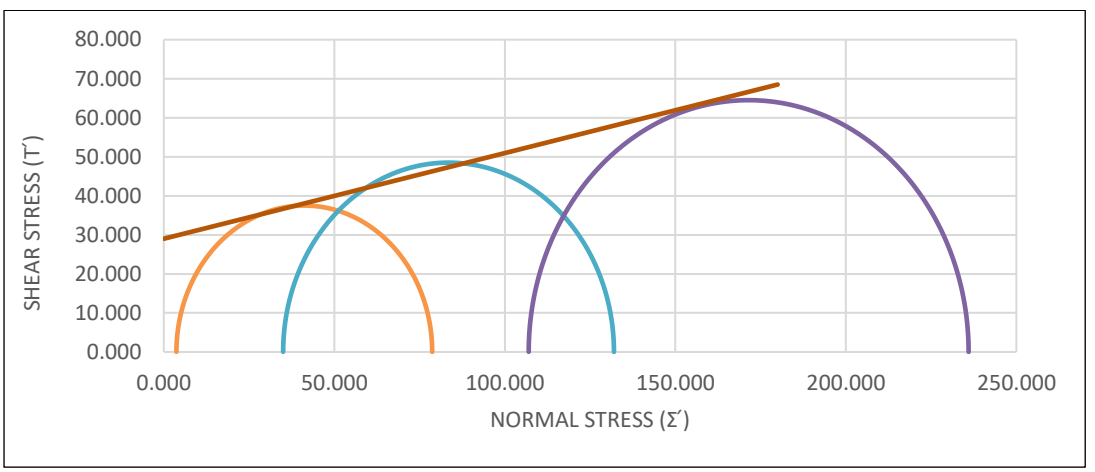


Figure 8. Mohr-Circle for S0

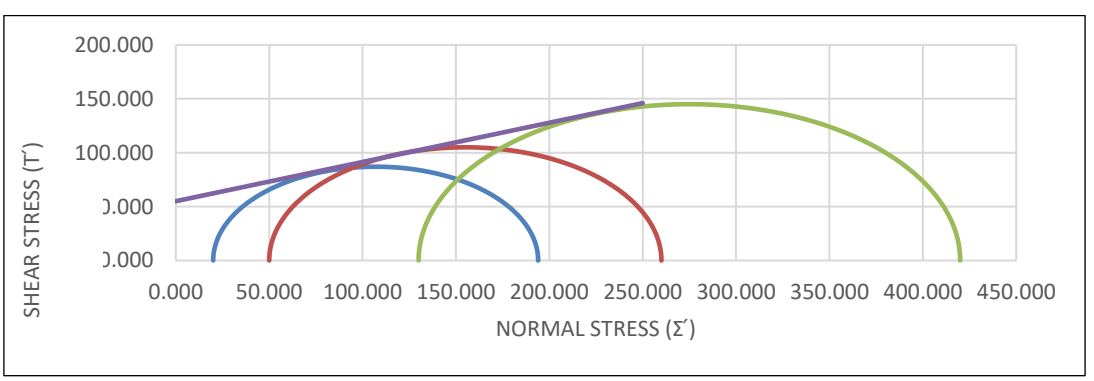


Figure 9. Mohr-Circle for S2

The results of this study's CIU test showed that stabilised soil altered from ductile to brittle behaviour, with lower axial strain at failure and higher peak deviator stress. The results of this study are consistent with a study by Patil and Panda (2021) that discovered that utilising construction and demolition waste in triaxial testing significantly improved soil strength, with the highest levels of strength occurring at 10-15% waste content (Patil and Panda, 2021). The improved stiffness findings in this study are supported by Zhang et al.'s (2022) investigation of C&D waste with polypropylene fibre in cement-stabilised soil, which showed notable improvements in stiffness and shear strength (Zhang et al., 2022).

Engineering Implications

The findings provide a clear pathway for applying CW and G as sustainable stabilisers for organic soils. The improved shear strength parameter ensures that stabilised soils can

withstand higher loads with reduced deformation, thus minimising long-term settlement issues in infrastructure projects.

The findings also revealed a transition from ductile to brittle failure behaviour. This transfer has essential engineering implications:

The bearing capacity increases as the stiffness and strength increase, making stabilised soil suitable for foundations, embankments, and road subgrades that demand high deformation resistance.

The reduced axial strain at failure leads to controlled failure patterns, which can be preferred for pavement structures where excessive deformation is undesirable.

Meanwhile, the increased brittleness may cause cracking under seismic conditions or cyclic loads, requiring careful design considerations in high-vibration or seismically active environments. To prevent excessive stiffness and maintain a balance between strength enhancement and flexibility, compaction techniques and curing conditions must be optimised.

Therefore, even though stabilisation with CW and G improves strength, engineers must consider the balance strength gain with ductility to avoid abrupt failure in practical applications.

CONCLUSIONS

This study investigated the stabilisation of organic soils using a sustainable combination of CW and G as alternative soil stabilisers. The findings revealed the effectiveness of novel additives in improving the mechanical properties of organic soils, addressing challenges such as low bearing capacity and high compressibility. The key findings of this study are as follows:

1) The optimal mix (10% CW + 10% G) increased UCS by 1108% after 28 days, while the CIU triaxial test showed an increase in cohesion from 5–10 kPa to 20–30 kPa (300% improvement) and an enhancement in the internal friction angle from 25° to 35–40° (40–60% increase). These results confirm that CW and G improve shear strength, stiffness, and load-bearing capacity, making them a viable alternative to traditional stabilisers like cement and lime.

2) This study also identified a shift in soil behaviour from ductile to brittle failure due to stabilisation. While this enhances stiffness and structural integrity, it may also lead to increased cracking risk under cyclic loads. Proper mix design, compaction techniques, and curing controls must be optimised to balance strength improvement with adequate ductility for practical geotechnical applications.

The outcomes of this study release new insight into the utilisation of demolition and construction waste for soil stabilisation. The combination of CW and G not only enhances soil strength but also aligns with circular economy principles by reusing industrial byproducts. This sustainable approach provides a feasible alternative to typical stabilisers such as cement, minimising the environmental impact of geotechnical and construction practices. However,

this study did not include environmental leachability tests or cost-benefit analyses, which are critical for large-scale implementation. Future research should focus on long-term durability assessments, environmental safety (e.g., groundwater contamination risks), and economic feasibility to validate the real-world applicability of this stabilisation approach.

ACKNOWLEDGEMENT

The authors would like to thank the Universiti Malaysia Pahang Al-Sultan Abdullah (UMPSA) for laboratory facilities as well as additional financial support under UMP Internal Research grants RDU223305 and RDU210342.

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FACTORS CONTRIBUTING TO SAFETY MANAGEMENT IN INFRASTRUCTURE CONSTRUCTION

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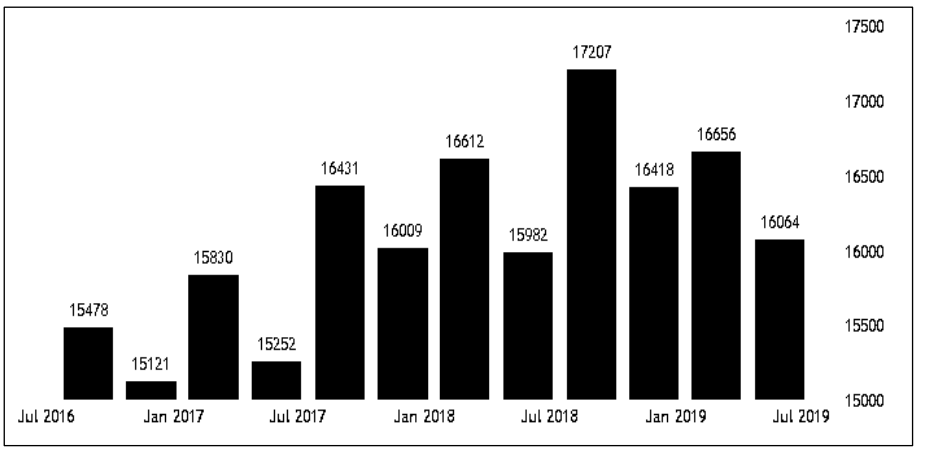
Abstract
A notable reduction in both the frequency and severity of injuries has been observed over the past two decades or more in the construction industry. However, despite these improvements, the construction sector continues to be identified as one of the high-risk industries characterised by its hazardous working conditions. This study aims to explore safety management practices within the Malaysian construction industry, particularly focusing on infrastructure construction, and highlight the importance of adhering to safety protocols. Despite its significant contribution to the country's economic development, the lack of systematic implementation of safety measures in construction management can result in accidents, potentially hindering the nation's economic progress. The research seeks to establish safety management as a crucial element influencing project performance and success in construction endeavours, with a specific emphasis on infrastructure projects in Malaysia. Additionally, efforts will be made to enhance awareness regarding the importance of safety management in construction projects. Data was collected through questionnaires and a case study conducted at the MRT Line 2 Construction Site. Subsequent analysis of the survey data was conducted using statistical tools, including the Relative Importance Index (RII) and Cronbach's alpha, employing SPSS software. The obtained scores were then transformed into importance indices based on a predefined formula. A significant proportion of high-impact factors belong to the categories of 'factors associated with the involvement of worker' and 'factors associated with material and equipment'. Among the top ten high-ranking factors, three are from 'factors associated with the involvement of worker', five from 'factors associated with material and equipment', and two from 'factors associated with workplace.'

Keywords: *Infrastructure; Construction; Safety; High-Risk; Hazardous*

INTRODUCTION

Malaysia is categorised as an emerging industrialised country. According to Lewis (1955), over half of the national capital formation, which includes construction work, is attributed to the construction industry. The Malaysian construction sector is essentially divided into two main areas: general construction, encompassing residential and non-residential construction. However, nothing is more crucial to a nation's or community's infrastructure than the ability to construct commercial and suburban structures effectively and efficiently. The overall Gross Domestic Product (GDP), as shown in Figure 1, is contributed substantially by the construction industry, which plays a vital role in the socio-economic growth. Up to 3% to 5% of the national GDP is contributed by construction. (Shari, 2000; Takim, 2005). The data highlights that GDP from construction reached its peak value of 14,517 MYR million in the fourth quarter of 2018 (DOSM, 2019). Observing the external environment, we perceive a visually dynamic world wherein the imperative role of infrastructure construction has become intrinsic to the progress of a developing country. This sector not only contributes significantly to economic growth and employment but also plays a vital role in enhancing social well-being and fostering the advancement of its citizens. Nevertheless, despite safety improvements in recent years, the construction industry is notorious for its elevated risk of accidents and fatalities at worksites.



(DOSM, 2019)

Figure 1. GDP Growth from The Construction Industry of Malaysia

LITERATURE REVIEW

The construction industry faces a concerning prevalence of accidents and injuries, which come with substantial personal, social, and economic consequences. Additionally, a company's standing and operational efficiency within this sector can suffer due to project delays and financial setbacks stemming from safety-related work stoppages mandated by safety officials, as well as the expenses associated with treating worker injuries. Thus, pinpointing the factors contributing to incidents becomes crucial in identifying effective safety measures. By adopting sound safety management practices, the occurrence of risks can be mitigated, leading to enhanced overall project safety performance.

Safety management stresses the importance of ensuring that safety measures are implemented and complied with diligently by all construction stakeholders. This section provides an overview of safety performance practices that impact inadequate safety management in infrastructure construction projects. Loosemore and Malouf (2019) demonstrate a notable awareness among the participants of their study regarding the significance of worker readiness in enhancing safety implementation. Additionally, Demirkesen and Arditi (2015) identify protection planning as one of five zero-accident programs with significant impacts. Table 1 shows a gap analysis of factors contributing to safety management.

Research Objective

The study objectives are:

- To explore the factors that impacted the efficacy of safety practice implementation in construction progress, which significantly impact construction safety performance and overall project success, utilising the Relative Importance Index (RII) and examining correlations among construction practitioners.

- To evaluate the prevailing safety practices affecting the adoption of safety measures through a case study analysis of a specific project.

Table 1. Comparison of Gap Analysis

FACTOR	RESEARCHER	KEY STATEMENT	GAP
MANAGEMENT			
Manual observation serves as a method for monitoring construction safety	• JeeWoong, Kyungki & Yong (2017)	• Safety monitoring through manual means is labor-intensive and susceptible to errors.	• What alternative methods can be implemented to decrease reliance on manual observation?
Inadequacy of proper occupational safety procedures	• Ayob, Shaari, Zaki & Munaaim (2017)	• Fall-related casualties are often attributed to the absence of safe occupational procedures among onsite workers.	• What strategies can be employed to effectively implement safe occupational procedures?
Safety Meetings	• Bayafa, Mahdiyar, Marono (2018)	• Enhancing safety performance at the project level involves increasing the frequency of formal safety meetings with supervisors, as recommended.	• What is the optimal frequency for conducting safety meetings?
Organizational Safety Policy	• Hinze and Wilson (1999); Wong et al. (1999)	• The development of more detailed written safety programs provides a better safety performance.	• How to improve the key point needed in safety policy?
Safety Inspection	• Hollnagel (2018)	• To enhance safety performance, it is necessary to increase the frequency of jobsite visits.	• What is the optimal frequency for site visits per week to ensure safety performance improvement?
WORKER INVOLVEMENT			
The attitude of workers towards safety	• Mohammadi, Tavakolan & Khosravi (2018) • Chol., Ahn & Lee (2017)	• The safety attitude of workers is identified as one of the root causes of accidents.	• What strategies can be implemented to enhance workers' attitudes towards safety or encourage a greater embrace of safety practices?
The allocated of Personal Protective Equipment (PPE)	• Ayob, Shaari, Zaki & Munaaim (2017)	• Unsuitable equipment and inadequate safety attire can lead to breakage due to high-impact incidents.	• How can we promote a culture where both workers and top management prioritize the use of Personal Protective Equipment (PPE) during construction activities?
Inadequate of Safety Training	• Demirkesen & Arditi (2015) • Loosemore & Malouf (2019)	• Safety training is identified as one of the top five high-impact zero accident techniques. • Lack of proper training is cited as a contributing factor to numerous falls.	• What measures can be taken to ensure the effectiveness of safety training?
Rates of employee turnover within the labor force	• Durdyey, S., Ismail, S., & Kandymoy, N. (2018)	• High turnover rates are associated with increased likelihood of higher injury rates.	• What factors contribute to newcomers being associated with higher injury rates, and what strategies can be employed to mitigate this issue?
Work Load	• Poon, Rowlinson, Koh and Deng (2013)	• Extended job-related stress increases the likelihood of making errors, which can ultimately result in fatal construction accidents.	• What are the recommended limits for workload that should be imposed on workers?
WORKPLACE CONDITION			
Lack of proper housekeeping	• Haslam et al. (2005) • Choudhry & Fang (2008)	• In accident studies, significant contributions to incidents were attributed to poor housekeeping and issues related to site layout and space availability.	Who bears the responsibility for addressing and overcoming this issue?
Limitations or restrictions present at the site	• Haslam et al. (2005)	• Fatalities are often contributed to by inadequate space or challenging access when performing tasks.	• Options and thorough planning.

This study focuses on safety management within construction sites, aiming to highlight its significance as a crucial component for project efficiency and advancement in the construction industry. It will specifically target construction projects in Malaysia, with a case study conducted at the MRT Line Two project. This research will underscore the importance and recognition of construction safety management endeavours.

RESEARCH METHODOLOGY

This study aimed to assess the factors influencing the effectiveness of safety practices implementation and rank them accordingly. To achieve this objective, the descriptive method was employed to address questions related to the research purpose, encompassing the 4W (Who, What, Where, When) and 1H (How) aspects. Additionally, a literature review was conducted to provide a comprehensive understanding of construction safety management. Subsequently, data collection was carried out through questionnaires, following a pilot survey, to ensure the questionnaire's effectiveness.

The research unfolded with an exploration of construction safety management through a thorough literature review. A pilot survey was conducted to validate and refine the questionnaire before proceeding with the main questionnaire survey. The actual data collection involved site visits to gather firsthand information. The data collected from both surveys and site visits will undergo analysis to extract valuable insights.

Pilot Survey

The pilot survey encompassed professional engineers from diverse backgrounds, including academia, construction, and consultancy industries. Upon gathering and assessing the pilot survey results, discussions were held to address technical, logistical, and any other encountered issues or challenges. Subsequently, adjustments were made to refine the questionnaire structure, and, if necessary, the survey type was modified to a more fitting format. Following these revisions, the large-scale survey was then implemented.

Preparation of Data Collection

The primary aim of data collection is to acquire insights into safety management within construction projects. To achieve this, a combination of observation and qualitative research methods will be employed, aligning with the objective of testing the presented theory. Through an extensive literature review, all pertinent factors have been identified and categorised into four (4) main groups: (1) Factors related to worker involvement, (2) Factors concerning materials and equipment, (3) Factors associated with the workplace environment, and (4) Factors pertaining to management involvement.

Interview

Interviews will be conducted to gather qualitative data on safety practices at the construction site. This method is considered effective for gaining a deeper understanding and exploring various perspectives, experiences, and opinions. Open-ended questions will be used to facilitate in-depth discussions. Interviews will be conducted either face-to-face or over the telephone, primarily with site safety managers.

Questionnaire

A total of 45 questionnaires were sent to project teams, including contractors, clients, and consultants. The questionnaire was designed based on factors affecting safety management in construction projects identified in the literature. Of the 39 construction professionals who responded, there was a positive feedback rate of 87%. The questionnaires were distributed online. The results indicated that the majority of respondents recognised the importance of adhering to good safety practices in construction projects to enhance safety efficiency and prevent workplace accidents and injuries.

Data Analysis

Upon the completion of data collection, the subsequent phase involves data processing. The information gathered through the questionnaires will undergo a thorough evaluation and summarisation. This process aims to derive accurate and pertinent insights into safety management for the construction project. The Average Index, Relative Importance Index (RII), and Cronbach's Alpha will be used to analyse the survey.

Relative Importance Index (RII)

The collected data will undergo analysis. The raw survey data from the questionnaires will be analysed using SPSS (PASW) version 18 software. RII will be determined to rank the important factors of construction project safety.

$$\text{Relative importance} = \frac{\sum w}{AN}$$

W represents the weighting of each factor (1 to 5). A is the highest weight (in this case, 5). N is the total number of samples.

Cronbach's Alpha

Cronbach's alpha is widely used to measure reliability. It assesses how items are closely related as a group. The coefficient value of Cronbach's alpha ranges between 0.0 and +1.0, where values closer to 1 indicate higher internal consistency among the items.

RESULT AND DISCUSSION

The Reliability of The Questionnaire

The reliability test result by Cronbach's Coefficient Alpha is shown in Table 2. A Cronbach's alpha exceeding 0.60 is deemed acceptable, surpassing 0.70 is considered good, and surpassing 0.90 is regarded as excellent. As illustrated in Table 2, all 28 factors influencing safety management in construction projects exhibited a commendable level of internal consistency in the formulated questionnaire, with a coefficient of 0.968.

The validity test value also stood at 0.968. These results indicate that the prepared questionnaires are both reliable and valid for the subject studies conducted in this research.

Table 2. The Reliability and Validity Statistics

Reliability Statistics		
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.968	.968	28

Reliability	Validity
0.968	0.968

The Exploration of RII and AI in Assessing the Factors That Influence Construction Project Safety

The findings from the analysis of the RII and Average Index for the factors are presented in Table 3.

The collective survey data is presented in Table 3, revealing that approximately 64.3 percent of the factors influencing health-related misbehaviour among workers in building projects fall into the high-impact category. The remaining 35.7 percent are classified as medium-impact factors. Notably, a significant proportion of high-impact factors belong to the categories of 'factors associated with the involvement of worker' and 'factors associated with material and equipment'. Among the top ten high-ranking factors, three are from 'factors associated with the involvement of worker', five from 'factors associated with material and equipment', and two from 'factors associated with workplace', with AVI values ranging from 3.718 to 3.949.

Upon analysing the results, respondents identified the top three factors as "B.2: Inappropriate storage and handling of material," "B.1: Shortcoming with equipment," and "B.3: Poor condition of tools," all belonging to the materials and equipment category. This underscores the significance of material and equipment-related issues as the primary contributors to safety misbehaviour. Other significant contributors to the highest causal misbehaviour comprise unsafe actions and mindsets, inadequate supervision, ineffective communication, negligence-induced accidents, insufficient coordination among contractors and subcontractors, improper tool setup, and inadequate housekeeping.

Conversely, factors such as 'design alteration' and 'lack of teamwork spirit' were less emphasised by the majority of respondents. Changes in design are deemed less frequent and necessary in the construction phase, particularly in infrastructure projects, as compared to the pre-construction phase. Additionally, the importance of work team spirit is downplayed, as engineers and workers generally prioritise effective communication and collaboration due to the interconnected nature of their work environments in completing construction projects.

Table 3. Statistical Summary of Factors Influencing Safety Management in Construction Projects

FC	Factors Description	1: Totally Oppose	2: Oppose	3: Neutral	4: Endorse	5: Totally Endorse	RII	AVI	Rank
Factors Associated with The Involvement of Worker									
A1	Dangerous behaviors and attributes	3	2	9	9	16	0.7692	3.8462	1
A2	Poor Communication	2	2	12	10	13	0.7538	3.7692	2
A3	Lack of Knowledge	3	4	11	16	5	0.6821	3.4103	5
A4	Lack of experience	2	5	10	19	3	0.6821	3.4359	6
A5	Tiredness and fatigue	1	3	18	12	5	0.6872	3.4359	4
A6	Lack of coordination between the main contractor and subcontractor	2	4	10	11	12	0.7385	3.6923	3
A7	Lack of teamwork spirit	3	11	11	10	4	0.6051	3.0256	7
Factors Associated with Material and Equipment									
B1	Equipment deficiencies	2	3	8	10	2	0.7795	3.8974	2
B2	Inappropriate storage and handling of material	1	2	8	15	13	0.7897	3.9487	1
B3	Poor condition of tools	2	3	8	10	16	0.7795	3.8974	3
B4	Poor configuration of tools	2	3	9	18	7	0.7282	3.6410	5
B5	Lack of supervision	2	2	12	9	14	0.7589	3.7949	4
B6	Lack of protection in material transportation	4	5	12	11	7	0.6615	3.3077	7
B7	Lack of personal protective equipment	4	5	13	12	8	0.6923	3.4616	6
Factors Associated with Workplace									
C1	Poor housekeeping	2	1	17	9	10	0.7231	3.6154	2
C2	Site constraint	2	7	14	11	5	0.6513	3.2564	6
C3	Accidents due to negligence/ careless	2	5	8	11	13	0.7436	3.7179	1
C4	Poor construction sequence	3	3	10	13	10	0.7231	3.6154	3
C5	Improper security of job site	5	6	10	13	5	0.6359	3.1795	7
C6	Deficiencies of inspection on worksite	3	3	11	9	11	0.7189	3.5946	4
C7	Hesitance to allocate resources for safety measures	3	4	12	14	6	0.6821	3.4103	5
Factors Associated with Management									
D1	Design alterations	3	6	19	2	2	0.6051	3.0256	7
D2	Lack of project management and planning	1	8	11	3	3	0.6615	3.3077	3
D3	Deficiencies in risk management	5	6	6	7	7	0.6667	3.3333	2
D4	Lack of awareness from top management	5	4	8	11	11	0.6974	3.4872	1
D5	Subcontractor selection and management	2	4	16	3	3	0.6615	3.3077	4
D6	Performance pressure	3	4	17	4	4	0.6462	3.2308	6
D7	Lack of organisational commitment	4	1	13	6	6	0.65	3.2500	5

The RII & AI of Current Practice in Construction Projects Pertaining to Safety Management

As for the current practice of safety management in construction projects, it consists of 14 items that required respondents to rate their feedback using a 3-point Likert Scale: Yes, Sometimes, No. The results of the RII and AI analysis of the factors are presented in Table 4.

Table 4. Descriptive Statistics of Current Safety Management Practices in Construction Projects

Practice	Factor Description	AVI	SD	RII	Rank
P01.	All employees have been briefed on the DOSH guidelines	1.3	0.53	0.148	14
P02.	The HSE policy is distributed to all staff members	1.3	0.61	0.200	4
P03.	A campaign of safety awareness is implemented	1.4	0.63	0.179	11
P04.	A safety toolbox session occurs either daily or weekly	1.1	0.45	0.184	8
P05.	The Safety Management System (SMS) is implemented	1.3	0.62	0.189	6
P06.	The Emergency Response Plan is enforced on-site	1.3	0.56	0.179	10
P07.	The designated personnel inspect the formwork braces and other supports	1.3	0.59	0.164	12
P08.	The erection and dismantling of scaffolds are carried out under supervision	1.5	0.72	0.194	5
P09.	The site worker is equipped with complete PPE at the construction site	1.3	0.56	0.179	9
P010.	Any accidents are promptly reported to the nearest Department of Safety and Health	1.3	0.59	0.164	13
P011.	Department of Occupational Safety and Health issued a certificate of fitness to all hoisting machinery	1.3	0.67	0.205	3
P012.	Safety signboards are placed at the workplace site	1.3	0.67	0.210	2
P013.	A safety and health officer has been employed to oversee safety measures at the construction site	1.2	0.54	0.189	7
P014.	A job safety/hazard analysis protocol is in place and being implemented at the construction site	1.4	0.71	0.2155	1

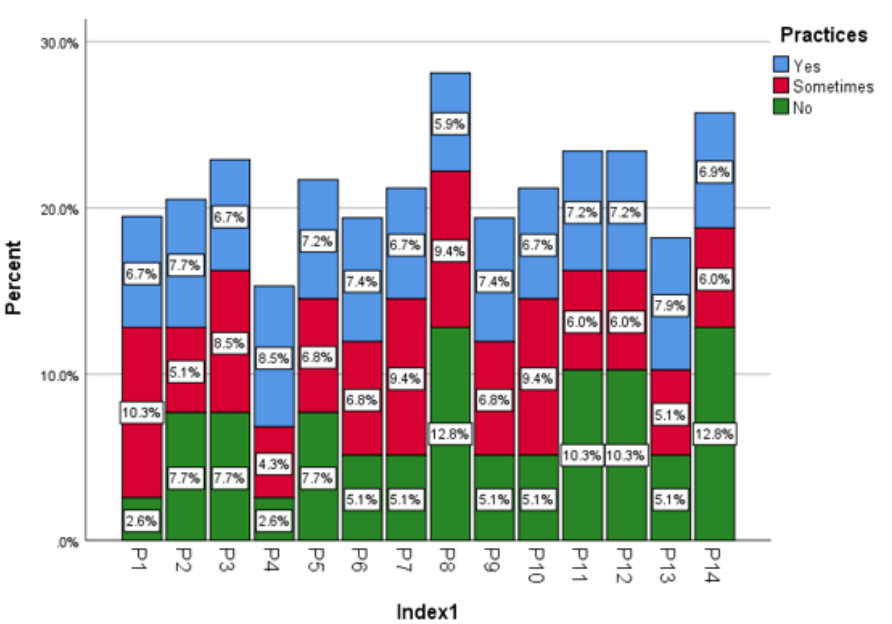


Figure 2. Percentage of Respondents Regarding Practices

The bar chart in Figure 2 indicates that a majority of respondents answered 'No' or 'Sometimes' regarding various safety practices. This suggests that many safety measures are either not yet enforced or not taken seriously at the construction site, potentially leading to safety misbehaviours. Specifically, "P014: Job safety/hazard analysis is implemented at the construction site", "P08: The erection and dismantling of scaffolds are carried out under supervision", "P011: Department of Occupational Safety and Health issued a certificate of fitness to all hoisting machinery," and "P012: Safety signboards are placed at the workplace site" are four commonly reported practices across most infrastructure construction projects.

Conversely, upon comparing the questionnaires with the findings gathered from observations at the MRT 2 construction site and casual conversations with engineers, a number of conclusions can be drawn regarding current practices. The employment of safety and health officers is deemed significant, ranking number 1. In this project, the company has indeed hired a safety health officer. However, according to conversations with engineers, it was mentioned that the safety officer is not always present on-site. Inspections are only conducted at specific times, leading to workers sometimes disregarding safety rules when officers are absent.

Furthermore, there exists a disparity between questionnaire responses and on-site observations regarding adherence to safety protocols. Both workers and upper management appear to demonstrate a lax attitude towards safety regulations. An example of this laxity is evident in instances where a resident engineer conducts inspections without donning appropriate personal protective equipment (PPE) or a full-body harness while examining elevated areas exceeding 1.2 meters from ground level. One plausible explanation for the lack of disciplinary action against workers could be attributed to upper management's apprehension that enforcing penalties might impede project progress, potentially resulting in stop-work orders.

The Spearman's Correlation of The Analysed Factors and Effective Practices at The Construction Project

Spearman's correlation was used to assess the relation between factors. The outcomes of the correlation reveal that all values lie within the -1 to +1 range, as shown in Table 5. Using SPSS software, the correlation test revealed the highest correlation values for specific pairs of factors. For instance, the correlation between "B06: Lack of protection in transporting material" and "P09: The worker is equipped with suitable PPE at the construction site" was found to be 0.549. Similarly, the correlation between "D01: Changes to design" and "P014: Job safety/hazard analysis is implemented at the construction site" was determined to be 0.484, while the correlation between "A04: Lack of experience" and "P07: The designated personnel inspect the formwork braces and other supports" was 0.442.

These findings suggest that there is a significant relationship between certain factors contributing to safety misbehaviour and corresponding effective safety practices. For example, addressing issues related to the lack of protection during material transportation can help prevent safety incidents by ensuring that workers wear appropriate PPE. Similarly, implementing job safety/hazard analysis practices can mitigate risks associated with changes to the design, and conducting inspections of formwork braces and supports by designated personnel can improve safety in cases of lack of experience among workers.

Table 5. Correlation Between Worker Involvement Factor and Safety Practices

Analysed Factors	Analysed Safety Practice	Correlation Analysis
Lack of Knowledge	Inspection of formwork braces and other supports.	"A3:P7" Result: 0.402
Lack of Experience	Inspection of formwork braces and other supports. The worker wears appropriate PPE at the construction site.	"A4:P7" Result: 0.442 "A4:P9" Result: 0.330
Tiredness and Fatigue	Publication of HSE policy. Conducted Safety Awareness Campaign. Inspection of formwork braces and other supports. The worker wears PPE at the site.	"A5:P2" Result: 0.317 "A5:P3" Result: 0.318 "A5:P7" Result: 0.414 "A5:P9" Result: 0.394
Lack of Coordination Between The Main Contractor and Subcontractor	Inspection of formwork braces and other supports.	"A6: P7" Result: 0.404
Lack of Teamwork Spirit	Inspection of formwork braces and other supports. All hoisting machinery obtained fitness certificate from DOSH.	"A7: P7" Result: 0.338 "A7: P11" Result: 0.365

CONCLUSION

In summary, it's clear that safety performance in construction development is significantly impacted by the adoption of safety practices. This research holds importance in assessing the efficacy of safety practices employed in ongoing infrastructure construction by outlining specific objectives.

The study successfully fulfilled its objectives by utilising the Relative Importance Index (RII) to pinpoint and prioritise factors influencing safety management in construction. Moreover, it endeavours to establish connections between factors affecting safety management and existing safety practices in construction projects while also validating the identified factors. This validation is carried out through a comprehensive case study utilising data gathered from the study's participants.

ACKNOWLEDGEMENTS

The author would like to express special gratitude to Yayasan UTP for supporting this research under Grant Yayasan UTP Fundamental Research Grant (Reference: YUTP-FRG 1/2022 (015-LC0-405).

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ASSESSING THE SUCCESSFUL IMPLEMENTATION OF TERM CONTRACTS: A CASE STUDY OF KRUGER NATIONAL PARK

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Abstract
Term contracts enable employers to expeditiously respond to small works, particularly for maintenance, within a fixed term at agreed rates. However, some organisations are still wary of the inherent difficulties associated with procuring small works. The procurement of contractors to implement urgent repairs and reactive maintenance has proven to be problematic because the work cannot be readily defined or measured at the outset of the project. And yet, the Kruger National Park (KNP) continues to use the term contracts model despite the challenges posed by this model. The research used semi-structured interviews to establish the critical success factors (CSF) for implementing term contracts using KNP as a case study. The data was analysed using a code-to-theory model for qualitative enquiry. The findings of this study identified planning, communication, project characteristics, stakeholder involvement and the project manager's competence as CSF for the implementation of term contracts to achieve effective procurement and operations management practices. Project managers raised a concern with the lack of monitoring tools during the implementation of the term contract, especially with regard to measuring the performance against the set objectives of empowerment of local contractors. However, the measures for project success were found in the traditional methods, which include cost, quality and time, as well as present practices involving safety awareness, environmental impacts and dispute resolutions. For term contracts to be successful, effective management programmes would let the KNP identify innovative and resourceful operational programmes that will enable project managers to understand their strengths and weaknesses.

Keywords: *Critical Success Factors; Maintenance; Procurement; Project Success; Small Works; Term Contract*

INTRODUCTION

Achieving the planned objectives of the client is crucial for the procurement of a construction project to be successful (Sayyed et al., 2023). The procurement of contractors to implement urgent repairs and reactive maintenance has proven to be problematic because the work cannot be readily defined or measured at the outset of the project (Hanák et al., 2021). Windapo et al. (2020) found that organisations are wary of the inherent difficulties associated with the procurement of small works as the approach is prone to be unstructured and unregulated than large-scale construction works. The need for the procurement of small works to enhance efficiency and effectiveness is critical since the delivery of maintenance work is important to the organisation's overall business. To overcome this challenge, one of the solutions identified for public sector clients is to use term contracts.

Watermeyer (2018), quoting from the ISO 6707-2, defines term contracts as "a contract which enables the employer to order work over a fixed term at agreed rates." The typical works executed using term contracts in construction are small works or minor works, renovations, maintenance and routine projects. Of the four forms of contracts permitted for use for construction and engineering works (CIDB, 2019), the NEC3 Term Service Contract

is the most suitable contract for the implementation of term contracts. However, in practice, employers such as KNP elect to use other forms of contracts for the implementation of term contracts (South African National Parks, 2021), which has led to failure to reach project objectives and contributed to contractual disputes.

This research focuses on the State-Owned Entities (SOEs) under the management of South African National Parks (SANParks). As a case study, the Kruger National Park (KNP) has been implementing term contracts since 2004, when the outsourced model of implementing planned and reactive maintenance was introduced. This was a result of the initiative by SANParks to offer economic opportunities to previously disadvantaged communities bordering its parks (Mabibibi et al., 2021), particularly emerging contractors. CIDB Grade 1 to 3 contractors were engaged for a period of three years to do construction and maintenance of buildings, fences and roads. For these contractors, these works can be complex, administratively burdensome and may lead to failure because of limited capacity and experience. To attain the best value for small works procurement, KNP needs to implement operational management methods to efficiently handle small-scale works within their estates.

Studies conducted by different researchers on successful small works project delivery regarded effective performance management (Offei et al., 2019) and categorised factors that could affect the project's success (Lamprou & Vagiona, 2022). Project success often focuses on task completion, and operational management success is defined as the repetitive steps required to achieve the project objectives by managing both tasks and teams (Zhang et al., 2024). To understand project success in small works, Klee (2015) describes it as a process that can provide rules and regulations for emerging contractors to cooperate. The main purpose is to establish a binding agreement between parties under the law. However, CSFs can contribute to achieving project success by focusing on why and what contributes to the success. This indicates a challenge of identifying key project components along with their CSF that meet client expectations. This involves implementing established project management methodologies such as initiating, planning, executing, monitoring and controlling, and closing. It also requires effective communication, risk management and resource management to ensure successful delivery. By following best practices, project managers can ensure successful project completion and the delivery of the intended results whilst considering environmental concerns that include factors such as legal, cultural, sociological, technological and financial. This holistic approach ensures all aspects are addressed and project managers can effectively navigate and mitigate potential challenges (Kumar et al., 2023). However, projects at the KNP continue to fail, and the client continues to be dissatisfied with the quality of completed work.

Since CSF can vary from project to project and organisation to organisation (Qammaz & AlMaian, 2020) and most studies did not consider the size of the projects and assumed that CSF applied across all project types, the need to identify factors that will lead to the successful implementation of term contracts in the KNP is required to coordinate a variety of tasks with different start and end dates, within a contract whilst adhering to safety protocols and employing modern technologies to enhance efficiency.

LITERATURE REVIEW

Term Contracts

Construction works can be classified into either large or small projects, and small works can be divided into unplanned (reactive) and planned (scheduled) projects (Bukari, 2022). With each project, an agreement detailing the contractor's service responsibilities and the client's compensation obligations is received (Hansen, 2021). The general principles of procurement and management apply to both, but practices should be customised to match the specific nature, characteristics, and scale of the task at hand. However, some urgent repairs are carried out with instructions without a prior quotation and without a formal arrangement between the contractor and a client (Windapo et al., 2020). Most term contracts are typically continuous and involve multiple activities with distinct start and finish dates within the same contract (Deprez et al., 2018). They do not always have specifics on how risks will be addressed and may not always accurately reflect the size, complexity and value of the work involved. Even though they can specify a minimum quantity of deliverables, with the possibility of additional needs, in most situations, they are set up for maintenance (Van Huyssteen & Maxwell, 2021).

Term contracts are defined as a preventative or corrective maintenance system over a predetermined period, as set out in contract documentation, managed by project managers responsible for both capital and operational expenditure (Mangano & De Marco, 2014; Yousefli et al., 2017). They are usually arranged by project managers who manage both the capital and operational expenditure (Birch, 2019) to minimise the time required for awarding, and sometimes the costs are negotiated. The NEC4 term service contract for maintenance defines term contracts as work that should be done over a period of more than one year (Eggleston, 2019). The JCT (2017) further adds that term contracts should be used by clients who require a continuous stream of maintenance, minor works, and improvement projects to be completed by a single contractor within a specified period.

The motivation for term contracts is that the main maintenance contract already exists, but other separate small works can be performed. Where a sound business relationship exists, one contractor can be appointed for different kinds of work. However, contract management problems resulting from inexperienced project managers may affect not just the main project but also the operation of the estate's life cycle. Thus, there is a need for an effective procurement management and operations system for small works in the context of KNP, as it is important to the business.

The Kruger National Park Context

In the KNP, term contractors are appointed for three years and utilised for small building works, renovations and road maintenance works (SANParks, 2021). According to the tender documents, these term contractors are required to execute planned renovation programs and to respond as and when required to urgent larger maintenance projects from floods or other damaged infrastructure in a geographical area of the park. This method of executing maintenance projects using the term contracts model was introduced to the KNP to minimise the time required to award construction projects to contractors and reduce the costs associated

with this process because the client can quickly initiate the work without the need for a lengthy tendering process.

The KNP is one of Africa's largest game reserves in northeastern South Africa, where it borders Limpopo and Mpumalanga provinces, west of the Lebombo Mountains on the Zimbabwean and Mozambique borders, as seen in Figure 1.



Figure 1. The location of the Kruger National Park in South Africa

The term contracts model in KNP describes the use of procurement to promote social and national agenda as a project's secondary objective while delivering the infrastructure within budget, cost and quality as the primary objective (Watermeyer, 2018). However, the distinction is important in measuring the project's success through a wider lens which considers the project's socio-economic impact. The focus of this paper is on the importance of implementing term contracts and how they can deliver the best value in the management of small works within the context of an organisation with a large property portfolio.

Suitable Form of Contracts for Term Contracts

The Construction Industry Development Board authorised the use of four main forms of contracts for engineering and construction works in the public sector (CIDB, 2019). The recommended contracts are contained in the JBCC Series 2000, the GCC for Construction Works, FIDIC and the NEC family of contracts. However, the South African construction industry continues to use the JBCC as it plays a fundamental role in offering standardised contract forms, dispute resolution services, and educational opportunities. Although its main aim is to promote fairness and transparency, the complex legal language and specific terminology may be intimidating for those not familiar with it. Certain provisions in this contract require actions to be taken within specified time frames. These can often be stringent, and missing these deadlines may lead to severe consequences, including financial losses. With most of the small contractors always exceeding the duration period and budget, this is always a problem. Another fundamental limitation of this contract form is its singular approach to procurement, which is the traditional approach and separation between design and construction. However, over the years, the KNP has implemented term contracts using mainly the JBCC Principal Building Agreement.

The NEC family of standards is suited for the implementation of term contracts through its Term Service Short Contract, which contains standard provisions drafted explicitly for this purpose (NEC, 2013). The JBCC is generally preferred. NEC offers more flexibility for a wider range of projects, including smaller works, whereas the JBCC is specifically designed for building projects. The key difference between the two contracts lies in their focus on risk allocation, collaboration, and suitability for specific project types: for small works.

In these small works, the pricing strategy is another important determinant of how the prices are calculated and the apportionment of risk between the parties (Cremer, 2021). Yabar-Ardiles et al. (2023) stated that the pricing strategies can be categorised as either price-based or costs based, the difference being that the contractor is paid based on the predetermined estimates which includes risks and market premiums regardless of his costs on the former and payment is according to what the contractor spent on the latter. The JBCC, GCC and FIDIC forms of contracts are suitable for use with price-based models, while the NEC can be used with both price and cost-based models (Deacon & Kajimo-Shakantu, 2024). SOEs such as KNP should consider using the NEC form of contract for the implementation of term contracts to improve project outcomes.

Success and Challenging Factors of Term Contracts

Large organisations like the KNP rely on vast, diverse property holdings that are crucial to their business. Sustaining these resources usually involves significant yearly costs for maintenance, upgrades, renovations, and minor construction projects. Such activities form the category of small works, which is defined as projects with a value of R3 million or less or projects with a duration of not less than 6 months (Conley & Gregory, 1999). Previous studies on CSFs did not consider the size of the projects, and it was assumed that CSF applied across all project types. Gao et al. (2020) supported this observation and noted that most studies were conducted on large projects due to the potential savings in value, and it was unknown whether the same success factors were appropriate and sufficient for small works. It was further argued that it has become apparent to researchers that a different approach is required for the unique nature of small works (Debela, 2022).

Silva et al. (2016) formulated a framework for evaluating CSF, which categorises various aspects of efficiency in the short term (quality, cost, schedules, safety and cash flow) and effectiveness in the long term (client satisfaction, employee morale, profitability, environment impact, learning and growth). Rowe (2020) expanded the idea with a process that includes reduced paperwork, increased teamwork, simplified design requirements, and innovative procurement. The benefits of this framework are listed as reduced design costs, lower schedule overruns, and lower change order costs. To assist in assessing and quantifying the success of projects in order to optimise resource allocation. Gunduz and Almuajebh (2020) considered the perspectives of all project stakeholders as crucial, with the most significant CSF relating to project finance and top management of resources like materials, production and workforce. Moeuf et al. (2020) further included risks and opportunities for SMEs as they must meet complex client expectations. The research highlights the significance of training as the most crucial factor for project success. It also emphasises that managers play a prominent role in the success of projects.

The challenge of low-price reliance for project appointments has resulted in schedule delays, compromised quality of work, increased costs and a high incidence of claims (Deacon & Kajimo-Shakantu, 2023). These bids do not guarantee maximum value as unqualified contractors may submit lower bids with an expectation of making profits through changes and claims.

Another disadvantage when outsourcing small works to emerging contractors is the lack of technical and managerial knowledge that has led to dealing with one contractor repeatedly. Since term contracts often lack specificity in terms of addressing risks comprehensively, project managers tend to enter into several identical term contracts with one contractor. Pascual et al. (2012) expand on this argument by suggesting that outsourcing maintenance services can result in a reliance on a single contractor, potentially leading to monopolistic behaviour from the contractor. This dependency can result in the contractor setting high rates for their services. Haidar (2021) highlighted that disputes often arise from irregularities and contradictions within contracts, which can negatively impact contractual performance. The increasing complexity of the issues involved in these disputes can make resolution more challenging. So, how then can the best value in both procurement and operational management of small works in the KNP be delivered?

METHODOLOGY

This research adopted the interpretivism philosophy, which offers precise insights into a phenomenon through firsthand experiences, avoiding broad generalisation (Creswell, 2015). Furthermore, qualitative research offers a nuanced understanding of a phenomenon by considering the perspective of those experiencing it, rather than relying on broad generalisations (Biggam, 2008). Interpretivism aims to incorporate a depth of insight and richness in understanding (Saunders et al., 2012) of the factors that will lead to the successful implementation of term contracts within Kruger National Park.

A qualitative research approach was employed to examine the problem thoroughly. Qualitative research allows for the development of new strategies while creatively gathering data, leading to a more comprehensive and insightful exploration (Neuman, 2014). A qualitative research approach is adequate because term contracts enable employers to expeditiously respond to small works, particularly for maintenance within a fixed term at agreed rates. The failures are attributed to the fact that not all projects are the same regarding CSF and that the factors can vary from project to project and organisation to organisation. Qualitative research enables participants to freely express themselves on the phenomenon under investigation without restriction. This openness can help overcome the challenges associated with procuring for small works.

Target Population and Sampling Technique

The sample selected is the entire population of project managers in the Kruger Park involved in the implementation and management of term contracts due to its manageable size of 15 people, according to the structure of the project management unit for the KNP. Staff members who have left KNP due to resignations and retirement will be contacted to obtain their views and a historical perspective on the implementation of term contracts. This was done to aid the researcher in gaining valuable insights from participants who have directly

experienced the issue being investigated. This method allowed for a more in-depth understanding of the problem from the perspective of those involved (Creswell, 2015). A purposive sampling was adopted, as the researcher intended to get insights from the KNP project managers only. Purposive sampling involves the researcher using their judgment to select participants who possess specific characteristics or qualities that are relevant to the research study. This approach allows for a targeted and intentional selection of participants based on the research objectives (Rai & Thapa, 2015). The sample comprises 15 project managers with building, civil engineering and quantity surveying backgrounds in the park.

Data Collection

Data collection is the process of systemically gathering the necessary information with minimal inaccuracies to ensure that the analysis yields reliable and meaningful results. By utilising appropriate methods and techniques, researchers can ensure that the data collected is accurate and representative of the phenomenon under investigation, leading to trustworthy and logical conclusions (Parveen & Showkat, 2017). Data was collected using semi-structured, open-ended interview questions. This method allowed for a flexible and exploratory approach to gathering information, enabling participants to provide detailed responses. These interviews were done using video conferencing tools like Zoom and Teams. The integration of digital technology in research offers a range of benefits, including the convenience and cost-effectiveness of online methods in comparison to traditional in-person data collection techniques (Labinjo et al., 2021). By leveraging digital platforms and tools, researchers can reach a wider audience and facilitate data collection from diverse geographical locations. Additionally, digital technology enables real-time data collection and analysis.

According to Blumberg et al. (2008), semi-structured, open-ended questions also enabled the researcher to get elaborated responses and help confirm the knowledge and perspectives the participants already possess, as well as uncover new information. The interview questions were themed around: (1) how CSF for implementing term contracts can be established. (2) how best can procurement and operational management be delivered for small works, and (3) the causes of failure or success in term contracts in KNP. The next step is to analyse the qualitative data, code and categorise themes to construct theories.

Data Analysis Techniques

The utilisation of NVivo10 software proved beneficial in the coding and categorising process, enabling the researcher to analyse and organise data effectively. Using this software helped to systematically identify patterns and themes and construct theories based on the refined data. Schreier (2012) describes qualitative content analyses as a method of assigning meaning to qualitative data in a systematic way. The initial level of coding typically involves descriptive coding, where raw data is broken down into smaller segments and assigned descriptive labels or codes (Elliott, 2018). This process helps to identify patterns, themes and overarching concepts present in the data. Through descriptive coding, several codes are grouped together to form a common idea or category.

Saldanha (2021) emphasised the importance of verifying the categories that have been developed through the coding process. Once the categories have been established, the final stage involves comparing them to the original data to ensure the accuracy and validity of the interpretations. This analysis helps researchers to confirm the relevance and coherence of the categories, ultimately leading to the construction of a well-developed scheme, design or theory. This iterative process of comparing, refining and validating is essential.

Corbin and Strauss (2008) explained that the systematic interrelation of themes and concepts develops a coherent and meaningful theory which contributes to the advancement of knowledge in the field. Figure 2 below shows descriptive coding categorising the problems affecting project success, and the pattern coding is appropriate for the second cycle coding, which pulls together material into a smaller number of more meaningful units. Although this does not capture the whole process, it still shows the complexity and richness of the data analysis.

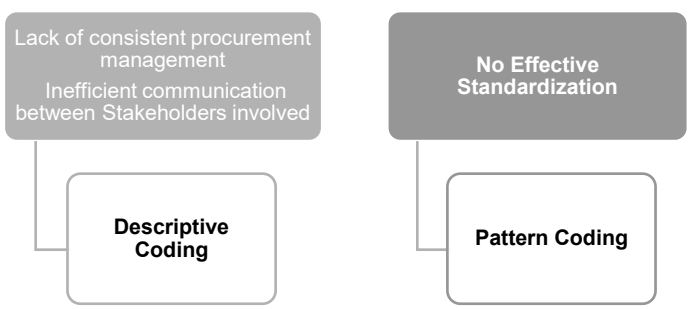

Figure 2. The First Level of Coding The Raw Data

The study's code to theme table for the implementation CSF in term contracts and how can the best procurement and operations management for small works be delivered is shown in Table 1. A manually created set of codes was generated by conducting a thematic analysis of qualitative data.

Table 1. Example of The Manually Created Set of Codes from The Theory Model

Code	Category	Common Theme	Refined Theme	Theory
Stakeholder Management and Collaboration	Project manager & team	Communication Planning Stakeholder involvement Project manager's competence	Critical success factors	Determining essential elements and critical success factors for project management in small works Spalek (2005) Herath & Chong (2021)
Project Scope and Resources Availability	Project related	Project characteristics Complexity of project	Technical Skills	Project management for small projects Altarawneh & Samadi (2019) Rowe (2020)
Contract Management Processes	Organisational	Procurement of contractors Allocation of budget	Procurement systems	The connection between criteria for success factors that contribute in organisations Cserháti & Szabó (2014) Deacon & Kajimo-Shakantu (2023)
Project and Risk Management Strategies	Golden triangle	Time Budget Quality	Measures of success	Evaluation systems for project control, success and failure Taherdoost & Keshavarzsaleh (2015) Gunduz & Almuajebh (2020)

Code	Category	Common Theme	Refined Theme	Theory
Change Management Considerations	Contract performanc e	Successful completion of projects Empowerment of contractors	Performance management	The link between perceived service quality and client satisfaction construction contract management competency Successes and challenges in sustainable development goals Saqib et al. (2008) Hansen, S. (2021) Mabibibi et al. (2021)
Project Components and Complexity	Project Allocation	Pre-establishment of term contract Post-establishment of term contract	Quality	Factors affecting the capacity of small enterprises Impacts of procurement strategies Key factors that prompt changes to standard contract forms Ogwueleka (2013) Windapo et al. (2020)

RESULTS AND DISCUSSION

The sample selected in this research comprises project managers in the KNP with experience in the implementation of term contracts. The level of involvement in the implementation of term contracts was not prescribed for this study. However, it became apparent that the years of experience and being part of the projects from initiation to close-out are important. According to Table 2 below, there are 15 different members involved in the management of projects. Their roles are of project managers, contracts managers, quantity surveyors, architects and quality assurers.

Table 2. Demographics And Years of Working in The KNP

Coding	Background	Professional Registration Status	Number of Years in KNP
PM-A	B-Tech in Architecture	SACAP Architectural Technologist	7
PM-B	National Diploma in Civil Engineering currently pursuing B-Tech	Not registered	8
PM-C	B-Tech in Civil Engineering & Post Graduate Diploma in Project Management	Not registered	2
PM-D	M-Tech Construction Management and Certificate in Project Management	Candidate Pr.CPM with SACPCMP	3
PM-E	MSc in Project Management	Not registered	2
PM-F	B-Tech in Quantity Surveying	Pr.CPM with SACPCMP	7
PM-G	B-Tech in Architecture	Not registered	2
PM-H	B-Tech in Civil Engineering	Not registered	3
PM-I	BSc Quantity Surveying	SACQSP candidate	5
PM-J	National Diploma in Civil Engineering	Not registered	4
PM-K	B-Tech in Architecture	Not registered	2
PM-L	BSc Construction Studies	Not registered	4
PM-M	B-Tech in Quantity Surveying	SACQSP candidate	6
PM-N	B-Tech in Civil Engineering	ECSA, Prof Eng	9
PM-O	National Diploma in Civil Engineering	Not registered	2

In terms of demographics, it is significant that none of the participants in this study have worked for the Kruger National Park for a period exceeding 10 years, which posed a challenge to answering one of the questions, which is whether the term contracts model has been successful over the past 10 years.

The primary question of this study, which guided the analysis, is: What are the CSFs that will lead to the successful implementation of term contracts?

Factors That Will Lead to The Successful Implementation of Term Contracts

The interview participants believed that there are many factors that will lead to the successful implementation of the terms of contracts in the Kruger National Park. But the outlined themes were mostly highlighted during the research. The researcher groups these factors according to categories to delineate the relationship between the different factors.

Theme 1: Planning

The interview revealed that planning is one of the CSFs for the successful implementation of term contracts as it is deliberate, with a focus on managing risks through step-by-step actions (Phillips & Landahl, 2021). For effective planning, projects should ensure the uninterrupted usage of resources like equipment, materials and human resources (Papke-Shields & Boyer-Wright, 2017). If delays happen, project managers should adjust time, cost and resources to meet the target. During the interviews, respondents referred to the lack of proper planning as a source of project failure. PM-B remarked as follows:

"Planning is a basic requirement for project performance. For term contracts, it cannot be undermined as it plays a role in the success or failure of the projects."

Furthermore, PM-J added that the most common way of overcoming project failures is to establish effective systems for capacity planning and spending enough time on defining work tasks, selecting appropriate technology, determining necessary resources and estimating the duration of each task.

With term contracts in the KNP, a lot of effort goes into work packaging for emerging contractors to manage workloads. These need to be project managers to keep track, analyse any deviations, detect out of control situations and take appropriate corrective actions for the projects they are involved in.

PM-E said that "If enough time is spent on planning, by the time contractors are appointed, everything should be in place, and technical problems may be avoided."

However, the planning process cannot be done in isolation from the other critical success factors. There is an interdependency between communication and the involvement of stakeholders (Gunduz & Almuajebh, 2020).

Theme 2: Communication

The goal of communication is to convey information from one party to another. Therefore, effective communication ensures that the receiver comprehends the message in the

same manner as intended by the sender (Carita, 2015). The problem is that construction projects have different parties with different goals, and these goals may not be compatible. The primary objective of the client is to achieve the highest quality and functionality while keeping costs to a minimum. On the other hand, the contractor aims to meet financial targets while ensuring client satisfaction (Ayhan, 2019).

To improve efficiency, aid communication, and promote consistency of action, the Park encourages standardised operational processes. However, communication can be intertwined as there is a client and there is also a Hospitality Services Managers or Camp Managers responsible for the tourism aspect of the Park's business operations. Effectiveness is then dependent on balancing both the strategic and operational teams. During peak seasons, work is constantly disrupted to accommodate tourists; both project managers and contractors need to adjust their schedules for low peak seasons and resources. But this does not always happen as more claims are done for delays, coordination errors, payments and idling labour.

PM-C commented on the alignment with tourism operations and said the following: "During peak times, there are usually issues as one will have to stop work to accommodate the visitors to the park."

PM-D stated that "Constant communication is the key as small contractors need constant guidance and also to avoid disputes."

Day-to-day issues affecting the project should be reported timeously and resolved through communication with the other stakeholders involved. But the park's remoteness, distances between camps, unavailability of network coverage, strict and limited working hours due to gate closure and the alignment of project plans with the tourism operations have caused too many contractual disputes, delays in payments, and changes in plans and scope.

The park's area of land has influenced improper communications. PM-E responded as follows: "KNP is big, and there are a lot of camps, and the traveling times from one campsite to another can be even an hour. If a contractor is awarded work on different sites, this can really cause delays and disruptions."

To improve on communication, efficiency and productivity, project managers should frequently communicate using innovative information and communications technology (ICT) tools and internet-based construction project management systems to enhance the ability to achieve project success in the KNP, considering the remote environment that does not have enough network coverage. Using the latest technological advances, such as having virtual meetings, would mitigate the challenges caused by the distances and remoteness of some of the locations of the projects.

Electronically linking and transferring project-related data between dispersed project participants, such as clients, project managers, and contractors, has numerous potential benefits. These include enabling seamless collaboration, facilitating the rapid resolution of ongoing project issues, and reducing the necessity for unnecessary travel time and associated cost overruns (Wuni & Shen, 2020).

Theme 3: Project Characteristics

As procurement and operational management becomes increasingly critical in public sector organisations, the importance of applying specific performance measurement methods to measure and improve processes cannot be overstated. These methods are essential for ensuring project success and achieving organisational goals effectively. Most projects aim to achieve five key objectives: relevance, efficiency, effectiveness, impact and sustainability. By focusing on these goals, project managers can ensure a positive contribution to the overall organisation. Project managers in this study listed the following project characteristics as success factors for the implementation of term contracts:

- The size of the projects is relatively small, with values ranging from R100 000 to R5 million in value
- The duration of the project should be less than 6 months
- The location of the projects is remote, with limited influence or impact from outside communities
- The scope of work is maintenance or renovations in nature
- The authority for scope, schedule and budget lies with the project manager
- Change in scope and budget is readily accepted while time is a critical constraint
- Attributes related to the delivery and contractor selection methods.

Although effective project management is important for the successful accomplishment of projects, an eco-innovative practice is required in the park to improve levels of sustainability. Most disputes have been on additional sustainable interventions because of verbal instructions and also the capacity and knowledge of these emerging contractors about the concept.

For term contracts, quality management programmes can also inspire the entire organisation to actively discover and tackle opportunities for improving operational performance while also helping project managers better understand their strengths and weaknesses.

Theme 4: Stakeholder Involvement Characteristics

Involving stakeholders allows projects to leverage the knowledge and expertise of different stakeholders. Relational multiparty contracting methods have been widely recommended as a solution for boosting value creation, benefiting not just the client but also other project stakeholders (Aapaoja et al., 2013). The internal stakeholders that also benefit are the different professionals within the Technical Services Department (Project Management Unit), such as the architect, quantity surveyors, civil engineer, electrical engineer and project managers. These stakeholders would provide expert judgement as input to the planning, execution and monitoring of the projects. Other internal stakeholders include the camp manager, maintenance officers, rangers, and supply chain management officials.

Respondents believe that the involvement of key stakeholders is critical because the requirements for the project are obtained from hospitality managers, and there could be different expectations from different managers. Some project managers explained that the stakeholders in the park were sometimes manageable because of the limited numbers

involved. The project managers also observed that there is very limited political interference on the projects in the park. A comparison with projects outside the Kruger was made by PM-K, stating the following:

"I would say that we have learnt that at KNP there is less political interference in the way in which we allocate work, because the Park is isolated, and we do not belong to any political coverage."

The project manager went on further to explain the allocation of work to contractors as based on an objective criterion for merits. This motivates contractors to deliver projects within the constraint of scope, costs and schedule. Furthermore, community protests, which have become a norm on most projects, are not witnessed in the Kruger. This is not to say that the neighbouring communities around the park are not consulted. But a department and processes specifically designed to do social engagements with local development support to the communities will do that.

Theme 5: Project Manager's Knowledge, Experience and Training

Project managers believe that knowledge, experience and training are critical. Knowledge-based leadership fosters a culture of self-evaluation and assessment of the operating environment, assisting project managers in identifying necessary improvements related to personnel, policy, and procedures. By encouraging continuous learning and adaptability, knowledge-based leadership empowers managers to make informed decisions and drive positive changes within their projects. Some project managers raised concerns that some project managers do not possess the necessary domain knowledge and experience, which has led to project failure.

PM-C made these comments: "My recommendation is, civil works project should be given to the civil engineers. And, building works, be given to the construction managers."

He further went on to say the following: "You cannot ask an architect to do a civil engineering project."

The emphasis by the project managers on specialist background was evident as the preference was that a project manager should either have training in Civil Engineering and Building Science or Construction Management or Quantity Surveying for building-related projects. The reason for this is that the project managers believe that the responsibility for coordinating tasks, comparing them to the baseline plan, analysing deviations by other stakeholders, taking appropriate corrective actions and monitoring the quality of the works lies with them; it is thus crucial to have the necessary specialist knowledge and experience.

Training platforms can serve as a catalyst for driving change and improvements in various areas, such as procurement systems; operational systems; educational, training, professional development, and cooperative learning systems; and technological systems. By offering a structured and interactive environment for continuous learning and skill development, project managers enhance their competencies, adopt best practices and leverage new technology.

Project managers also raised a concern with the lack of monitoring tools during the implementation of the term contract, especially with regards to measuring the performance against the set objectives of empowerment of local contractors.

Practical Implication of the Findings

Procurement and operations practices are essential but costly activities for any organisation, as a significant portion of their revenue and operational budget (sometimes up to 70%) is allocated towards acquiring goods and services necessary to maintain its operations. The study identified keywords, labelled and clustered as codes to form categories and the following themes: planning, communication, stakeholder involvement, project manager's competence and project characteristics, as CSF for the implementation of term contracts (Silva et al., 2016). According to the experience of the project managers in this study, the term contracts have been successful during the period in which they have been employed in the KNP. The measures for project success are evolving to include both traditional metrics such as quality, time and cost as well as contemporary indicators like safety, environmental impact and minimum site disputes. While the traditional focus on economic aspects of the project, the contemporary measures are aimed at sustainability and addressing community-related issues that are pertinent for sustainable construction practices.

As part of implementing an effective management process, the overall performance of the term contracts has heavily depended on improved performance of the contracting processes. The project managers raised a concern with the lack of a monitoring tool during the implementation of the term contract, especially with regards to measuring the performance against the set objectives of empowerment of local contractors. The current practice is to evaluate the achievement of the intended objectives using the upward mobility of the contractor from a lower CIDB grading level to a higher level. Usually, this upward mobility is achieved at the end of the term of the contract.

For term contracts to be successful, quality management programmes can inspire the entire organisation to actively discover and tackle opportunities for improving operational performance whilst also helping project managers better understand their strengths and weaknesses. And implement alternative procurement systems that may provide flexibility in planning and managing workloads to contribute towards the best value in the management of small works.

CONCLUSIONS

Based on the findings, the study suggested that planning for the small works involves improved communication between stakeholders; employing project managers with relevant skills, qualifications, knowledge, and experience; maintaining good relationships; and formulating a win-win situation for all stakeholders involved. Most of the work done in the park encompasses a broad spectrum of interrelated tasks; these need to be managed by setting up standardised procurement strategies and project documentation, monitoring contractors' performance and defining roles precisely.

In managing term contracts, challenges often arise, as revealed by the study indicating that most participants strongly agreed on several key issues. These challenges include unclear project scope, unrealistic timelines, and budget constraints, which can impact project delivery and overall success. Additionally, inflexibility in contract terms, payment conflicts, and inadequate utilisation of information and communication technology (ICT) were also identified. Addressing these challenges requires effective communication, strategic planning, enhancing project transparency, ensuring project performance and the adoption of advanced technologies to streamline contract management processes. By addressing these challenges proactively, procurement and operational practices will improve, and better project outcomes will be achieved.

Employing project managers with good management of contractors' performance may lead to improving monitoring tools for emerging contractors within the national contractor development programme. By creating an enabling environment, these contractors' capabilities may be developed, and their management skills may improve as they upgrade their CIDB statuses.

Contributions

This study made findings which have useful implications to practice. The contributions to practitioners are:

- It emphasises the importance of practical actions which can be taken by project managers to enhance their ability to achieve project success.
- Implementing term contracts necessitates thorough planning and consideration of various factors, including plant and equipment specifications, local labour availability and the complexities of maintenance work involved.

Recommendations

The outcome of this study listed critical success factors for the implementation of term contracts. However, there is no ranking, and the study does not identify the most important success factors.

For the Kruger National Park, it is recommended that the park employs qualified project managers as procurement and operational management of term contracts require skills in contract management, claims management and stakeholder management. A programme for continuous learning and professional development competencies should be in place. And performance metrics should be established for all employees.

For the project managers, implementing term contracts requires skills to keep track, analyse any deviations, detect out-of-control situations and take appropriate corrective actions for the projects they are involved in.

ACKNOWLEDGEMENTS

This research is funded by the CIDB Centre of Excellence in Sustainable Construction Industry Growth (SuCIG).

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INFLUENCE OF BUILDING ENVELOPES ON ENERGY EFFICIENCY USING BUILDING INFORMATION MODELLING (BIM): A CASE STUDY OF ACADEMIC BUILDINGS

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Abstract
Energy sustainability is a growing concern as energy demand rises and climate change awareness increases. Buildings in tropical climates consume substantial energy, mainly due to air conditioning. The materials used in construction significantly impact heat exchange and energy dissipation. Thus, sustainable design decisions should be made early, preferably during the feasibility and initial design phases. Building Information Modelling (BIM) can expedite this process by enabling the evaluation of design alternatives and materials that affect building energy performance. This paper explores the use of BIM to evaluate the energy-saving potential of different wall materials for the academic buildings of Block A, Faculty of Engineering, Universiti Malaysia Sabah. Design alternatives included Insulated Concrete Forms (ICF), Vacuum Insulated Panels (VIP), Aerated Concrete, and Polyurethane (PU) foam insulation. This study used BIM software to create a case study model, which was then simulated with energy analysis software to analyse current energy consumption patterns. The study identified that VIP had the lowest Energy Use Intensity (EUI) and U-value among the wall types, providing optimal insulation and energy efficiency. A subsequent cooling load analysis demonstrated that VIP walls led to a 23.6% reduction in cooling load and energy consumption compared to traditional brick walls, translating to substantial energy savings. The optimised wall materials identified through energy analysis resulted in an impressive cooling load energy savings of 113 kWh/m^2 of electrical energy, with an EUI value of 203 kWh/m^2/year.

Keywords: *Energy Sustainability; BIM Energy Analysis; Building Envelope; Wall Materials*

INTRODUCTION

Energy saving has become increasingly important due to concerns about climate change and the need to reduce greenhouse gas emissions. With finite resources and rising fossil fuel costs, improving energy efficiency and transitioning to renewable sources are essential for environmental preservation, economic benefits, and energy security (Akram et al., 2022). This research compares external wall materials in terms of energy consumption using a case study and Building Information Modelling (BIM) to analyse their characteristics and environmental impact comprehensively. Buildings are among the largest energy consumers, with usage influenced by factors like size, location, age, and design. Older buildings typically consume more energy due to outdated systems and a lack of energy-saving features (Motalebi et al., 2022). On the other hand, energy-efficient buildings equipped with high-performance windows, insulation, and advanced lighting systems significantly reduce energy consumption and operational costs (Firdaus et al., 2021). Campus buildings, in particular, contribute significantly to greenhouse gas emissions, as their high energy demands for cooling, heating, and lighting often rely on fossil fuels (Nagpal & Reinhart, 2018). Globally, the building sector accounts for about 28% of CO_2 emissions from energy use (Ortega-Ruiz et al., 2022).

In Malaysia, achieving the government's target of a 45% reduction in emissions intensity by 2030 requires energy-efficient practices and renewable energy adoption. However, reliance on fossil fuels and deforestation from palm oil production remain challenges (Mustaffa et al., 2022; Vats & Mathur, 2022). By leveraging BIM, this study evaluates the energy-saving potential of wall materials, focusing on their thermal performance in tropical climates. The findings aim to support Malaysia's sustainability goals while contributing to global efforts to reduce energy consumption and greenhouse gas emissions.

The building envelope, which includes the roof, walls, windows, and foundation, plays a critical role in energy sustainability because it acts as a barrier between the interior and exterior of the building (Motalebi et al., 2022). A well-designed building envelope can help to reduce the amount of energy needed to heat and cool the building, resulting in lower energy costs and a smaller carbon footprint. Additionally, the building envelope also contributes to in natural ventilation and passive solar heating, which can further decrease the need for mechanical heating and cooling systems (Verma & Rakshit, 2023). Overall, the building envelope is an important aspect of energy sustainability because it can significantly impact the energy efficiency of a building and reduce its environmental impact (Gao & Meng, 2023) (Ali-Ashgar et al., 2022). The materials used for the building envelope can have a significant impact on the energy efficiency and sustainability of a building. The type of materials used, their insulating properties, and their durability can all play a role in determining how well the building envelope performs in terms of energy efficiency (Al-Yasiri & Szabó, 2021). The use of appropriate materials for the building envelope is significant because it can greatly affect the energy efficiency and sustainability of the building. One of the most important factors to consider when selecting materials for the building envelope is their insulating properties. Using high-quality insulation materials can help reduce heat loss or gain through the walls, roof and foundation, which can reduce the amount of energy needed to heat and cool the building (Macek & Kosina, 2021). This can result in lower energy costs and a smaller carbon footprint.

Additionally, the use of durable and low-maintenance materials can help to prolong the life of the building and reduce the need for maintenance or repairs, which can save resources and costs over time. Another important consideration is the thermal mass of the materials used. Materials with a high thermal mass can absorb and store heat energy, which can help to reduce heating needs in the winter. Similarly, materials with high solar reflectivity can be used to reduce the amount of heat absorbed by the building during the summer, which can reduce cooling requirements. Using sustainable and renewable materials for the building envelope can also help reduce the environmental impact of the building. For example, using materials made from rapidly renewable resources or materials that have lower embodied energy can contribute to the reduction of the building's carbon footprint. The utilisation of appropriate materials in the building envelope is significant as it can greatly impact the energy efficiency, durability, and sustainability of the building. Choosing the right materials can help reduce energy costs, prolong the building's life, and minimise its environmental impact (Wei et al., 2023).

Building Information Modelling (BIM) is a digital tool that can be used to design, analyse, and manage the construction of a building. It can also be used to improve the energy efficiency and sustainability of the building envelope. One of the key benefits of using BIM in the design of the building envelope is that it allows architects and engineers to analyse the energy

performance of different design options in a virtual environment. This can help to identify areas where energy losses occur and determine the most effective ways to improve the energy efficiency of the building envelope (Shah et al., 2023). BIM also allows for the simulation of different weather conditions and the assessment of different materials and systems for their energy performance, thermal properties, and energy efficiency. This can help to optimise the design of the building envelope and ensure that the final design is as energy efficient as possible. Additionally, BIM can also be used to manage the construction of the building envelope, which can help to ensure that the materials and systems used are installed correctly and that the building envelope performs as intended. BIM is a powerful tool that can be used to improve the energy efficiency and sustainability of the building envelope. By using BIM to design, analyse, and manage the construction of the building envelope, it is possible to create a more energy-efficient and sustainable building (Ali-Ashgar et al., 2023).

Previous research has been conducted on the selection of materials and other factors for the building envelope to improve energy efficiency. For instance, Kumar et al. (2020) compared the properties and performance of various building insulation materials, such as polyurethane foam, polystyrene foam, mineral wool, cellulose fibre, and aerogel, and to analyse the thermal conductivity, density, compressive strength, water absorption, and fire resistance of the insulation materials, and evaluates their performance in terms of energy efficiency, durability, and environmental impact. Additionally, Kini et al. (2022) evaluated the impact of passive design strategies on building performance in warm and humid climates. The study focuses on variations in the building envelope design, including shading devices, window-to-wall ratio, and insulation levels. Another study by Stritih et al. (2018) focused on the integration of phase change materials (PCMs) into the building envelope to achieve net-zero energy performance. The study provides a comprehensive review of passive PCM technologies and their application in the building envelope for heating and cooling purposes. It covers various aspects such as the types of PCMs, their thermal properties, their compatibility with different building materials, and their effectiveness in reducing energy consumption.

The selection of appropriate materials in the building envelope can have a significant impact on the energy efficiency and sustainability of a building. It is important to consider the energy performance and environmental impact of the materials when designing and constructing a building. Malaysia, as a tropical country, is hot and humid, and consequently, an enormous amount of energy has been used by the cooling system in public buildings. Most problems in these buildings are wasting energy related to a cooling system, and most of the time, users of these buildings are not satisfied with the level of temperature (Hosamo et al., 2023). For this study, four materials were selected for evaluation based on their insulation capabilities, durability, affordability, ease of construction, and environmental impact. The reasons for selecting these materials are as follows:

ICF is a building construction material consisting of expanded polystyrene (EPS) foam blocks that are stacked on top of each other and then filled with concrete. This material is known for its excellent insulating properties, durability and resistance to fire, moisture, and pests. ICF walls are also easy to build and can save on construction time and labour costs (A. et al., 2022). VIP is a high-performance insulation material consisting of a core material such as fibreglass or foam enclosed in an airtight envelope. The vacuum within the envelope reduces heat transfer through the material, resulting in a very high R-value per inch of

thickness. VIPs are lightweight, thin, and easy to install, making them a good choice for retrofitting existing buildings (Kan et al., 2022). Aerated concrete, also known as cellular concrete, is a lightweight and porous building material composed of cement, water, and a foaming agent. It has good insulating properties, is fire-resistant, and has high sound absorption. Aerated concrete is also environmentally friendly, as it is made from recycled materials and requires less energy to produce than traditional concrete. (Adilkhodjaev et al., 2021). PU foam insulation is a type of spray foam insulation that is applied as a liquid and then expands to fill gaps and cavities. It has excellent insulation properties, is resistant to moisture and pests, and can help improve indoor air quality by reducing air infiltration. PU foam insulation is also durable and can help improve the structural integrity of a building (Amaral et al., 2021).

In this research, the authors conducted a cooling load analysis to compare the amount of cooling needed for the current wall and the lowest U-Value wall material among the four materials that were tested. The selected materials were chosen based on their good insulation properties, thermal resistance, and low embodied energy. The objective of the study was to determine which material had the lowest U-value, which is a measure of the rate of heat transfer through the wall. By obtaining this information, it becomes possible to design and manage more sustainable and energy-efficient buildings that reduce unnecessary energy waste and save on electricity bills.

RESEARCH METHODOLOGY

This study utilises Building Information Modelling (BIM) to evaluate the energy efficiency of various wall materials by simulating their impact on building energy performance. The methodology involves modifying the physical specifications of building wall components, simulating these changes using BIM, and analysing the energy consumption through Autodesk Energy Analysis.

The case study selected is Block A of the Faculty of Engineering, Universiti Malaysia Sabah (UMS), a four-story building located on the UMS Kota Kinabalu campus. This building was chosen due to its high energy consumption, typical of administrative and academic facilities in Malaysia. The base model assumed standard construction practices, with wall materials commonly used in Malaysian public buildings. The intended steps are:

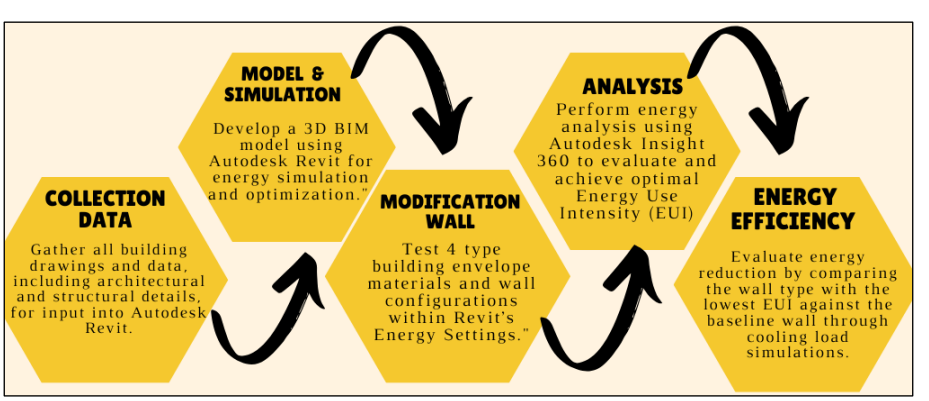


Figure 1. Methodology of This Study

Case Study

The Faculty of Engineering (FKJ) is an academic building located at the main campus of UMS in KK, Sabah. Block A, which operates as the main building, was selected as a research centre and consumes a high electric load. This building, as administration, is fully occupied by students, administrative staff, and academic staff. Other buildings in FKJ include Block B, Block C, Block D, and Block E. Block A serves as the case study building, comprising administration offices and tutorial rooms. The operation hours are from 8 AM to 10 PM, Monday through Friday for lectures and 8 AM to 5 PM for administration offices. The occupancy rate is high for Block A throughout the week, while the rest of the blocks are used based on class schedules or upon request. The building's structure is reinforced concrete, and the roofs are pitched and covered with clay tiles without roof and wall insulation.

The facade is covered with cement sand render, and the main materials of the exterior walls are plaster and brick. Figure 2 is the front view of the Block A, FKJ building at UMS, Kota Kinabalu, Sabah. To begin the analysis, the location of the FKJ UMS was determined to be positioned at latitude 6.0345° N and longitude 116.1217° E. The region experiences an average monthly precipitation of 196 mm, with wind speeds ranging from calm to moderate breeze, rarely exceeding 7 m/s. The dry-bulb temperature in the area ranges from 21.9°C to 32.8°C, and the relative humidity typically varies between 82% and 86%. Overall, the climate in this region is characterised by consistently high air temperatures and relative humidity throughout most of the year.



Figure 2. The Front View of The Selected Building for The Energy Analysis

Development of A 3D Model

The CAD drawings of Block A were imported into Autodesk Revit 2023 to create an accurate 3D architectural model, capturing all essential structural and functional elements, including walls, windows, floors, and roofs. Key material properties, including thermal resistance (R-values) and thermal transmittance (U-values), were input to reflect real-world conditions accurately. Additionally, the model incorporated zoning and occupancy data to simulate energy use across different spaces, such as offices and tutorial rooms. Figure 3 illustrates the detailed 3D architectural model of Block A, showcasing its structural components and spatial layout as prepared for energy analysis.



Figure 3. Block A FKJ 3D Architecture Plan by Autodesk Revit Software

Development of Building Energy Model

After the building had been modelled in Revit Architecture, an energy model was generated using Autodesk Energy Analysis, which is a built-in feature of Revit software (Figure 6). Before creating the energy model, the location of FKJ UMS was setting, as depicted in Figure 4.

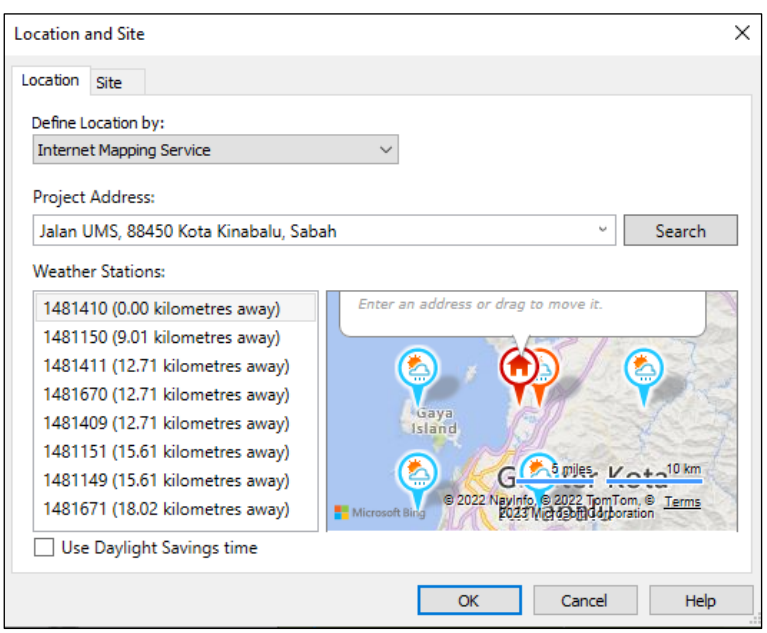
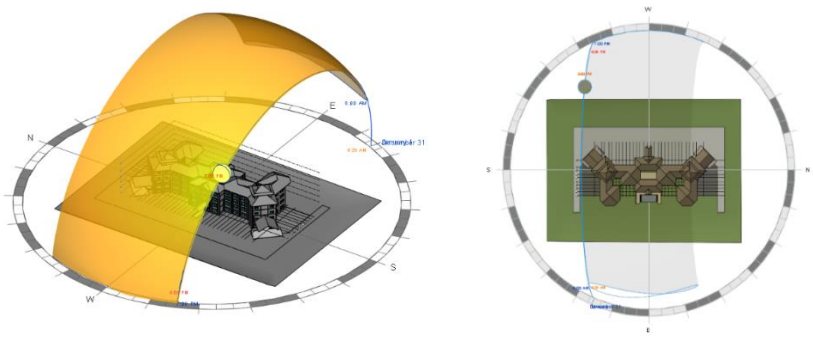


Figure 4. Location Setting of The Project

Based on the current specification, FKJ is facing west. Therefore, the author needs to rotate the project's direction from True North to West. The Sun path analysis is as below:



(a) (b)

Figures 5 (a) and (b). Sun Path Analysis Throughout The Year at Sabah

To improve a building's energy efficiency, it's recommended that its windows face north and east directions and are positioned near the centre. This is because windows facing south and west tend to receive more direct sunlight and heat, which can increase the need for cooling and ventilation, while windows facing north and east receive less direct sunlight and heat, resulting in a more stable indoor temperature and reduced need for energy consumption. However, the specific energy efficiency results of a building depend on various factors such as the building's location, climate, design, and materials used. Additionally, energy efficiency can be further improved by using BIM to evaluate energy consumption by building services, along with other relevant factors. However, current BIM practices still have uncertainties that can limit the effectiveness of the solutions proposed for a building. These uncertainties arise from factors such as neglecting external shading, building textures and materials, variations in sun angles throughout the year, not evaluating different locations and climatic conditions, and not considering lighting loads.

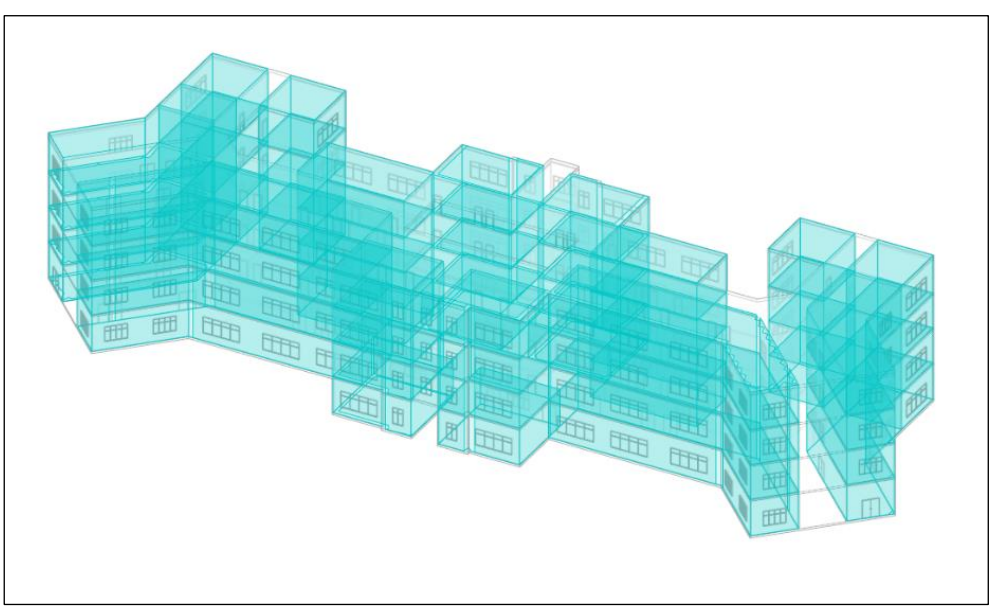


Figure 6. The Development of A Simplified Energy Model to Use for The Energy Simulation

Modification of Wall Materials

This study evaluated four wall materials, selected based on their thermal performance. Each material was matched with equivalent wall types available in Revit to ensure accurate simulation. The U-values were calculated to evaluate the thermal resistance of each material, with lower U-values indicating better insulation and energy efficiency. The selected materials and their corresponding U-values are summarised as follows:

1. **Base Case**: 110mm thick brick walls with 20mm plaster on both sides (U-Value: 3.773 W/m²K, Table 1).
2. **Aerated Concrete (AAC)**: 150mm AAC blocks (U-Value: 1.3636 W/m²K, Table 2).
3. **Polyurethane Foam Insulation (PU)**: 50mm PU foam applied to brick walls (U-Value: 0.4415 W/m²K, Table 3).
4. **Insulated Concrete Forms (ICF)**: Concrete forms with insulation (U-Value: 0.3 to 0.1 W/m²K, Table 4).
5. **Vacuum Insulated Panels (VIP)**: High-performance panels (U-Value: 0.005 to 0.001 W/m²K, Table 5).

The U-values for these materials were calculated using the formula:

$$U=1/\text{Total R} \quad (1)$$

Where: U is the overall heat transfer coefficient (U-value) in W/m2K; Total R is the total thermal resistance of all layers combined in m2K/W.

The thermal resistance of each layer was calculated based on its thickness and thermal conductivity, while some U-values were directly sourced from reputable literature or manufacturer specifications to ensure accuracy. This methodology enabled a detailed comparison of the thermal performance of various wall types and their impact on overall energy efficiency. For example, the baseline case (brick wall with plaster) demonstrated the highest U-value, indicating the least insulation performance, whereas advanced materials like VIPs offered significantly lower U-values, showcasing superior energy efficiency. The following tables (Tables 1–5) summarise the U-value calculations for the baseline and alternative cases.

Table 1. U-Values for Baseline Case: Brick Wall
(110mm Thick Brick Walls, With 20mm Plaster on Both Sides)

Material	Thickness (mm)	k (Thermal Conductivity W/mK)	R (Thermal Resistance m²K/W)	References
Plaster	20	0.57	0.035088	(The Open University, 2023)
Brick wall	150	0.77	0.194805	
Plaster	20	0.57	0.035088	
		Total R (m²K/W)	0.264981	
		U-Value (W/m²K)		3.773861

Table 2. U-Value for Case 1: Aerated Concrete (AAC)
(150mm Thick Aerated Concrete Wall)

Material	Thickness (mm)	k (Thermal Conductivity W/mK)	R (Thermal Resistance m²K/W)	References
Plaster	150	0.2044	0.7333	(The Open University, 2023)
		U-Value (W/m²K)	1.3636	

Table 3. U-Value Calculation for Case 2: Polyurethane (PU) Foam Insulation (110mm thick brick walls, 20mm plaster at both sides, with 50mm external PV foam insulation)

Material	thickness (mm)	k (Thermal Conductivity W/mK)	R (Thermal Resistance m²K/W)	References
PU form	50	0.025	2	(The Open University, 2023)
Plaster	20	0.57	0.035087719	
Brick wall	150	0.77	0.194805195	
Plaster	20	0.57	0.035087719	
		Total R (m²K/W)	2.264980633	
		U-Value (W/m²K)		0.441504879

Table 4. U-Value for Case 3: Concrete Forms (ICF)

Material	U-Value (W/m²K)	Reference
Concrete Forms (ICF)	0.3 to 0.1	(Build It, 2023)

Table 5. U-Value for Case 4: Vacuum Insulated Panels (VIP)

Material	U-Value (W/m²K)	Reference
Vacuum Insulated Panels (VIP)	0.005 to 0.001	(Architect's Journal, 2023)

Cooling Load Simulation

After identifying the wall type with the lowest Energy Use Intensity (EUI) through energy analysis in Autodesk Insight 360, two simulation cases were conducted to compare the cooling load requirements and determine the potential energy reduction. The first case, serving as the baseline, used traditional brick walls with plaster on both sides (Table 3), while the second utilised VIP. For these simulations, the walls in the 3D model were modified accordingly: the first model featured traditional brick walls with plaster, and the second incorporated VIP.

RESULTS AND DISCUSSION

The results highlight the energy performance of the building when using four different wall materials, focusing on their thermal resistance and their impact on the building's cooling load, as summarised in Table 6. Autodesk Insight 360 simulations provided EUI values, enabling a comparison of the efficiency of each wall type. As a result, the closest U-values were used to match equivalent wall types in Revit, ensuring that the wall materials' properties, including composition and structure, aligned accurately. This approach provided reliable insights into their energy-saving potential.

Lower U-values indicate greater energy efficiency, with VIP demonstrating the best thermal performance among the materials analysed. ICF showed U-values ranging from 0.3 to 0.1, indicating good energy efficiency. VIP proved to be the most energy-efficient material

in the analysis, with U-values from 0.005 to 0.001. The energy efficiency of a material improves as its U-value decreases. These findings suggest that using VIPs can substantially enhance a building's energy efficiency.

Table 6. Wall Types and Equivalent Revit Wall Configurations

Item	Description	U-Value (W/m²K)	Equivalent Wall type in Revit	U-Value (W/m²K)
1	Base case: 110mm thick brick walls, with 20mm plaster on both sides.	3.773	N/A	N/A
2	Case 1: Aerated Concrete (AAC block 150mm)	1.3636	R-2 CMU wall	1.4142
3	Case 2: 110mm thick brick walls, 20mm plaster at both sides, with 50mm external PV foam insulation	0.4415	R-13 wood frame wall	0.4869
4	Case 3: Concrete Forms (ICF)	0.3 to 0.1	R-13 + R10 metal frame wall	0.3316
5	Case 4: Vacuum Insulated Panels (VIP)	0.005 to 0.001	R-38 wood frame wall	0.1545

Insight Output Report

An Insight output report, which includes the EUI values, was generated from the Energy Analysis in Insight 360. EUI stands for Energy Use Intensity and is a key measure of a building's energy efficiency. Expressed in units of kWh/m²/year, EUI represents the total energy consumed per unit area of the building over the course of a year. It is calculated by dividing the building's total annual energy consumption (in kilowatt-hours, or kWh) by its total floor area (in square meters, or m²) and then dividing that by the number of days in the year. EUI serves as a valuable metric for comparing the energy performance of different buildings, especially those with similar use types. Generally, buildings with lower EUIs are considered more energy-efficient, as they consume less energy per unit area compared to those with higher EUIs. The following Table 7 presents a summary of the wall-type modifications analysed in this study to assess the impact on the energy performance of the case study building.

Table 7. Summary of Analysis on The Modification of Wall Types

Item	Description	U-Value (W/m²K)	Equivalent Wall Type in Revit	U-Value (W/m²K)	EUI (kWh/m²/yr)
1	Base case: 110mm thick brick walls, with 20mm plaster on both sides.	3.773	N/A	N/A	218
2	Case 1: Aerated Concrete (AAC block 150mm)	1.3636	R-2 CMU wall	1.4142	208
3	Case 2: 110mm thick brick walls, 20mm plaster at both sides, with 50mm external PV foam insulation	0.4415	R-13 wood	0.4869	208
4	Case 3: Concrete Forms (ICF)	0.3 to 0.1	R-13 + R10 metal	0.3316	204
5	Case 4: Vacuum Insulated Panels (VIP)	0.005 to 0.001	R-38 wood	0.1545	203

As seen in Table 7, a lower U-value for a wall corresponds to greater energy savings for the building (Sofias et al., 2023). This relationship can be further explained using the Overall Thermal Transfer Value (OTTV) formula:

$$OTTV = SC \times (1 - F) \times U + SHGC \quad (2)$$

Where: SC = shading coefficient; F = fraction of opaque surface; U = overall heat transfer coefficient of the building envelope; SHGC = solar heat gain coefficient

The OTTV measures the overall heat transfer through the building envelope, helping to quantify the building's energy efficiency. This formula considers factors such as solar heat gain coefficient, shading coefficient, and U-value of the building envelope (Shah et al., 2023). The OTTV formula is used to determine the amount of heat that is transmitted through the building envelope, which in turn affects the amount of energy needed for heating or cooling the building. By applying the OTTV formula, designers and architects can optimise building designs to reduce energy consumption and improve energy efficiency.

In this study, the wall component contributes approximately 0.2% to 5% of heat transfer into buildings in tropical climates. Thus, modifying wall types in such climates is not expected to yield substantial energy savings. However, in a four-season climate, as shown in Figure 4, the impact of wall components on overall energy consumption becomes significantly higher. The variation in seasonal temperatures requires walls with greater insulation capacity to reduce heat loss during cold months and heat gain during warmer months. This underscores the importance of wall insulation in lowering a building's EUI.

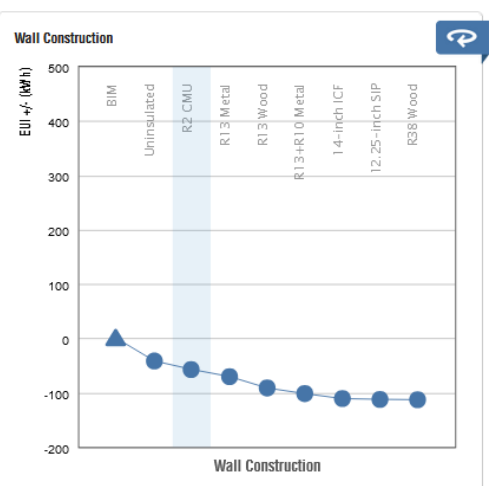


Figure 4. Wall Construction Curve Under 4 Seasons Climate Location

Based on Insight 360's Energy Analysis, four (4) wall types were assessed to identify the configuration that achieves the lowest EUI for the case study building. Among the tested materials, VIP demonstrated the lowest EUI, indicating superior energy efficiency. Consequently, VIP was selected for further analysis to quantify the impact of this material on the building's cooling load requirements, thereby providing insights into its energy-saving potential.

Cooling Load Simulation Result

To evaluate the cooling load reduction achieved with the VIP material compared to the baseline traditional brick walls, a detailed cooling load analysis was conducted. To understand the cooling needs across the building, the interior rooms were categorised by use and grouped into four zones, with each floor represented as one zone. This zoning strategy allows efficient

management of the air conditioning system and ensures each zone receives the appropriate cooling. The installed Variable Refrigerant Volume (VRV) system adjusts cooling output based on demand in each zone, enabling precise temperature control and improved energy efficiency. By conducting this cooling load analysis, the cooling requirements for each space were determined, ensuring that the air conditioning system was optimised for maximum efficiency and cost-effectiveness.

Table 3. Cooling Load Energy Simulation Report for Brick

Calculated Design Load [W]	User Design Load [W]	Calculated Design Load [W]	User Design Load [W]	Calculated Design Load [W]	User Design Load [W]
1	12143.75	21	5516.33	41	6712.13
2	4605.21	22	5515.95	42	5555.76
3	4597	23	5000.81	43	1409.57
4	12107.23	24	5002.31	44	3339.72
5	4924.13	25	6773.7	45	3774.33
6	4410.89	26	17213.17	46	8203.57
7	4410.94	27	3822.97	47	17579.15
8	4987.49	28	3418.32	48	7032.66
9	2716.91	29	1426.69	49	3478.24
10	2222.95	30	5597.09	50	3896.3
11	659.58	31	7962.09	51	5096.71
12	2575.12	32	16951.32	52	5160.39
13	2129.76	33	6713.72	53	5622.99
14	2810.49	34	3335.01	54	5622.37
15	4170.01	35	3820.63	55	17594.05
16	8106.39	36	5416.15	56	7031.51
17	3932.51	37	4919.2	57	5853.18
18	3332.94	38	4926.46	58	3509.42
19	17195.66	39	5414.14	59	3893.94
20	6830.58	40	16963.79	**TOTAL**	**477684.53**

Table 4. Cooling Load Energy Simulation Report for Vacuum Insulated Panels (VIP)

Calculated Design Load [W]	User Design Load [W]	Calculated Design Load [W]	User Design Load [W]	Calculated Design Load [W]	User Design Load [W]
1	14789.34	21	7335.2	41	7701.9
2	5874.96	22	7342.1	42	8235.5
3	5868.98	23	6431.3	43	2418.5
4	15014.93	24	6443.5	44	4686.4
5	4787.51	25	7728.1	45	5370.3
6	5277.57	26	21213	46	11533
7	5208.9	27	5385.9	47	22309
8	5100.64	28	4851.8	48	8144
9	3799.3	29	2502.6	49	5335.3
10	3350.79	30	8477.6	50	5173.6
11	1562.15	31	11356	51	6330.4
12	5200.72	32	21355	52	6509.4
13	3451.25	33	7564.8	53	7615.9
14	3853.25	34	5134.7	54	7672.8
15	7314.06	35	5137.3	55	22066
16	11793.97	36	7342.5	56	8268.9
17	5365.72	37	6234.6	57	8965.6
18	5070.83	38	6349.9	58	5301.4
19	21492.15	39	7311.4	59	5530.6
20	7752.92	40	21089	**TOTAL**	**364945.4**

The results from the HVAC Sizing Summary in Autodesk Revit indicate that the design cooling load for the brick wall is 477,684.53 W, while for the VIP wall, the design cooling load is 364,945.4 W. This demonstrates that the building with VIP walls requires significantly less cooling energy compared to the one with brick walls due to VIP's lower U-value (thermal transmittance). A lower U-value reduces the amount of heat transferred through the external walls, resulting in lower cooling energy needs. This means that better-insulated walls, such as VIP walls, require less energy to maintain a comfortable indoor temperature compared to traditionally insulated walls. By selecting well-insulated materials like VIP, cooling energy consumption can be significantly reduced, leading to cost savings and a reduced environmental impact.

CONCLUSION

The use of VIP as a wall material, rather than traditional brick walls, has demonstrated a significant reduction in cooling load and energy consumption. Research findings indicate that VIP walls have the lowest U-value and EUI value among the four wall types assessed, indicating superior insulation and energy efficiency. This improved insulation reduces heat transfer into the building, which translates into decreased cooling energy requirements and achieves a 23.6% reduction in cooling load. While the change in wall types did not yield substantial energy savings for the EUI in this particular case study, the impact of VIP walls becomes more pronounced in four-season climates, where temperature variations are greater. This highlights the importance of considering energy-efficient materials for potential energy savings and environmental benefits in diverse climates.

The study underscores the need to consider specific properties of wall materials, such as U-value, thermal admittance, solar absorption, and thickness, to maximise energy efficiency in buildings. The thermal properties of wall materials directly influence the cooling load required to maintain a comfortable indoor environment, making material selection critical in reducing energy consumption. Wall materials with a lower U-value provide better insulation, thereby decreasing heat transfer between indoor and outdoor spaces, which leads to lower cooling loads and reduced energy use. Conversely, materials with high solar absorption can increase heat gain, raising the cooling load.

Overall, these findings demonstrate the critical role of wall material selection in achieving optimal energy efficiency in buildings. By choosing materials that reduce cooling needs, energy consumption can be minimised, resulting in cost savings and a reduced environmental impact.

ACKNOWLEDGEMENTS

The authors would like to acknowledge financial support under UMSGreat (GUG0565-1/2022).

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THERMAL COMFORT AND ENVIRONMENTAL FACTORS IN CERTIFIED GREEN BUILDINGS: AN EVALUATION OF OCCUPANT EXPERIENCE

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Abstract
Occupant comfort is paramount in determining the overall performance and success of green buildings, but, in tropical climates, inside thermal conditions are very difficult to regulate effectively. This paper presents a study on thermal comfort and IEQ assessment for gold-certified GreenRE under the new GreenRE certification in Malaysia. A cross-sectional survey design was used, and the data were collected from 63 participants occupying the building, including professionals such as green managers, consultants, and developers. The survey parameters that were regarded in the study included thermal sensation, temperature perception, airflow perception, and humidity. Results indicated that 57.1% of the participants confirmed stable thermal comfort, while 28.6% mentioned an improved comfortable feeling. Temperature was found acceptable by 69.8% of the respondents, and 63.5% felt comfortable in the general thermal environment. However, 30.2% of participants preferred more air movement, which indicates a potential need for further development with regard to ventilation design. In the same way, although 47.6% of respondents experienced humidity characterised as "neutral," fully a fair proportion believed the air was slightly dry (23.8%), which may also indicate a need for better control of humidity. These findings suggest that the building would likely pass the major threshold standards of the existing green building certifications in terms of temperature and energy efficiency but could be improved in response to airflow distribution and humidity regulation. The study prioritises occupant-centred strategies for indoor environmental quality, given the importance of aligning the performance of green buildings with energy efficiency objectives and human comfort standards in tropical climates.

Keywords: *Indoor Environmental Quality; Airflow; Humidity; Occupant Comfort; Tropical Climate; Malaysia*

INTRODUCTION

In response to global sustainability efforts, the construction industry has increasingly adopted green construction practices (Lakhiar et al., 2024a; Zhao et al., 2019). Green buildings aim to reduce the environmental impact while improving the comfort and health of residents. These structures, integrated with sustainable materials, energy-efficient technologies and innovative design strategies, maximise the use of resources and reduce emissions, and contribute to a more sustainable construction environment (Muhammad et al., 2024). Green buildings are estimated to reduce energy consumption by 30 per cent, which brings significant benefits to the environment and economy (Franco et al., 2021; Lakhiar et al., 2024c). Green building certifications such as LEED, BREEAM and GBI in Malaysia provide a framework for assessing and certifying buildings on the basis of their sustainability performance (Ismail et al., 2024). These certifications are aimed at ensuring that green buildings meet high standards of energy efficiency, water conservation, and indoor environmental quality (IEQ) (Altomonte et al., 2019). One of the crucial components of these

certifications is the expectation that certified buildings provide superior thermal comfort and improve indoor air quality, thus promoting the well-being and productivity of the inhabitants. Despite the promises of green construction certificates, however, questions remain as to whether these buildings consistently provide the desired benefits, especially from the perspective of the occupants. Several studies reported differences between the expected and actual performance of green buildings, particularly in terms of thermal comfort (Gang et al., 2019; Li et al., 2021). Although energy efficiency and environmental sustainability are well-known documented results, the satisfaction of the inhabitants with the indoor environment is especially thermal comfort, has not consistently achieved (Ganesh et al., 2021; Khudzari et al., 2024). Thermal comfort is affected by several factors, including temperature, humidity, airflow, clothing, and the level of activity of residents, making it a complex and multifaceted problem (Lakhiar et al., 2024a; Mao et al., 2024).

In tropical regions such as Malaysia, where ambient temperatures and humidity are high, maintaining thermal comfort in green buildings is another challenge. Green building certification systems, such as GBI, are designed to address environmental sustainability but cannot fully address the specific climate challenges faced in these regions (Olanrewaju et al., 2022). Previous research suggests that green-certified buildings in tropical climates often struggle to provide consistent thermal comfort, mainly due to insufficient cooling and ventilation systems (Khan et al., 2019). These conclusions emphasise the need to conduct assessments focused on the inhabitants to assess whether green buildings really meet the comfort needs of their users in such challenging climates. While green buildings are certified on the basis of energy efficiency and environmental performance standards, the actual experience of residents often differs from the theoretical standards of certification systems (Qiang et al., 2023). Certification frameworks such as GBI, LEED and BREEAM emphasise energy savings and environmental sustainability but may overlook the subjective experience of the building's inhabitants, especially in terms of thermal comfort (Ascione et al., 2022). This disconnect is crucial because buildings that do not meet energy efficiency objectives but do not provide adequate thermal comfort are not considered to be fully successful (Ruiz et al., 2022). In tropical climates like Malaysia, where the challenge of maintaining thermal comfort is increasing, this problem becomes even more pronounced.

This study aims to address this gap through an empirical assessment of certified green buildings in Malaysia. Specifically, the research aims to evaluate whether the building is providing the promised thermal comfort benefits as stated in the green certification. This study will focus on key environmental factors such as temperature, humidity, airflow and occupants' clothing preferences to determine whether the building meets occupants' comfort standards. Previous studies focused mainly on the energy efficiency aspects of buildings (Azis et al., 2021; Gan et al., 2020; Lakhiar et al., 2023; Manzoor et al., 2021), but few studies examined the comfort levels experienced by inhabitants in the real world, especially in tropical climates. The study addresses this surveillance by providing an assessment of thermal comfort for occupants in a certified green building.

The aim of the study is fourfold:

- To evaluate the thermal comfort of green buildings by examining trends and comfort levels.
- To assess thermal sensation and temperature perception based on the current conditions of the occupant.
- To analyse the perception of airflow and humidity.

The study aims to achieve these objectives by contributing to a growing literature on green building performance and filling critical gaps by focusing on the experiences of occupants rather than focusing on energy efficiency metrics.

METHODOLOGY

This study adopts a cross-sectional survey design to assess thermal comfort and indoor environmental quality (IEQ) in a gold-certified GreenRE building in Malaysia. The research focuses on key environmental factors such as thermal sensation, temperature perception, airflow, and humidity as experienced by both occupants and visitors. Data was collected over a 15-day period, capturing occupant experiences at different times. However, responses were aggregated for analysis rather than examined on a daily basis. A total of 63 responses were obtained from a potential sample of 100 individuals, resulting in a 63% response rate. Participants included administrative staff, consultants, contractors, and other visitors, ensuring a diverse range of perspectives. In addition to thermal comfort factors, demographic data (age, gender, and occupation) were collected and analysed to explore potential influences on thermal comfort perceptions.

Survey Design and Data Collection

Table 1. Questionnaire Utilized in The Study

Factor	Sub Factor	Code	Questions	Scale
Thermal Comfort Trends	General Trend	TCT1	Since you first arrived at the office, how has your thermal comfort changed?	1. Staying the same 2. Deteriorating 3. Improving 4. Fluctuating
	Comfort in Environment	TCT2	How comfortable is the thermal environment in your office right now?	1. Comfortable 2. Slightly uncomfortable 3. Uncomfortable 4. Very uncomfortable
Thermal Sensation	Current Sensation	TS1	How do you feel right now in your office?	-3. Cold -2. Cool -1. Slightly cool 0. Neutral +1. Slightly warm +2. Warm +3. Hot
	Preferred Sensation	TS2	How would you prefer to feel?	-3. Much cooler -2. Cooler -1. Slightly cooler 0. No change +1. Slightly warmer +2. Warmer
Temperature Perception	Current Temperature	TP1	How do you find the temperature at this moment?	1. Acceptable 2. Slightly acceptable 3. Not acceptable 4. Slightly not acceptable
Airflow Perception	Airflow Perception	AP1	How do you feel about the airflow at this moment?	1. Completely unacceptable 2. Not acceptable 3. Slightly unacceptable 4. Acceptable 5. Perfectly acceptable
Humidity Perception	Indoor Humidity	HP1	How would you describe the indoor humidity in your building?	-3. Much too dry -2. Too dry -1. Slightly dry 0. Neutral +1. Slightly humid +2. Too humid +3. Much too humid

This study relies entirely on self-reported occupant perceptions rather than direct instrumental measurements of temperature, humidity, and airflow. While subjective assessments provide critical insights into occupant experiences, they may not always reflect actual environmental conditions. A structured questionnaire was developed based on standardised thermal comfort frameworks such as ASHRAE 55 and ISO 7730. The questionnaire was structured into five key areas: thermal comfort trends, thermal sensation, temperature perception, airflow, and humidity. The survey employed Likert-scale questions, allowing participants to report their perceptions using a graded response system. Table 1 shows the questionnaire utilised in the study.

Descriptive statistics were used to analyse the survey responses, with results presented as percentage distributions for each category. Furthermore, the relationship between thermal comfort trend and environmental factors is analysed through correlation analysis. Additionally, cross-tabulations were conducted to examine differences in perceptions across gender, age groups, and occupational roles. Furthermore, this study evaluates whether the building's thermal comfort aligns with GreenRE certification benchmarks, particularly in relation to temperature acceptability, airflow satisfaction, and humidity control. The findings aim to identify areas where occupant satisfaction may be improved while maintaining energy.

RESULTS

Demographic Distribution

The demographic characteristics of the participants are illustrated in terms of gender, age, and occupation.

a) Gender Distribution: The gender distribution of the participants shows a nearly equal representation between males and females. Males constitute 51% of the respondents, while females account for 49%, as demonstrated in Figure 1a. This balanced distribution ensures that both perspectives are well represented in the study, providing insights from both genders.
b) Age Distribution: In terms of age, 60% of the respondents were 30 years old and above, while 40% were under 30 years of age, as depicted in Figure 1b. This indicates a dominant representation of more experienced individuals in the sample, which could potentially influence their perceptions of thermal comfort and related environmental factors due to differing age-related sensitivities to temperature and comfort.
c) Occupation Distribution: Figure 1c illustrates the occupational backgrounds of the respondents, with the highest representation being "Green Manager," making up 21 participants. This is followed by consultants (17 participants), developers (6 participants), and contractors (4 participants). Other occupations included academician (2 participants), administrative staff (3 participants), and suppliers (6 participants). A smaller number of respondents were categorised under "Others" (5 participants). The diverse occupational backgrounds of the respondents suggest a wide range of expertise and viewpoints on thermal comfort, air quality, and environmental conditions in office spaces.

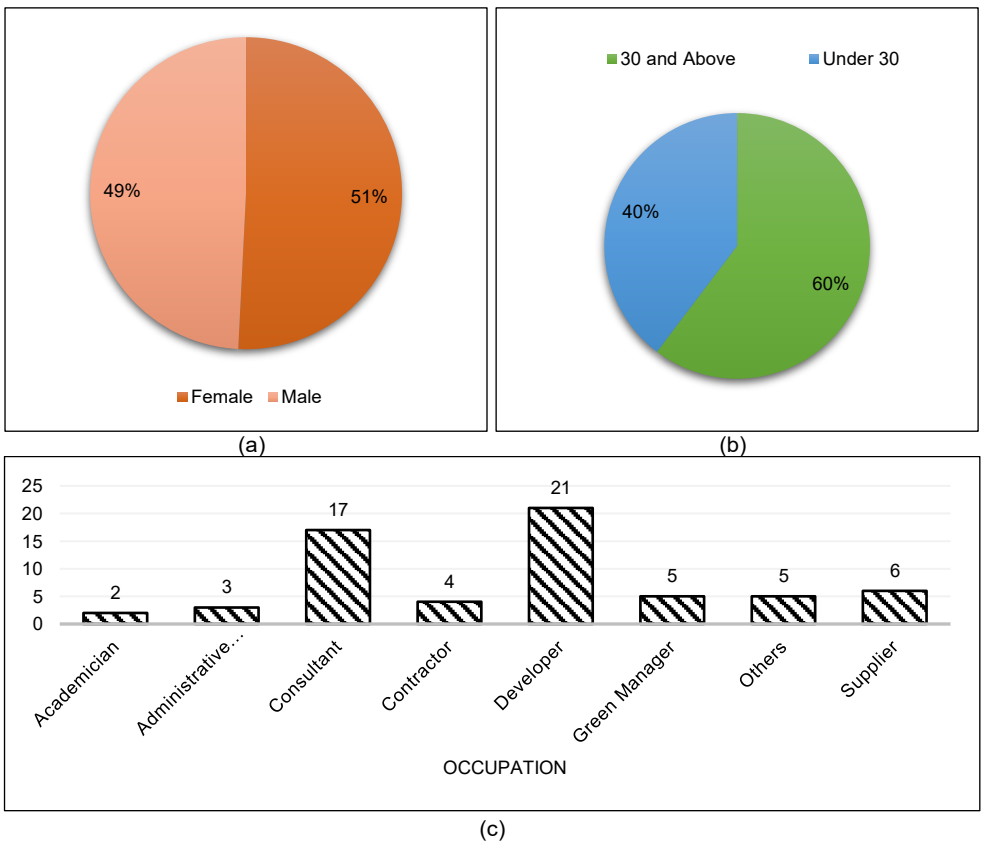

Figure 2. (a). Gender Distribution (b). Age Distribution (c). Occupation Distribution

Thermal Comfort Trends

The thermal comfort of participants in the office environment was evaluated using a structured questionnaire. The results are presented in two key areas: general trends and comfort in the environment.

a) General Trend: Responses to the question regarding changes in thermal comfort since arriving at the office revealed that 57.1% of participants indicated their comfort had remained stable, as shown in Figure 2. A further 28.6% reported an improvement in thermal comfort, suggesting that environmental conditions either improved or were perceived to improve over time. Conversely, 9.5% of respondents indicated fluctuating comfort levels, while a minority of 4.8% reported a deterioration in thermal comfort throughout their stay in the office.

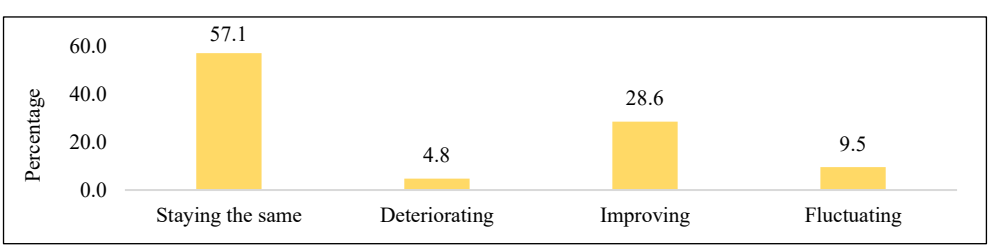

Figure 2. General Trend

b) Comfort in the Environment: The majority of participants (63.5%) reported feeling comfortable in the current thermal environment, as demonstrated in Figure 3. However, 20.6% rated their comfort as "slightly uncomfortable," indicating mild dissatisfaction. Additionally, 7.9% of respondents indicated they were uncomfortable, with an equal percentage reporting that they were very uncomfortable. These figures suggest that, while a majority of occupants are content with the current thermal conditions, there remains a significant proportion of individuals who experience varying degrees of discomfort.

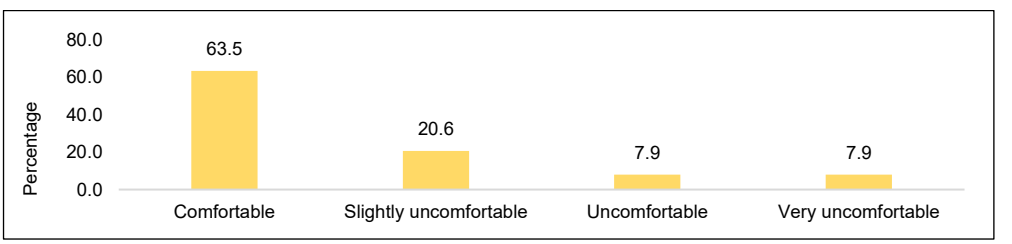

Figure 3. Comfort in Environment

Thermal Sensation

The responses to the thermal sensations from participants were analysed based on two dimensions: the current sensation and the preferred sensation. The results are outlined below.

a) Current Sensation: Participants were asked to assess their thermal sensation using a scale from -3 (cold) to +3 (hot). Figure 4 shows that most of the respondents (34.9%) selected -1, indicating a slightly cool sensation. Additionally, 27.0% of participants reported a neutral thermal sensation (0), signifying general comfort with the current conditions. A significant proportion (19.0%) rated their thermal sensation at -2, suggesting that they felt moderately cold. Only a small percentage (3.2%) of respondents reported experiencing warmth (+1 and +2), indicating that the thermal environment was generally perceived as slightly cool rather than warm.

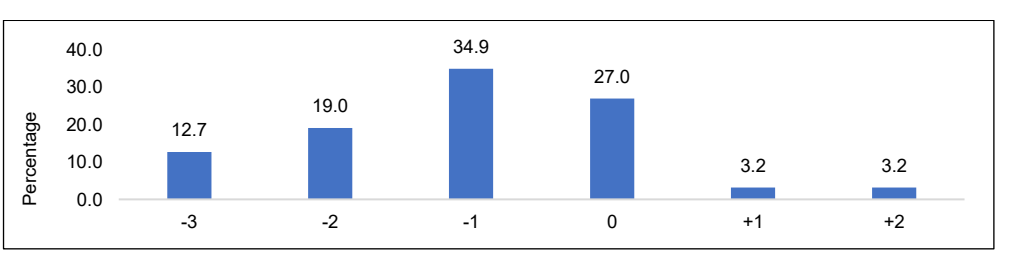

Figure 4. Current Sensation

b) Preferred Sensation: Figure 5 demonstrates the overall distribution of thermal sensation; 42.9% of participants rated their thermal sensation as neutral (0). A substantial proportion of respondents (36.5%) rated their sensation as slightly cool (-1), indicating that the prevailing conditions might have been perceived as cooler than optimal by a large portion of the group. Extreme responses were minimal, with only 6.3% of participants reporting sensations of cold (-3) or slight warmth (+1). A very small minority (3.2%) indicated warmth (+2), further reinforcing the trend toward cooler perceptions.

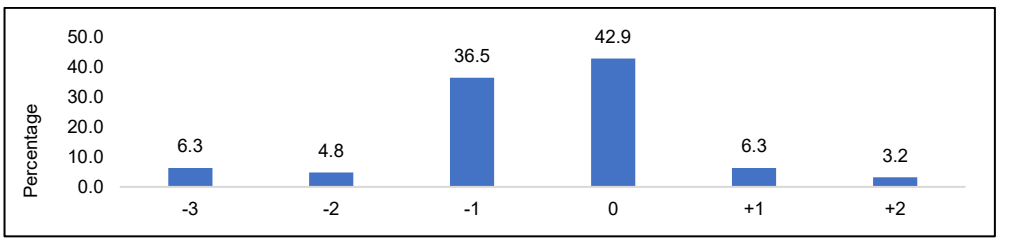

Figure 5. Preferred Sensation

Temperature Perception

The analysis of temperature acceptability was conducted based on participants' responses to the thermal environment in the office.

a) Current Temperature: The majority of respondents (69.8%) rated the thermal environment as "acceptable," indicating that the current temperature met the comfort expectations of most participants. A further 22.2% described the temperature as "slightly acceptable," suggesting minor discomfort but still within a tolerable range. However, a small portion of participants (3.2%) indicated that the temperature was "not acceptable," while 4.8% considered it "slightly not acceptable," reflecting a limited but noticeable level of dissatisfaction with the thermal conditions as shown in Figure 6.

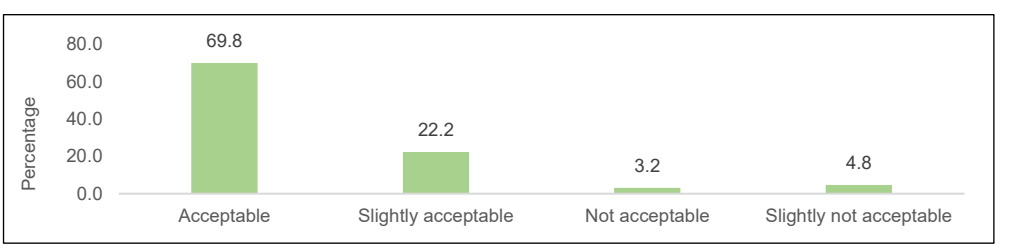

Figure 6. Current Temperature

Airflow Perception

The responses from participants regarding the acceptability of the current airflow were analysed. The results are presented below.

a) Airflow Perception: A majority of respondents (52.4%) rated the current airflow in the environment as "acceptable," indicating overall satisfaction with air movement. Additionally, 6.3% of participants found the airflow to be "perfectly acceptable." However, a portion of respondents (15.9%) rated it as "slightly acceptable," showing minor dissatisfaction. Smaller groups reported more significant discomfort, with 11.1% rating the airflow as "slightly not acceptable," 6.3% as "not acceptable," and 7.9% as "completely not acceptable." These findings, as shown in Figure 7, suggest that while the majority are content with the airflow, there is a considerable group that experiences varying levels of discomfort.

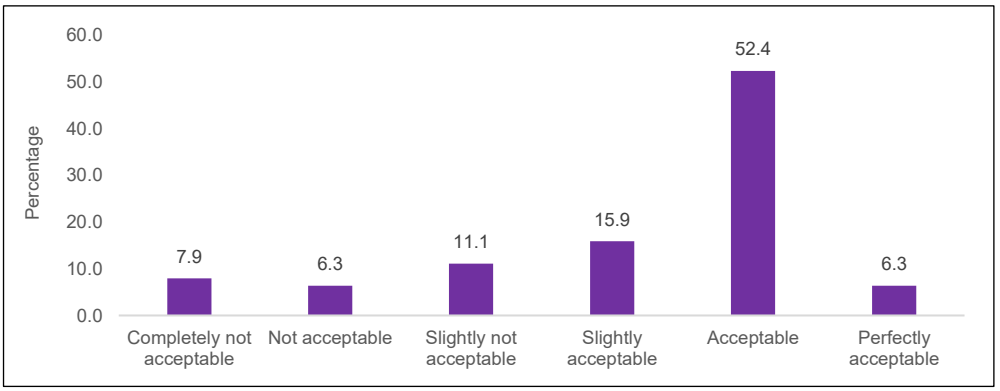

Figure 7. Airflow Perception

Humidity Perception

The responses from participants regarding their perception of indoor humidity were analysed. The results are summarised below.

a) Indoor Humidity: Participants were asked to rate their sensation of the current humidity on a scale from -3 (too dry) to +2 (too humid). Figure 8 shows that nearly half of the respondents (47.6%) indicated a neutral sensation (0), suggesting that the majority of participants found the humidity level to be comfortable. A notable portion (23.8%) reported a slightly dry sensation (-2), while 17.5% felt moderately dry (-1). Only 7.9% of participants expressed a preference for slightly more humid conditions (+1), and a very small minority (1.6%) indicated extreme dryness (-3) or higher humidity (+2).

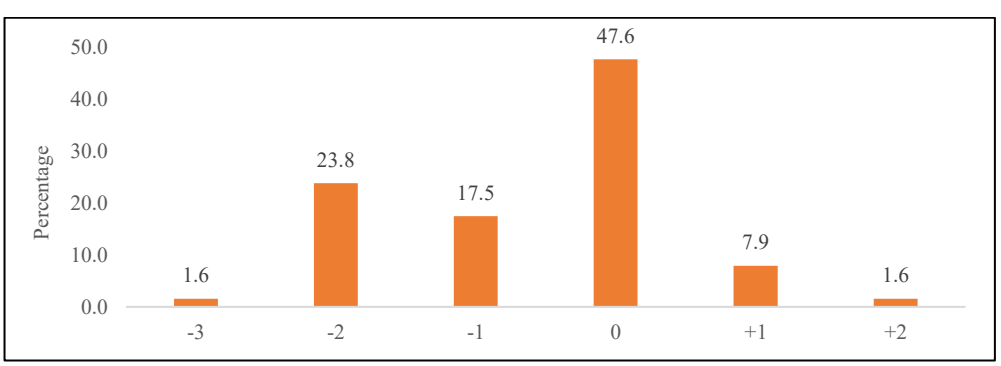

Figure 8. Indoor Humidity

Relationship Between Thermal Comfort and Environmental Factors

Thermal comfort is a key determinant of indoor environmental quality (IEQ), influencing occupant satisfaction and well-being. This study examines relationships between thermal comfort trends (TCT1, TCT2) and key environmental perceptions, including thermal sensation (TS1, TS2), temperature perception (TP1), airflow perception (AP1), and humidity perception (HP1). To analyse the relationship between thermal comfort trends and environmental perceptions, Spearman's Rho correlation analysis was conducted. The correlation coefficients and significance values are summarised in Table 2.

Thermal Comfort Trends and Thermal Sensation

Thermal sensation measures how occupants currently feel in relation to temperature. A moderate negative correlation between TCT1 and TS1 ($\rho = -0.645$, $p = 0.015$) indicates that as occupants experience fluctuations in comfort, their real-time sensation of warmth or coldness becomes unstable. Similarly, TCT2 and TS1 ($\rho = -0.528$, $p = 0.022$) confirm that greater consistency in thermal conditions leads to more stable sensations. However, the correlations between TCT1 and TS2 ($\rho = -0.124$, $p = 0.075$) and TCT2 and TS2 ($\rho = -0.032$, $p = 0.062$) are weak, suggesting that occupants preferred thermal sensations (cooler/warmer) do not significantly influence their overall comfort trends. This implies that real-time adjustments matter more than personal preferences.

Thermal Comfort Trends and Temperature Perception

Temperature perception has the strongest positive correlation with thermal comfort trends. The relationship between TCT1 and TP1 ($\rho = 0.742$, $p = 0.002$) and TCT2 and TP1 ($\rho = 0.693$, $p = 0.003$) confirms that when occupants perceive temperature as stable and acceptable, their overall comfort trends improve significantly. This highlights temperature regulation as the most critical factor for thermal comfort stability.

Thermal Comfort Trends and Airflow Perception

Airflow also plays a significant role in perceived comfort. The moderate positive correlations between TCT1 and AP1 ($\rho = 0.483$, $p = 0.012$) and TCT2 and AP1 ($\rho = 0.528$, $p = 0.011$) suggest that better airflow enhances comfort trends over time. This emphasises the importance of optimising ventilation and air circulation to maintain long-term comfort.

Table 2. Correlation Analysis of Thermal Comfort Trends and Key Environmental Factors

Items/Code		TCT1	TCT2	TS1	TS2	TP1	AP1	HP1
TCT1	Correlation Coefficient	1.000	0.725	-0.645	-0.124	0.742	0.483	0.252
	Sig. (2-tailed)		0.001	0.015	0.075	0.002	0.012	0.090
TCT2	Correlation Coefficient	0.725	1.000	-0.528	-0.032	0.693	0.528	0.301
	Sig. (2-tailed)	0.001		0.022	0.062	0.003	0.011	0.055

Thermal Comfort Trends and Humidity Perception

Humidity has a weaker influence on thermal comfort compared to temperature and airflow. The weak positive correlations between TCT1 and HP1 ($\rho = 0.252$, $p = 0.090$) and TCT2 and HP1 ($\rho = 0.301$, $p = 0.055$) indicate that humidity contributes slightly to comfort perceptions but is not a primary driver. While not as significant, maintaining balanced humidity levels can support overall comfort.

The analysis highlights temperature perception (TP1) as the strongest determinant of thermal comfort trends, followed by airflow perception (AP1). Managing these two factors effectively can stabilise occupants' comfort over time. While humidity perception (HP1) has a lesser impact, it still plays a supporting role in thermal satisfaction. Additionally, negative correlations with thermal sensation (TS1, TS2) indicate that real-time thermal conditions influence comfort more than personal preferences. This underscores the need to align actual

indoor conditions with occupant expectations. To enhance thermal comfort in green-certified buildings, facility managers should prioritise temperature control, optimise airflow, and maintain balanced humidity to create a comfortable and productive indoor environment.

DISCUSSION

This study offers valuable insights into the thermal comfort and indoor environmental quality (IEQ) perceptions of occupants in a gold-certified green building under the GreenRE certification framework. By analysing the responses of 63 participants, we explored how the building's design and systems align with the goals of green building standards, identifying both successes and areas needing improvement.

Demographic Distribution

The study's sample included nearly equal numbers of male and female respondents (51% and 49%, respectively), ensuring balanced insights into thermal comfort perceptions across genders. Research suggests that women often prefer slightly warmer environments than men, which could influence reported dissatisfaction with temperature (Indraganti & Humphreys, 2021). In terms of age, 60% of participants were 30 years or older, a group more sensitive to temperature fluctuations (Jowkar et al., 2020; Martins et al., 2022). This demographic may explain some of the reported discomforts. Participants' occupations varied widely, with "Green Managers" making up the largest group (33.3%), followed by consultants (27%) and developers (9.5%). This diversity indicates varied familiarity with green building systems, affecting expectations of comfort and IEQ.

Thermal Comfort Trends

Most participants (57.1%) reported stable thermal comfort, while 28.6% noted improvements, suggesting the building generally maintains conditions conducive to occupant well-being. This aligns with green building goals, particularly in energy-efficient HVAC management. However, 9.5% experienced fluctuating comfort, possibly due to localised inconsistencies in cooling or ventilation, common in green buildings with passive design elements (Duan et al., 2024). The 4.8% reporting deteriorating comfort highlights a need for personalised thermal control systems to address individual preferences. When assessing overall thermal comfort, 63.5% found the environment comfortable, while 20.6% reported slight discomfort. While this indicates effective thermal management for most, 14.3% of those who were uncomfortable or very uncomfortable suggested that localised climate control is needed, such as zoning systems or task-specific ventilation (Taheri, 2024). Green building standards like ASHRAE 55 aim for 80% occupant satisfaction, so further improvements in airflow or cooling strategies are needed to meet these expectations.

Thermal Sensation

The thermal sensation scale revealed that 34.9% felt slightly cool (-1), and 27% reported neutral comfort (0). However, 19% felt moderately cold (-2), indicating potential overcompensation by cooling systems in some areas. This highlights the need for personalised climate control, as occupants have varying metabolic rates and clothing preferences (Li et al., 2021). Over time, 33.3% reported feeling colder, suggesting a cooling drift in HVAC systems,

which can lead to discomfort in open-plan spaces (Al-Atrash et al., 2020). Regular monitoring and adjustments are needed to maintain stable thermal conditions.

Temperature Perception

Temperature acceptability was high, with 69.8% finding the environment acceptable and 22.2% rating it slightly acceptable. This suggests the building meets ISO 7730 and ASHRAE 55 recommendations. However, 8% of dissatisfied occupants highlight individual variability in temperature preferences.

Airflow Perception

While 52.4% found airflow acceptable, 40.7% reported dissatisfaction, indicating a need for increased air circulation in certain areas. ASHRAE 55 recommends air velocities of 0.1–0.3 m/s in offices, particularly in tropical climates where humidity affects heat perception. Task-based ventilation or adjustable air vents could address these concerns without compromising energy efficiency (Boulmaiz et al., 2022).

Humidity Perception

Most participants (47.6%) reported neutral humidity, aligning with ISO 7730's 30–60% range. However, 23.8% found the air slightly dry, suggesting improved humidity control is needed to prevent discomfort in air-conditioned spaces (Paolini et al., 2017).

Relationship Between Thermal Comfort Trends and Environmental Perceptions

Statistical analysis showed strong correlations between temperature perception and thermal comfort trends ($\rho = 0.742$, $p = 0.002$), emphasising the critical role of temperature regulation. Airflow perception also correlated moderately ($\rho = 0.528$, $p = 0.011$), while humidity played a smaller role ($\rho = 0.301$, $p = 0.055$). Thermal sensation negatively correlated with comfort trends ($\rho = -0.645$, $p = 0.015$), indicating fluctuations in comfort affect real-time sensations. These findings highlight the need for adaptive HVAC systems that adjust dynamically to occupant feedback, ensuring stable comfort conditions. This study underscores the importance of balancing energy efficiency with occupant-centered design in green buildings. While the building generally meets thermal comfort standards, improvements in airflow distribution and humidity control are needed. Future designs should prioritise adaptive HVAC systems and personalised climate control to enhance occupant satisfaction in tropical climates.

CONCLUSION

This study assessed occupant thermal comfort and indoor environmental quality (IEQ) in a gold-certified GreenRE building in Malaysia, focusing on evaluating thermal comfort trends, thermal sensation, temperature perception, airflow, and humidity preferences. The findings revealed that while the building generally met thermal comfort expectations, specific areas required improvement to enhance occupant satisfaction. The majority of occupants (57.1%) reported stable thermal comfort, and 63.5% found the overall thermal environment comfortable. However, 14.3% of occupants experienced discomfort, highlighting the need for

localised climate control solutions. Regarding thermal sensation, 34.9% of participants felt slightly cool, and 19.0% felt moderately cold, indicating potential overcooling in some areas. The preferred thermal sensation showed that 36.5% of occupants desired a slightly warmer environment. These results emphasise the need for personalised climate control systems to accommodate individual preferences. In terms of temperature perception, 69.8% of respondents found the temperature acceptable, and 87.3% were satisfied with the overall thermal environment. However, 30.2% of occupants desired increased air movement, and 23.8% found the air slightly dry, indicating the need for improved airflow distribution and humidity regulation. The correlation analysis further highlighted the relationships between thermal comfort trends and environmental perceptions. Thermal sensation had a moderate negative correlation with thermal comfort trends ($\rho = -0.645$, $p = 0.015$), indicating that fluctuations in comfort lead to greater deviations in real-time thermal sensations. Temperature perception had the strongest positive correlation with thermal comfort trends ($\rho = 0.742$, $p = 0.002$), followed by airflow perception ($\rho = 0.528$, $p = 0.011$). Humidity perception had a weaker but notable correlation ($\rho = 0.301$, $p = 0.055$). These results emphasise the critical role of temperature regulation and the supporting role of airflow and humidity in maintaining thermal comfort. Therefore, while the building aligned with green certification standards, further enhancements were needed to optimise occupant comfort. To ensure that green-certified buildings achieve both energy efficiency and occupant well-being, adaptive environmental control strategies, such as personalised ventilation and dynamic humidity regulation, should be prioritised. Future research should explore occupant-centered approaches to climate adaptation in tropical buildings, ensuring that sustainability efforts align with human comfort needs.

ACKNOWLEDGEMENTS

The research was supported by the Ministry of Higher Education (MoHE) through the Fundamental Research Grant Scheme (FRGS/1/2021/TK0/UTAR/02/34).

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BUILDING INFORMATION MODELING IMPLEMENTATION IN THE INDONESIAN CONSTRUCTION INDUSTRY: A SYSTEMATIC LITERATURE REVIEW

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Abstract
Building Information Modeling (BIM) implementation is crucial for enhancing project performance in the construction industry. This study systematically reviews the literature on BIM practices in Indonesia's construction industry to provide insights into its current status and implementation barriers. Prior studies were analysed, focusing on four themes: successful BIM implementations, innovative applications, implementation barriers, and industry readiness. Findings reveal significant implementation gaps, particularly in cost-benefit analyses, readiness assessments at both project and market levels, and implementation discrepancies between large and small enterprises. The review underscores the need for strategic investment in workforce training, educational initiatives, and infrastructure to improve BIM proficiency. This study is a resource for scholars, practitioners, and policymakers to advance BIM integration in Indonesia. Addressing these barriers and fostering stakeholder collaboration can drive greater efficiency, sustainability, and innovation in Indonesia's construction industry. The review outlines the necessary steps toward comprehensive, industry-wide BIM implementation.

Keywords: *Building Information Modeling; Construction Industry; Indonesia; Systematic Literature Review*

INTRODUCTION

The Architecture, Engineering, and Construction (AEC) industry faces challenges such as cost overruns, time delays, quality issues, and communication gaps, all of which impact project success and efficiency (Jallow, Renukappa, & Suresh, 2023). To address these persistent issues, Building Information Modeling (BIM) has emerged as a transformative tool in construction, enabling digital representations of buildings' physical and functional characteristics. BIM facilitates collaboration among stakeholders across the project lifecycle, from design to construction and operation, thereby enhancing design accuracy, coordination, and resource management (Alwan & Jones, 2020; Rastogi, Kumar, & Bansal, 2023; Chong, Fans & Lo, Piroozfar, Farr, & Elsawahli, 2021). Consequently, BIM has become standard practice in many developed countries, demonstrating measurable benefits in cost savings, time efficiency, and quality improvements (Shehzad, Ibrahim, Yusof, Khaidzir, Shawkat & Ahmad, 2022).

In developing countries like Indonesia, however, BIM implementation remains limited due to constraints such as high initial implementation costs, a shortage of skilled professionals, and resistance to industry-wide change (Jones & Alwan, 2020; Zhou, Liu & Wang, 2023). The Indonesian construction industry—a key driver of the national economy, often experiences project delays, budget overruns, and quality deficiencies (Nugroho,

Ramadhani & Susanti, 2023; Pratama & Tjandra, 2020; Putri & Saptari, 2021; Rani, Al-Mohammad, Rajabi & Rahman, 2023; Van Roy & Firdaus, 2020). These ongoing challenges underscore BIM's potential to improve project delivery and overall industry performance, positioning it as a promising solution for Indonesia's construction industry (Nugroho et al., 2023; Rani et al., 2023; Utomo & Wicaksono, 2021; Fitriani, Budiarto, Ajayi & Idris, 2019; Hermawan & Hidayat, 2020).

Despite these advantages, BIM implementation in Indonesia is still in its early stages, and a thorough understanding of BIM implementation, associated barriers, and strategies to facilitate broader implementation is essential for accelerating its uptake (Santoso & Yuwono, 2023; Firdaus & Van Roy, 2020; Nugraha, Syahreza & Widjaja, 2023; Pratama & Wibowo, 2020; Wahyudi & Saptari, 2021). Previous studies have explored various aspects of BIM in Indonesia, including government initiatives, industry readiness, and successful case studies (Rani el al., 2023; Van Roy & Firdaus, 2020; Nugraha et al., 2023; Pratama & Wibowo, 2020). These studies highlight BIM's benefits and unique barriers within the Indonesian context, such as limited awareness and technical skills among industry professionals (Nugraha et al., 2023; Wahyudi & Saptari, 2021).

A systematic literature review (SLR) can provide a comprehensive overview of BIM implementation in Indonesia by synthesising existing research across four main themes: successful BIM case studies, potential applications, barriers to implementation, and industry readiness. Such a review identifies factors influencing BIM implementation, highlights barriers, and offers recommendations to guide stakeholders in Indonesia's construction industry toward broader BIM implementation (Nugroho et al., 2023; Pratama & Tjandra, 2020; Van Roy & Firdaus, 2020; Wicaksono & Saptari, 2021; Santoso et al., 2021).

Research on BIM implementation in other developing countries reveals barriers such as high costs, limited workforce skills, and organisational resistance, which also affect Indonesia (Nugroho et al., 2023). In Indonesia, where construction challenges like project delays and quality issues persist, BIM has shown the potential to drive significant improvements yet remain underutilised. For instance, a case study on a commercial project in Jakarta demonstrated cost and time savings through BIM's real-time tracking and data integration capabilities (Nugroho et al., 2023), and a small-scale residential project in Bali highlighted implementation barriers related to limited budgets and technical infrastructure, underscoring disparities in BIM's benefits across project scales (Fitriani et al., 2019).

This study systematically reviews the literature on BIM practices in Indonesia's construction industry to provide insights into its current status and implementation barriers. By focusing on context-specific barriers and industry readiness, this study offers a roadmap for stakeholders in Indonesia to enhance BIM implementation and integration. The study findings are intended to guide future research, policies, and practice, contributing to a more robust and effective framework for BIM implementation in Indonesia. This study contributes to the growing body of BIM literature in developing countries, providing actionable insights for policymakers, researchers and practitioners. By addressing identified gaps in BIM implementation and fostering industry-wide collaboration, Indonesia's construction industry can leverage BIM to enhance efficiency, sustainability, and innovation. This study provides a structured, context-specific analysis of BIM implementation in Indonesia, offering a unique contribution by identifying barriers and strategies aligned with Indonesia's socio-economic

and industry conditions. This review thus bridges existing literature gaps and proposes tailored solutions for Indonesia's construction industry.

METHODOLOGY

This study adopts the SLR methodology to synthesise existing research on BIM implementation within Indonesia's construction industry. The SLR approach was chosen for its structured and replicable process, facilitating a comprehensive assessment of the literature while minimising research bias (Santos & Gama, 2022). This method captures both broad trends in BIM implementation and specific regional barriers, providing a nuanced understanding of the factors influencing BIM implementation in Indonesia's unique construction landscape.

Identification of Prior Studies

Figure 1 presents a flowchart of the study selection process, illustrating each stage from initial identification to final inclusion, providing a visual representation of the systematic approach used in this review. The study selection process followed a rigorous, systematic approach based on the PRISMA framework, ensuring transparency and reproducibility. The process began with an initial search in Scopus using keywords "Building Information Modeling," "BIM," and "Indonesia," and focusing on studies published between 2015 and 2023 to ensure relevance. Titles and abstracts were then screened to exclude studies unrelated to BIM in Indonesia's construction industry. Following this initial filtering, inclusion and exclusion criteria were applied, focusing on studies conducted in Indonesia, written in English, and empirically examining BIM implementation. Duplicates, review articles, and irrelevant studies were removed. In other words, only empirical studies in English addressing BIM in Indonesia were included, excluding non-English studies, duplicates, and review articles (Zhou et al., 2023). A full-text review of the remaining studies was conducted to ensure they met quality and relevant standards for in-depth analysis. The CASP (Critical Appraisal Skills Programme) checklist was utilised to evaluate the quality and methodological rigour of the selected studies (Saka & Chan, 2023).This systematic selection process resulted in a final set of studies that examine BIM implementation in Indonesia's construction industry. Ultimately, 21 studies met the inclusion criteria.

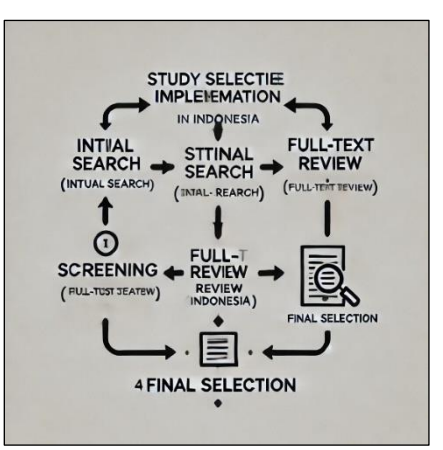

Figure 1. Study Selection Process for Systematic Literature Review on BIM Implementation in Indonesia

Data Analysis

The extracted data were categorised into four thematic clusters: successful BIM case studies, potential applications of BIM, barriers to BIM implementation, and industry readiness for BIM, contributing to a comprehensive understanding of BIM's state in Indonesia (Nugroho et al., 2023).

A thematic analysis was then conducted to identify common patterns, barriers, and benefits associated with BIM implementation, ensuring the reliability and validity of the selected studies through the CASP checklist (Berg, Zhai & Zhai, 2023; Utomo, Putra, Farrel & Novandy, 2023).

To minimise bias, studies were sourced from multiple databases, and strict selection criteria were applied. However, the research acknowledges limitations such as the limited number of studies available on BIM implementation in Indonesia and the variation in methodologies across studies, which may lead to inconsistencies in findings. Additionally, while the majority of sources were academic, the limited inclusion of industry reports may introduce gaps in understanding.

RESULTS

This SLR analysed 21 studies that met the inclusion criteria, organised around four primary themes: case studies, potential applications of BIM, barriers to BIM implementation, and industry readiness for BIM implementation in Indonesia. This section provides a thematic discussion of the findings, highlighting barriers and opportunities that characterise BIM's role in Indonesia's construction industry.

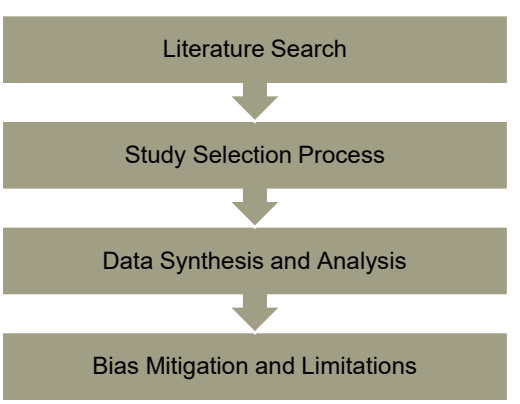

Figure 2. Systematic Literature Review Process

The reviewed studies reveal the use of diverse BIM software tools in Indonesian construction projects. Autodesk Revit is commonly applied in commercial projects for its robust design coordination, while Tekla is frequently used in prefabrication for precise structural detailing. Heritage preservation projects integrate laser scanning techniques with BIM models to create accurate digital representations, aiding conservation efforts. These examples illustrate Indonesia's adaptive approach to selecting BIM tools based on project demands, showcasing the flexibility of BIM applications to meet diverse project requirements.

Case Studies of BIM Implementation

Several studies provide detailed analyses of BIM implementation in Indonesian projects, illustrating practical applications and benefits. For example, a study on a large-scale commercial project documented significant improvements in budget control and labour productivity through enhanced time tracking and data integration (Nugroho et al., 2023). In another study, BIM facilitated conservation efforts for heritage sites in Yogyakarta by generating precise digital representations of historic buildings (Santoso, Purnama & Hidayat, 2021; Yoga, Oktaviana, Wahyu & Adriyati, 2022). These case studies underscore BIM's potential to streamline project management, optimise resource allocation, and support long-term asset maintenance in various sectors of Indonesia's construction industry.

Potential Application of BIM

The literature identifies various promising BIM applications to advance construction practices in Indonesia. For example, BIM enables better design coordination in prefabrication, reducing material waste and accelerating project timelines. Other studies illustrate BIM's role in promoting sustainable practices in green government projects, where BIM integration with web-based systems improves environmental metrics like waste management and landscape design (Zhou et al., 2023; Aryanti, Busono & Siswoyo, 2023; Fitriani, Wijayanto & Sutrisno, 2023). Additionally, BIM has proven effective for slope stability and risk mitigation in high-risk areas like Aceh, highlighting its adaptability to Indonesia's diverse geographical challenges. Implementing BIM in disaster-prone areas could improve project resilience, establishing BIM as a transformative tool for efficiency and safety in the Indonesian context.

Barriers to BIM Implementation

Despite its advantages, BIM implementation in Indonesia faces significant barriers. Barriers include high initial costs, a shortage of skilled professionals, and resistance to change. Financial investments required for BIM software, training, and infrastructure are prohibitive for smaller firms (Van Roy & Firdaus, 2020; Siregar, Yuliani & Prabowo, 2023; Mostafa, Ali, Badr & Salah, 2023). The shortage of professionals with BIM expertise presents another critical barrier, emphasising the need for targeted education and training programs (Sholeh, Nurdiana, Setiabudi & Suharjono, 2023). Organisational factors, such as low stakeholder awareness and reluctance to adopt new technologies, further hinder implementation. Addressing these barriers will require strategic investments in workforce development, awareness programs, and financial support mechanisms (Al-Mohammad, Haron, Aloko & Rahman, 2023; Wicaksono, Juliastuti & Arumsari, 2023). Government-subsidised training programs and financial incentives for SMEs could bridge the readiness gap, promoting a more inclusive environment for BIM implementation across the industry.

BIM Readiness in The Industry

BIM readiness varies across Indonesian construction firms. Larger firms demonstrate higher readiness levels due to greater access to resources and technology, while SMEs face financial and technical constraints (Putra, Nugraha & Prasetya, 2023). Surveys among contractors in Palembang indicate that larger firms are better positioned to implement BIM, whereas SMEs often lack the necessary technology and training (Siregar, Prasetya & Fitriani,

2023). Although BIM requires substantial initial investment, financial analyses suggest that the long-term benefits, including improved efficiency and cost savings—justify these expenses. These findings highlight the importance of targeted support for smaller firms to close the readiness gap and foster broader BIM implementation (Yoga et al., 2022).

Synthesis of Findings

The synthesis of findings reveals a complex landscape for BIM implementation in Indonesia. Although BIM's benefits in improving project efficiency, sustainability, and safety are well-documented, significant barriers impede its widespread use. Strategic investments in training, education, and infrastructure are essential to develop a skilled workforce capable of implementing BIM. Leadership initiatives, stakeholder collaboration, and financial incentives can foster enhanced organisational readiness to reduce implementation costs. With coordinated efforts across the industry, Indonesia's construction industry could leverage BIM to achieve higher standards in project delivery, environmental responsibility, and innovation (Zhang, Li & Setiawan, 2022).

Table 1. Summary of Findings, Barriers, and Recommendations for BIM Implementation in Indonesia's Construction Industry

Theme	Findings	Barriers	Recommendations
BIM implementation in case studies	- Improved budget control, labour productivity, and heritage management (Nugroho et al., 2023; Saka & Chan, 2023). - Effective in large-scale projects and heritage conservation (Utomo et al., 2023).	- Limited documentation across project types. - Implementation gap between large and small projects (Zhou et al., 2023).	- Expand case study documentation. - Encourage BIM use in small projects.
Potential BIM applications	- Promising for prefabrication, sustainability and risk management (Berg et al., 2023). - Enhances safety in disaster-prone areas (Zhang et al., 2022) (Santos & Gama, 2022).	- Limited real-world applications in high-risk areas. - Low awareness of BIM's environmental benefits (Zhou et al., 2023).	- Promote BIM in sustainable projects. - Raise awareness of BIM's role in risk mitigation.
Barriers to BIM implementation	- High costs for software, training, and infrastructure (Nugroho et al., 2023). - Shortage of skilled BIM professionals (Saka & Chan, 2023).	- Financial constraints for SMEs. - Industry resistance to change (Utomo et al., 2023).	- Provide subsidies and financial support. - Develop targeted training programs.
Industry readiness	- Larger firms show higher readiness due to resources (Berg et al., 2023). - SMEs struggle with limited capacity and support (Santos & Gama, 2022).	- Readiness gap between large firms and SMEs. - Lack of national BIM standards (Zhou et al., 2023).	- Establish national BIM standards. - Enhance SME support programs.
Policy and government support	- Policies are critical for implementation (Nugroho et al., 2023). - Need for financial incentives and grants (Utomo et al., 2023).	- No mandatory regulation for BIM. - Limited government initiatives (Saka & Chan, 2023).	- Implement tax breaks and training incentives. - Develop policies for public project implementation.
Future research directions	- Need for long-term studies on BIM impact (Berg et al., 2023). - Integration with IoT and AI for efficiency (Santos & Gama, 2022).	- Lack of data on long-term benefits. - Readiness assessments remain underexplored (Zhou et al., 2023).	- Conduct longitudinal BIM studies. - Explore IoT and AI integration for sustainable construction.

DISCUSSION

The synthesised literature offers insights into BIM implementation in Indonesia's construction industry, covering themes of case studies, potential applications, barriers, and readiness strategies. Table 1 summarises the findings, barriers, and recommendations identified in this study regarding BIM implementation in Indonesia's construction industry. Each thematic area, ranging from practical case studies and potential applications to barriers, industry readiness, policy implications, and future research directions, is outlined with specific insights. This summary highlights critical obstacles, such as high costs and skill shortages, as well as opportunities for improvement through government support, workforce training, and technological integration. The recommendations provided in the table aim to guide policymakers, industry practitioners, and researchers in fostering a supportive environment for BIM implementation across diverse project scales and sectors in Indonesia.

Successful Case Studies

The reviewed studies present case studies that demonstrate BIM's tangible benefits in Indonesian construction, such as improved budget control, labour productivity, and cultural heritage management. For instance, BIM application in large infrastructure projects has improved budget control and labour efficiency through enhanced data integration and real-time tracking (Sukmono, Putra, Bashit & Nugraha, 2021; Santosa, Yudono, Adhitama, 2023). BIM's use in managing heritage sites in Yogyakarta further illustrates its value in preservation efforts by generating detailed digital representations of historical structures (Santoso et al., 2021).

Potential Applications of BIM

Beyond conventional uses, BIM offers the potential for prefabrication, sustainable building, and safety improvements in challenging geographical areas (Hróbjartsson, Lalu, Li, Loder, Mayo-Wilson, McDonald & Moher, 2021). BIM facilitates design coordination, minimises waste, and shortens construction timelines in prefabrication. In sustainable building, BIM integration with web-based information systems has led to significant advancements in government projects (Zhou et al., 2023; Yoga et al., 2022). Its application in slope stability analysis in disaster-prone areas like Aceh further emphasises BIM's role in risk management (Fitriani et al., 2023).

Barriers to Implementation

As observed in other developing countries, barriers such as high costs, limited skilled personnel, and resistance to change hinder BIM implementation in Indonesia. Studies from Malaysia and India highlight similar barriers, with government-led initiatives and training programs proving effective in overcoming these barriers (Sholeh et al., 2023; Al-Mohammad et al., 2023). Adopting similar measures could improve BIM readiness, especially for SMEs in Indonesia.

Strategies for Enhancing Readiness

Enhancing BIM readiness across the industry is critical. Larger firms are better prepared for BIM due to resource access, while SMEs face readiness gaps due to limited capacity (Siregar et al., 2023; Pratama, Utami & Rahardjo, 2022). Although BIM entails high initial costs, the long-term benefits justify implementation. Targeted support for SMEs, such as government-backed training and incentives, could bridge this gap (Putra et al., 2023).

Integration of Findings

The findings underscore BIM's transformative potential in Indonesia's construction industry. Case studies demonstrate practical benefits, while innovative applications highlight BIM's versatility in addressing industry challenges. However, realising BIM's full potential requires addressing implementation barriers and improving readiness across all sectors. Strategic investments in training, infrastructure, and stakeholder collaboration are essential to maximising BIM's benefits.

Policy Implications and Government Support

Government policies play a crucial role in facilitating BIM implementation. Regulatory frameworks and financial incentives, as seen in other countries, have successfully promoted digital transformation in construction. In Indonesia, similar policy initiatives, including subsidised BIM training, tax incentives for technology adoption, and grants for SMEs, could enhance industry-wide BIM implementation, particularly benefiting SMEs that face financial and technical barriers. Such policies lower initial costs and support workforce skill development, fostering a robust environment for BIM integration.

CONCLUSION

This study systematically reviews the literature on BIM practices in Indonesia's construction industry to provide insights into its current status and implementation barriers. The study findings highlight the need for targeted workforce training, financial support for SMEs, and the development of national BIM standards to facilitate a gradual, impactful shift toward comprehensive BIM implementation. These recommendations aim to enhance efficiency, sustainability, and resilience across Indonesia's construction industry. This study provides insights into BIM implementation, revealing promising applications alongside implementation barriers. Case studies demonstrate successful BIM implementation, improving budget control, labour productivity, and heritage asset management. These examples illustrate BIM's potential to streamline construction processes, improve collaboration, and support sustainable project outcomes. Beyond conventional uses, BIM shows promise for advancing Indonesian construction practices through prefabrication, green building initiatives, and enhanced safety, particularly in disaster-prone regions.

However, high initial costs, limited skilled personnel, and industry resistance to change remain substantial barriers. Addressing these barriers requires strategic investment in training, education, and organisational initiatives to build a supportive environment for BIM. To leverage BIM's potential, the Indonesian construction industry should adopt targeted strategies, including enhanced workforce development, organisational change efforts, and the

establishment of foundational infrastructure. Future research should prioritise assessing BIM's impact on productivity and cost efficiency across diverse Indonesian construction projects to offer measurable benchmarks. Research into policy interventions, such as subsidies or mandatory BIM standards, could reveal effective practices to accelerate BIM implementation. Furthermore, BIM readiness assessments at both project and market levels remain underexplored and would benefit from developing a comprehensive, Indonesia-specific readiness framework. Longitudinal studies tracking BIM implementation over time would offer insights into sustained impacts on project performance and industry adaptation. There is also a need for cross-sector studies to identify the best practices and transferable strategies across different construction project types, supporting broader BIM implementation in Indonesia.

ACKNOWLEDGEMENTS

The researchers would like to express their heartfelt appreciation to the Universitas Muhammadiyah Aceh for their generous support, which made the publication of this study possible. Their commitment to advancing research in our field has been invaluable. We also wish to thank all those who contributed to this study.

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BIBLIOMETRIC REVIEW OF BUILDING INFORMATION MODELLING (BIM) FOR ROAD INFRASTRUCTURE MANAGEMENT

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Abstract
Building Information Modelling (BIM) is an emerging and transformative digital system that addresses the challenges of conventional road infrastructure management by improving data integration, visualisation, and collaboration throughout the lifecycle. This study conducted a comprehensive bibliometric review of BIM for road infrastructure management to show the current state of the art, knowledge gaps, and future research directions. The leading publications, collaborative networks and key research themes were identified. A bibliometric analysis was carried out by utilising data from the Scopus database, which covered publications from 2010 to August 2024. The PRISMA protocol was employed for the bibliometric review process. Furthermore, VOSviewer and Biblioshiny bibliometric tools were employed to analyse publication trends, citations, author and country collaboration and production, and thematic mapping and Evolution. This study highlights a growing interest in BIM for road infrastructure management but is limited to specific geographical areas. This study also highlights gaps and future research directions on integrating BIM with emerging technologies, addressing regional adoption challenges in developing countries, and highlighting the importance of international collaborations for sustainable and practical solutions.

Keywords: *BIM; Road Management; Bibliometric analysis; 4th Industrial Revolution; Thematic Mapping; Thematic Evolution*

INTRODUCTION

Road infrastructure is vital for the socio-economic growth of the countries for providing access to services, work, and markets (Percoco, 2016; Weiss et al., 2018; Nawir et al., 2023). It is also the heart of an integrated transportation system and vital for each country's quality of life, competitiveness and sustainable development (Cafiso et al., 2016). Road infrastructure management is a systematic process of planning, designing, constructing, operating, and maintaining road networks to provide a safe and efficient transportation system(Matsumoto et al., 2017). The conventional road infrastructure management approach encounters many challenges, such as ageing infrastructure, inefficient data, poor data collection, poor data storage and management, limited collaboration among stakeholders, budget constraints, and environmental consequences (U.S.FHA, 2024). However, Building Information Modelling (BIM) is an emerging technology for tackling these challenges by improving 3D visualisation, data storage and management (Eastman et al., 2011), improving safety and efficiency (Azhar, 2011) and (Shou et al., 2015); enhancing collaboration between stakeholders (Bynum et al., 2013) and develop sustainable design through simulations of environmental impact assessment (Ghaffarianhoseini et al., 2017). It is an emerging and transformative technology that has revolutionised the AECO industry (Saedin & Brahim, 2023). BIM is a digital system for managing a built asset's physical and functional characteristics (X Liu & Xie, 2014). It also functions as a digital system by integrating technology, processes, and policies to handle

infrastructure data throughout its lifecycle. In other words, BIM doesn't just change technology; it changes the entire process. For several decades, BIM has been adopted and implemented in the design and construction of building projects(J.-U. Kim et al., 2015). Its use has expanded to civil infrastructures like bridges, roads, railways and sewer networks (Alaghbandrad & Hammad, 2018; Pazzini et al., 2023). Implementation of BIM in road infrastructure has been slow to gain prevalent acceptance and implementation (J. U. Kim et al., 2015). However, it is currently being adopted and used in the transportation sector (Cheng et al., 2016; Aaron Costin et al., 2018). These emerging technologies enhance the construction industry's productivity, efficiency, and sustainability (Khudzari et al., 2024).

In this study, bibliometric tools and the Scopus database were utilised to conduct a comprehensive bibliometric review. Bibliometric tools like VOSviewer and Biblioshiny offer a methodological strategy for systematically reviewing and identifying key trends, including leading publications, influential authors, collaborative networks, and the Evolution of topics within a specific research domain. It is also used to highlight the co-occurrence of critical keywords and the conceptual structure of the research landscape, facilitating a more precise understanding (van Eck & Waltman, 2010) and (Stephan et al., 2017).

Scopus is a reliable and comprehensive electronic abstract and citation database. It is a well-known database covering 330 distinct research fields with peer-reviewed publications. It offers over 28,000 serial titles and 24 million open-access papers from over 7,000 international publishers, making it a unique resource compared to Web of Science (WoS), ScienceDirect and Google Scholar(Elsevier, 2024). Unlike WoS, it is more selective in the inclusion of high-impact journals. Scopus indexes a wide variety of journals, including emerging topics, thus providing a more inclusive overview of global research trends(Mongeon & Paul-Hus, 2016). Regarding citation analysis, Scopus offers detailed metrics like h-index and citation counts, which are critical for tracking research impact, especially in interdisciplinary fields of Engineering, Construction and Technologies(Aghaei Chadegani et al., 2013). While Google Scholar offers broader content, including grey literature, it lacks a rigorous selection process, which limits its reliability compared to Scopus (Harzing & Alakangas, 2016). Compared with ScienceDirect, Scopus offers the advantage of using more than eight Boolean Operators, facilitating a more refined approach. Therefore, for in-depth bibliometric studies. In summary, Scopus is preferred due to its well-structured database, high-quality data, extensive coverage and support by advanced tools to visualise and track research trends. Regarding review and data extraction protocols, the PRISMA Framework, introduced in 2009, is often used to support systematic review and reporting (Page et al., 2021). It offers a wide-ranging protocol that ensures a meticulous and rigorous investigation of all available literature relevant to a specific research topic and evidenced by several key sources (Lockwood et al., 2020; Hutton et al., 2015).

This study addresses critical research gaps in BIM for road infrastructure management by systematically analysing trends, influential works, and emerging themes. It uniquely contributes by offering an exhaustive investigation of the scholarly landscape, highlighting the future research direction on underexplored areas of the adoption of BIM in developing countries and the potential of BIM integration with emerging 4th IR technologies for sustainable and efficient road infrastructure management.

Formulating Research Questions

The bibliometric analysis addressed the research gap on BIM for road infrastructure management by formulating the following four key questions:

RQ1: What has been the publication trend, including volume and growth rate, of research on BIM for road infrastructure management from 2010 to August 2024?

RQ2: Which are the most frequently cited papers in the field of BIM for road infrastructure management, and what makes them influential?

RQ3: How do collaboration networks shape the publication landscape in BIM for Road Infrastructure Management, and how are the authors and countries?

RQ4: What are the key concepts, themes, and emerging topics in BIM for road infrastructure management, and how has keyword use evolved?

METHODOLOGY

This study aligned with positivist research philosophy, focusing on objective, quantifiable and qualitative data in bibliometric methods for evaluating academic contributions and understanding the scholarly landscape through mixed research approaches. A bibliometric review was conducted to quantitatively analyse publication patterns while providing qualitative insight into the thematic trends and research gaps. Performance analysis was used to assess research output over time, examine most cited articles and influence (citation analysis), the individuals, institutions and country's research impact (H-index) and identify influential contributors (Cobo et al., 2011; Xiaozhong Liu, 2013). Science mapping was used to identify the collaborative networks (co-authorship analysis), detect influential references and intellectual bases of the field (co-citation analysis), map key research keywords and thematic clusters (co-occurrence analysis), and analyse trends and shifts in research focus over time (thematic mapping and evolution). As illustrated in Figure 1, the six basic steps were employed for bibliometric analysis in this study.

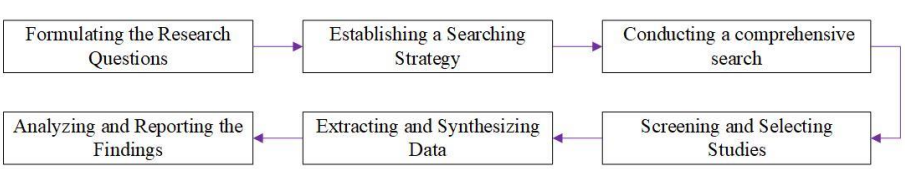


Figure 1. Basic Steps to Conduct a Bibliometric Review

The PRISMA protocol was utilised for bibliometric review analysis based on the extracted bibliometric data from the Scopus database. Open-source tools of VOSViewer, version 1.6.20 (2023) and Biblioshiny, version 4.3.0 (2024), are employed for bibliometric analysis. VOSViewer is intended primarily to analyse academic records and create a network map. Network, overlay, or density visualisations in VOSviewer are also used to visualise co-authorship, co-occurrence, citation, bibliographic coupling, and co-citation links. The Biblioshiny tool in R-packages is used to analyse annual publication trends and conceptual structure insights into the evolution of research themes and the growing influence of emerging trend topics.

Bibliometric Data Extraction

As shown in Figure 2 below, the PRISMA protocol was utilised to extract bibliographic data from the Scopus database. The search was conducted using the Scopus retrieval schema (TITLE-ABS-KEY), whereas relevant keywords were identified, and search strings were formulated accordingly.

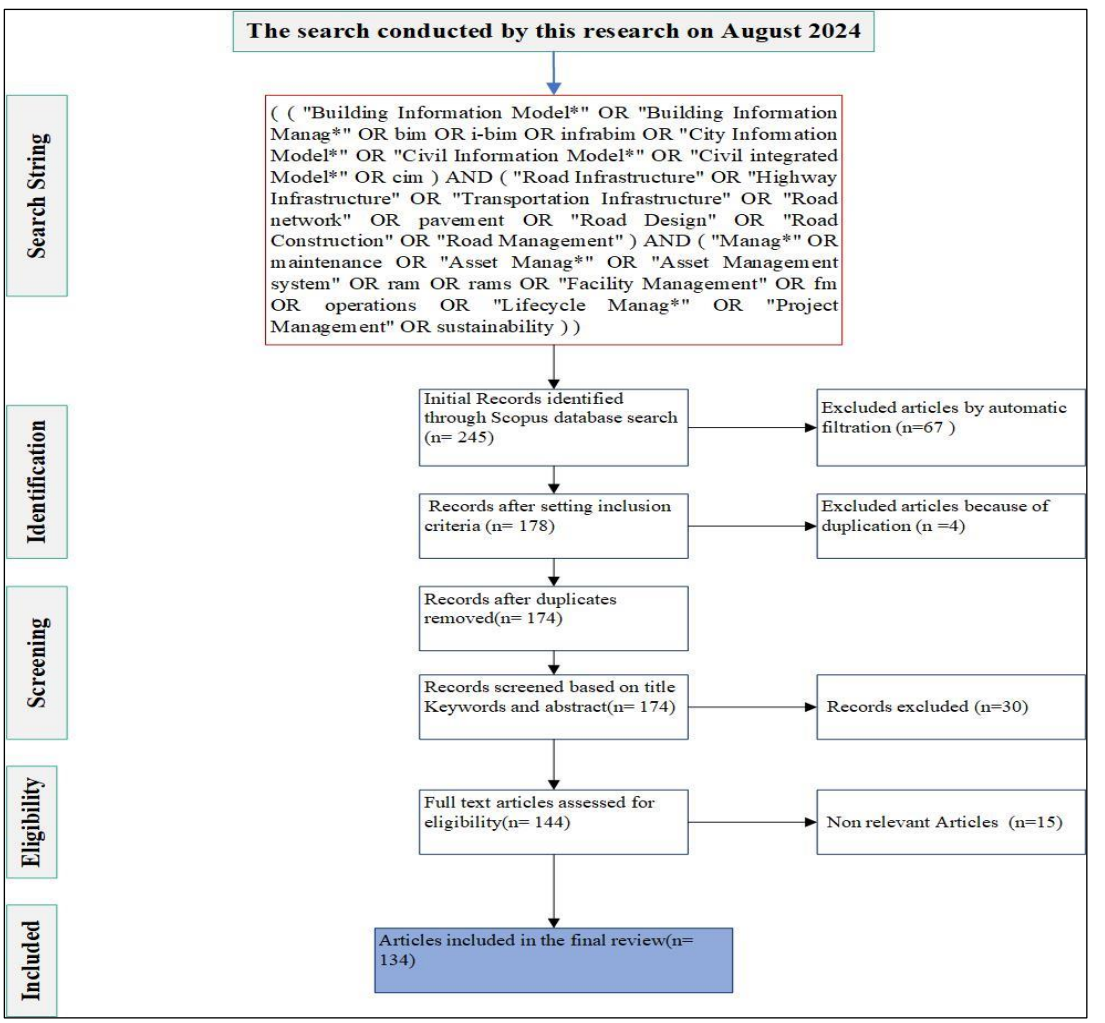


Figure 2. Modified PRISMA Framework for Bibliometric Review

The keywords were identified based on defined research questions and a preliminary literature review. Searching strings were established by combining keywords with the Boolean operators "AND" and "OR". The study utilised "AND" to connect terms for a narrow search, "OR" to link related terms for broadening a search, " " to search exact phrases, () for grouping terms or operators and asterisk (*) or a wildcard character at the end was used to find all words that start with keywords. The "TITLE-ABS-KEY" search was used to identify documents based on the title, abstract, and keywords. This study incorporated peer-reviewed journal articles and conference proceedings to get the compressive state of the art. Publication year, document type, source types, subject area, publication stage, open access and

publication language were considered for inclusion and exclusion criteria. Hence, the documents published in English in the subject area of Engineering and Computer Science were considered in this review. Since the early 2000s, scientific research on BIM in Construction has started and shown progress, while the concept of BIM is traced back to earlier ideas about digital representations of buildings. The substantial research growth in this research field came after 2010. So, this study was considered a document published between the 2010s and August 2024. Conversely, articles that focus on the application of BIM in buildings or other forms of infrastructure, articles that are not published in English, unpublished articles and duplicate articles were excluded from the review. The keywords, exclusion and inclusion criteria were identified based on relevance and related to the research domain. As a result, 245 articles were obtained using search terms in the Scopus database's search bar. After auto-refining the results based on the inclusion and exclusion criteria, 178 articles were identified. The selected articles were exported in CSV file format from the Scopus database, containing metadata such as citations, bibliographic details, abstracts, keywords, and conference information. After data extraction, a manual screening process was carried out to identify duplicates and assess the eligibility of the articles. This process resulted in 134 articles published between 2013 and August 2024 being selected for bibliometric analysis. However, it has limitations, as it may exclude relevant studies and perspectives found in other databases.

RESULTS AND DISCUSSION

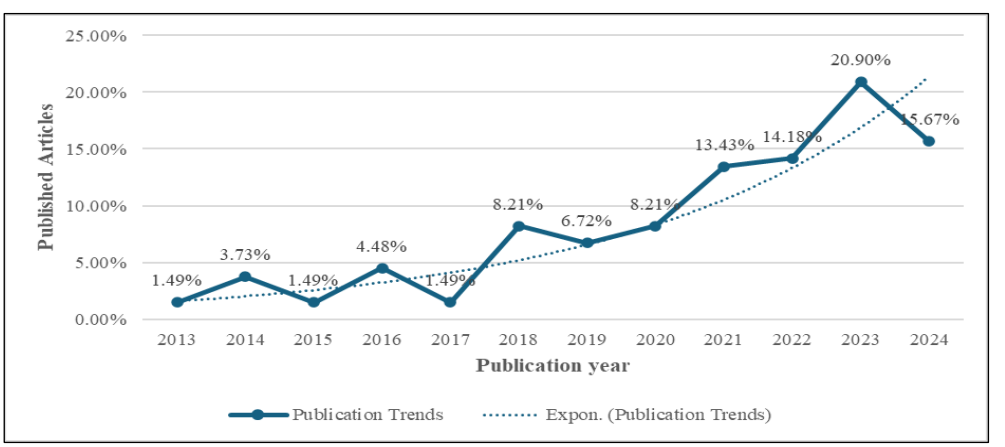
The relevant bibliometric data shown in Table 1 below was extracted from Biblioshiny software. The analysis highlighted that 134 articles from 87 sources were published between 2013 and August 2024, a 23.83% annual growth rate from 452 authors' contributions, with a low rate of 4 single-authored publications. International co-authorship is prevalent, with 16.42% of documents featuring international collaborations and an average of 4 co-authors per document. Furthermore, the analysis showed that 14.82 % is the highest average of citations per document, suggesting a significant impact. The 4578 references cited in the papers highlighted the existing literature contribution. The publication growth rate indicates the growing interest in this research domain and highlights the significant potential for future research.

Table 1. Bibliometric Data (Extracted from Biblioshiny Software)

Description	Bibliometric Data
Timespan	2013: 2024
Sources	87
Documents	134
Annual Growth Rate	23.83%
Authors	452
Authors of single-Author	4
International Co-Authorship	16.42%
Co-Authors per doc	4
Author’s Keywords (DE)	421
Reference	4578
Document Average Age	3.19
Average citation per doc	14.82

Annual Publication Trends

As illustrated in Figure 3, the annual publication trend between 2013 and 2024 demonstrates a steady increase in research output and has a notable change in 2023. The publication trend in 2013 was 1.49%, followed by a slight rise to 3.73% in 2014. This upward trajectory continued, reaching 8.21% in 2018 and facing a temporary decline in 2019 to 6.72 %. However, the research community rebounded strongly, with publication rates rising to 20.90% in 2023. This exponential growth demonstrates that scholars are more interested and engaged in this field, indicating a positive outlook for adopting BIM for Road infrastructure management and future research. Furthermore, in this dataset, Infrastructures, Automation in Construction, Sustainability (Switzerland), The International Society for Optical Engineering, Journal of Construction Engineering and Management, Advances in Civil Engineering and Architecture, and various Engineering Journals are the top publishers in the research field.



(Data Adapted from Biblioshiny)

Figure 3. Annual Publication Trends from 2013 to 2024

Most Cited Articles

As illustrated in Table 2 below, the 10 most cited articles from the 134 selected studies are discussed. A comprehensive literature review conducted in 2018 by Costin et al. (A Costin et al., 2018) stands out with an impressive 346 citations, demonstrating its broad application and relevance. Other notable articles by Chong et al. (Chong et al., 2016) comparative analysis, which achieved 129 citations, Tang et al. (Tang et al., 2020) parametric modelling, which gained 96 citations, and Fanning et al.(Fanning et al., 2015) two bridge project comparisons, which received 79 citations. These findings infer a growing interest and recognition of the importance of BIM in road infrastructure management. The increasing citation numbers for recent publications conducted by Han et al. 2022 (Han et al., 2022). A study on compaction quality monitoring indicates a promising future for research in this area. As a result, research on BIM applications is still in progress and needs further research.

Table 2. Most Cited Articles on The Application of BIM for Road Infrastructure Management

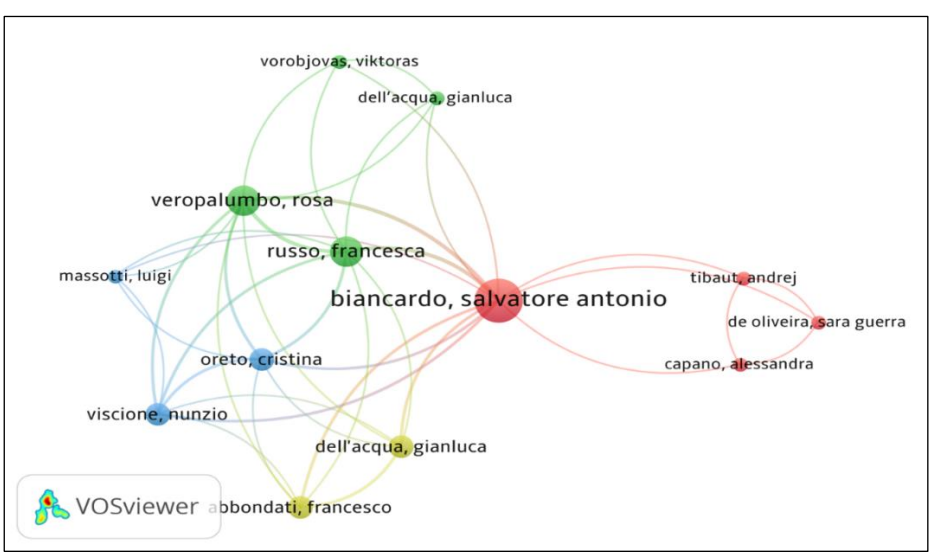
Author	Article Title	Key Findings	Total Citations	TC Per Year
Costin A. et al. 2018	Building Information Modelling (BIM) for transportation infrastructure: Literature review, applications, challenges, and recommendations	This study highlighted the growing interest in BIM for transportation infrastructure. It identifies key gaps in asset management, interoperability, and as-built data capture.	346	49.43
Chong Hy et al. 2016	Comparative Analysis of the Adoption and Use of BIM in Road Infrastructure Projects	This study's findings showed that notable cash was saved, and project time was reduced by implementing BIM.	129	14.33
Tang F et al. 2020	Parametric modelling and structure verification of asphalt pavement based on BIM-ABAQUS	This study enhances 3D visualisation and design accuracy for semi-rigid base pavements by developing a data conversion interface and employing parametric modelling.	96	19.20
Fanning B et al. 2015	Implementing BIM on infrastructure: Comparison of two bridge construction projects	The study highlights that BIM has limited use in horizontal structures. Also, highlights that BIM has a high initial cost but saves operational costs by reducing change orders and rework.	79	7.90
Vignali V et al. 2021	Building Information Modelling (BIM) application for an existing road infrastructure	The study demonstrated the effective use of I-BIM to optimise design and meet regulations, improve project visualisation with a 3D terrain model, integrate infrastructure elements, and enhance project management through an innovative plugin.	69	17.25
Aziz Z et al. 2017	Leveraging BIM and Big Data to deliver well-maintained highways	This study emphasised the advantages of BIM with Big Data in highway infrastructure management. For improving data handling and predictive analytics. However, information loss during project handovers is a critical challenge.	65	8.13
Biancardo Sa et al.2020	Integration of BIM and procedural modelling tools for road design	This study highlights VisualARQ's role in enhancing IFC interoperability and emphasises verifying IFC models with BIMcollab ZOOM for compliance and issue tracking.	58	11.60
Liu Z et al. 2021	3D Visualization of Airport Pavement Quality Based on BIM and WebGL Integration	This study highlights latency issues and calls for further advancements in 3D structural quality analysis using BIM and WebGL to improve infrastructure management.	43	10.75
Sofia H et al. 2020	Mobile mapping, machine learning and digital twin for road infrastructure monitoring and maintenance: Case study of Mohammed VI bridge in Morocco	The key findings of this study are the effective use of a Digital Twin for the transformation of cloud point data into a BIM model to enhance maintenance and the creation of a bridge maintenance system for improved infrastructure performance monitoring	40	8.00

Author	Article Title	Key Findings	Total Citations	TC Per Year
Han T et al. 2022	A BIM-IoT and intelligent compaction integrated framework for advanced road compaction quality monitoring and management	This study developed a prototype system that demonstrates effective real-time tracking and data management, improving construction efficiency and sustainability while accurately detecting weak areas for timely interventions.	39	13.00

(Data Extracted from Biblioshiny)

Authors Co-Authorship Analysis

The leading authors are identified through co-authorship analysis, with higher nodes indicating larger labels in visualisation and thicker link lines indicating stronger connections between items(van Eck & Waltman, 2023). The co-authorship network visualisation has four distinct clusters of authors that suggest potential collaborations and knowledge sharing within specific research domains. The co-authorship was analysed based on setting a threshold of a minimum of 1 author per document and 1 citation of the author, which identified 324 authors out of 475. The cluster centred, as illustrated in Figure 4, Salvatore Antonio Biancardo, strongly linked with Francesca Russo and Cristina Oreto on research focused on BIM applications in road pavement management (Biancardo et al., 2020, 2022; Fabbrocino et al., 2023; Intignano et al., 2021, 2022; Maltinti et al., 2021; Oreto et al., 2021; Oreto, Biancardo, Veropalumbo, Viscione, Russo, & Dell'acqua, 2022; Oreto, Biancardo, Veropalumbo, Viscione, Russo, Abbondati, et al., 2022) and linked with Veropalumbo Rosa on the research focused on the integration of BIM, GIS, IoT, and AR/VR for smart road network maintenance and management (Carneiro et al., 2018). The cluster-centred Gianluca Dell'Acqua linked with Salvatore Antonio Biancardo on research focused on the integration of BIM with life cycle cost analysis for Road Pavement Maintenance(Oreto, Biancardo, Veropalumbo, Viscione, Russo, & Dell'acqua, 2022). The findings demonstrate that the authors have had significant collaboration in the research domain.

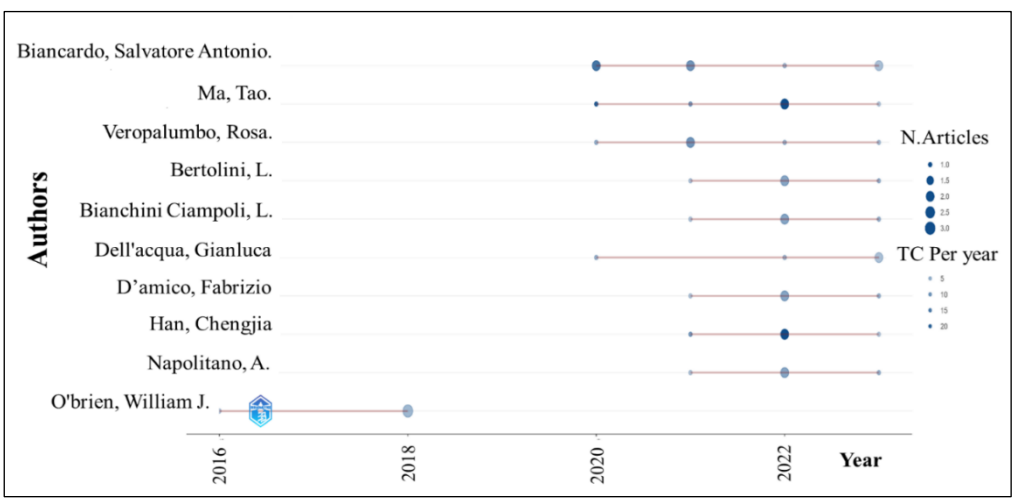


(Extracted from VOSviewer)

Figure 4. Results of Author Co-Authorship Analysis

Production by Author

The author's production analysis is used to describe a dynamic research landscape in the field. As shown in Figure 5 below, Biancardo, Salvatore Antonio, and Bianchi Cimpolli L. are fruitful authors with consistent publications. While Bianchi Cimpolli L.'s output has remained relatively steady, Biancardo, Salvatore Antonio has shown a significant increase in recent years, indicating a growing research interest and productivity. Veropalumbo, Rosa and Dell'Acqua, Gianluca, both researchers, have demonstrated a consistent publication record. However, as shown in the figure below, Bertolin and O'Brien, William J, have a more irregular publication pattern. In general, the finding highlighted a diverse and evolving research community within the field of BIM for managing road infrastructure. The varying levels of author productivity and the emergence of new researchers show a vibrant and dynamic research landscape with potential for future growth and innovation.

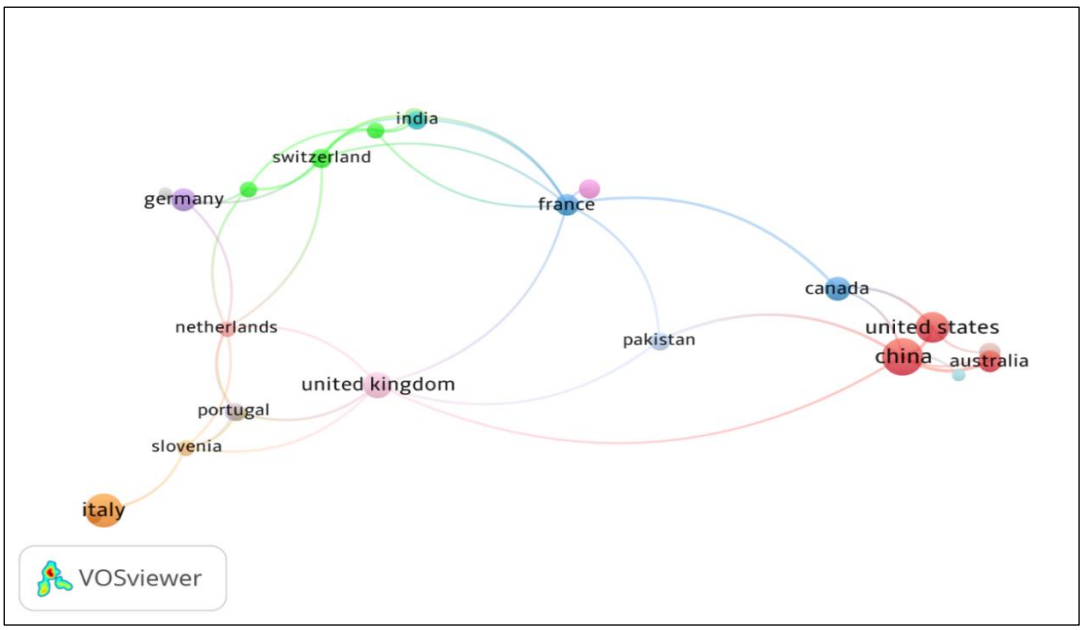


(Extracted from Biblioshiny)

Figure 5. Author's Production Over Time

Countries Co-Authorship Analysis

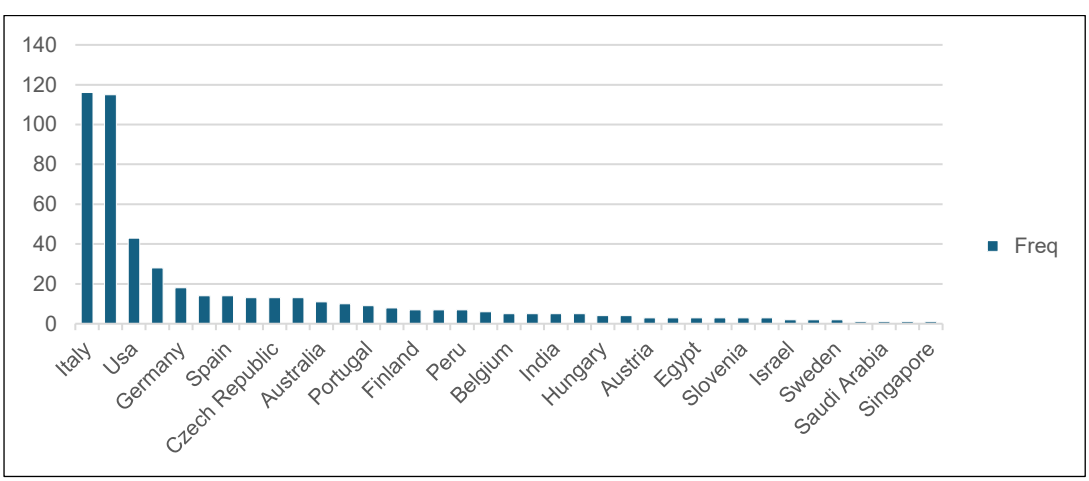
The VOSviewer network visualisation highlighted the co-authorship patterns between the countries in this research domain. The clustering of countries indicates the creation of research networks or collaborations. The analysis was carried out by setting the minimum number of papers and citations of a country as one, and 37 countries met the criteria from 42 countries in the data sets. The analysis included 24 items with a cluster of 19. The weight of the nodes corresponds to the number of publications from each country, emphasising the relative research output with the corresponding author. As a result, as shown in Figure 6, China, Italy, the USA, and the UK emerged as major contributors to the field, with numerous connections to other countries. This suggests their active engagement in international collaborations and significant influence on global research. The thicker lines between countries indicate more frequent and stronger collaborations. Therefore, the cluster of the USA, chain, Canada, Australia, South Korea and Singapore, and the cluster of the United Kingdom, Belgium, Italy, Lithuania, Slovenia, and Portugal indicate potential for joint research projects and knowledge sharing within this field. Thus, the network visualisation highlighted the interconnection of countries in the field of BIM for road infrastructure management.



(Extracted from VOSviewer)

Figure 6. Results of Country Co-Authorship Analysis

Production by Country



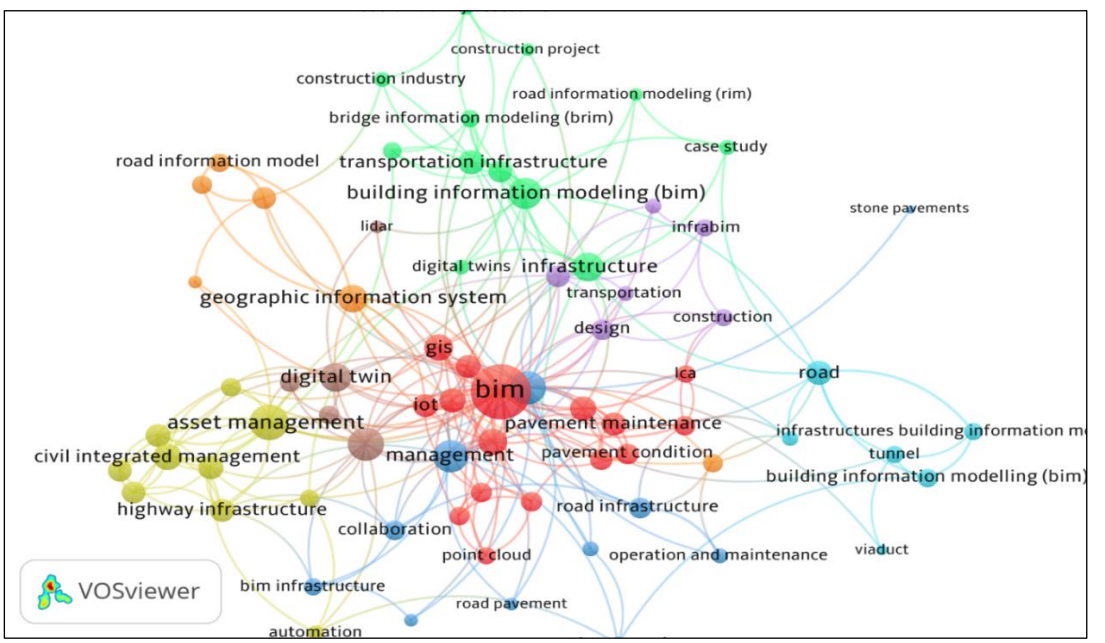
(Data Adapted from Biblioshiny)

Figure 7. Results of Production by Country

As shown in Figure 7 above, Italy and China are the dominant contributors to the global research landscape of BIM for road infrastructure management in this dataset. Italy led the dataset with 116 publications, closely followed by China with 115. This showed high levels of research engagement and output in both countries. Although the United States, the United Kingdom, and Germany also show significant research activity, their publication frequencies are notably lower than in Italy and China. Morocco and Spain, with 14 publications each, represent a growing interest in BIM research, although they are behind the leading nations. Canada, the Czech Republic, Norway, and Australia, with 10 to 13 publications, demonstrate

moderate research engagement, indicating a developing interest. South Korea, Portugal, France, and Finland, with fewer than 10 publications, present relatively lower research output. Despite the limited research output and BIM implementation in Africa, Morocco and Egypt are leading countries in this data set that show potential to drive BIM research and development on the continent. This analysis underscores the need for greater research efforts and collaboration with developed nations to advance BIM adoption in road infrastructure management in Africa. Through bridging knowledge gaps and fostering collaborations, the researchers can contribute to the global discourse and develop innovative and context-specific solutions for the road infrastructure management challenges in the continent.

Co-Occurrence Analysis



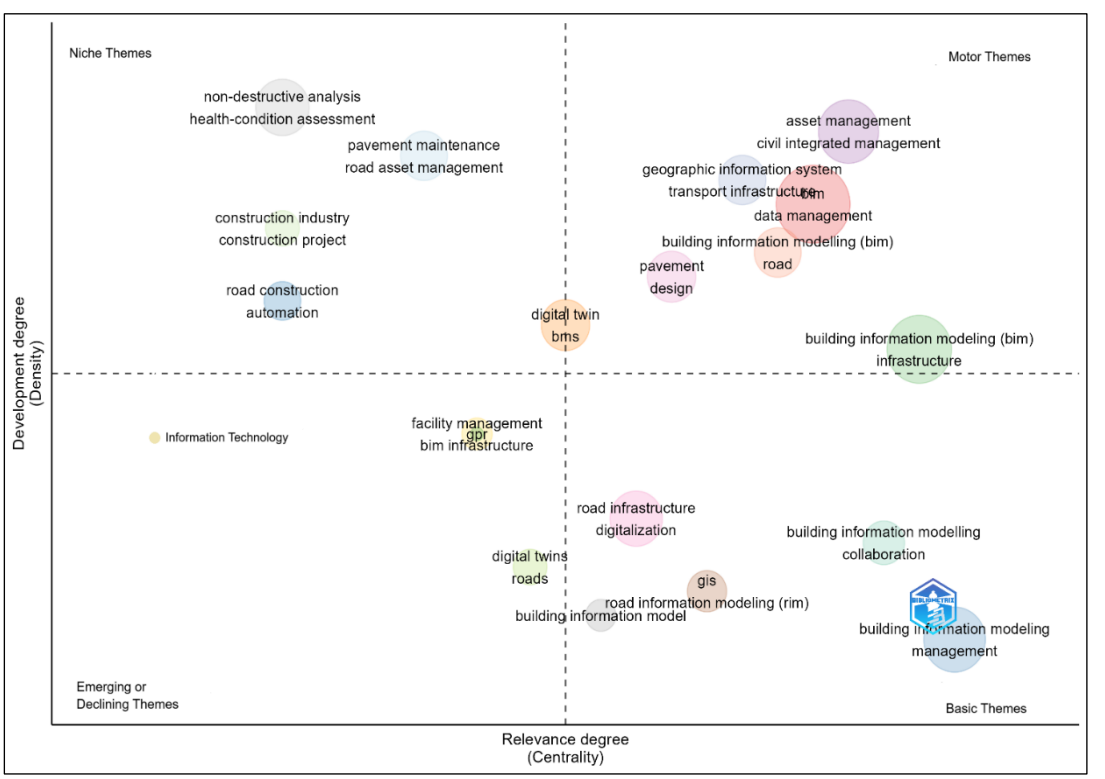
(Extracted from VOSviewer)

Figure 8. Result of Co-Occurrence Analysis

Co-occurrence analysis visualises and analyses the relationships between different concepts or keywords within a dataset. It helps to identify patterns, clusters, and relations between terms, providing valuable insights into the thematic connections between keywords and how research topics are grouped. In this study, the analysis was conducted by setting two minimum occurrences of keywords and selecting 81 keywords from 421, and 72 items were grouped into 10 distinct clusters, showing important relationships and trends. As shown in Figure 8 above, BIM emerged as the most frequent and central keyword, reflecting its dominance in this research field, and it's clustered with road asset management, road infrastructure, bridge inspection, pavement condition and maintenance, pavement attributes, IoT, GIS, database, data management and digitalisation. As a result, this cluster mainly highlighted research on the application of BIM in pavement and road infrastructure management. The green cluster highlighted Building Information Modelling for Infrastructure and Sustainability. This cluster shows themes such as building information modelling, sustainability assessment, transportation infrastructure, digital twins,

and emerging 4IR technologies. It represents research exploring the integration of BIM with sustainable practices in the construction industry's design and management of transportation infrastructures. The blue cluster centred on the keywords of BIM Infrastructure, road infrastructure, road construction, road pavement, stone pavements, Facility management, collaboration, operations and maintenance. This cluster reflects studies that focus on these physical aspects of infrastructure management, collaboration and data acquisition. The final Light blue cluster highlighted automation and BIM for Infrastructure. This cluster represents the integration of BIM infrastructure with automation technologies, reflecting research on automating processes within BIM frameworks to improve the sustainability and efficiency of road infrastructure management. In summary, the co-occurrence cluster analysis highlighted a key thematic area, revealing the interdisciplinary nature of BIM research in road infrastructure management, spanning from digital twin technologies to sustainability assessments and GIS integration for efficiency, sustainability, and long-term asset management.

Thematic Map Analysis of BIM for Road Infrastructure Management



(Extracted from Biblioshiny)

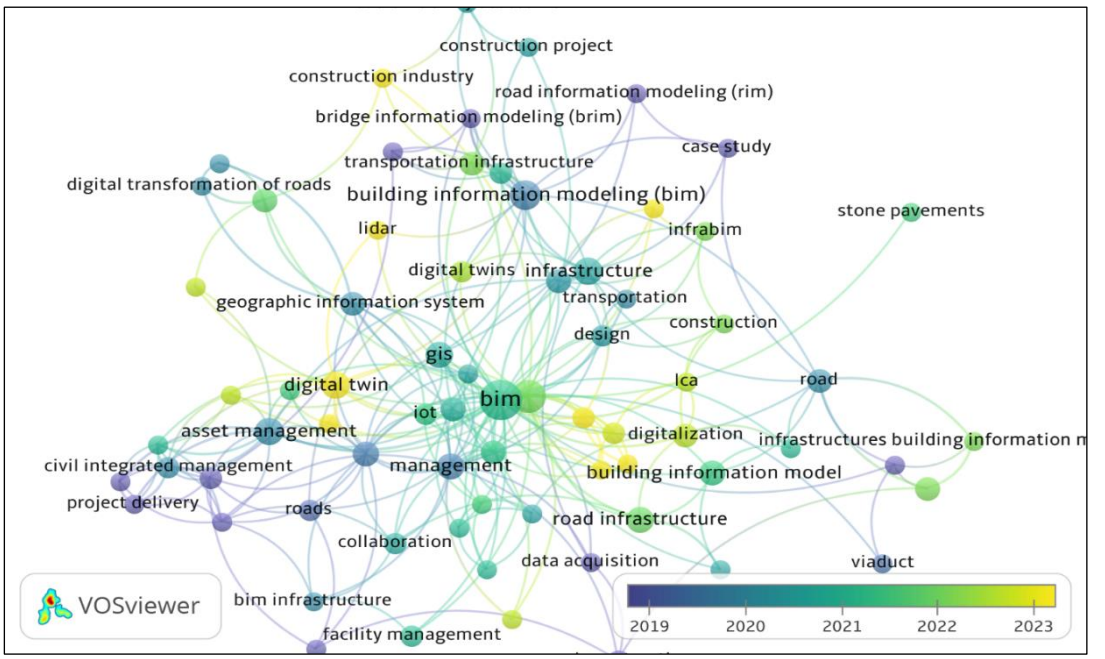
Figure 9. Thematic Map Analysis

The thematic map analysis is used to illustrate the research landscape in the field of BIM for road infrastructure management. The clustering algorithm defined as infomap, the authors' keywords, a minimum cluster frequency of 5 per 1000 documents, 2.5 label numbers, and 0.2 label sizes were defined as analysis parameters in the Biblioshiny software. As shown in Figure 9 above, the theme map analysis has four quadrants, each representing different themes

based on their centrality (relevance) and density (development). The top-right quadrant (motor themes) includes keywords such as BIM, asset management, data management, transport infrastructure, and pavement design, highlighting well-established, highly relevant, and developed topics in the field. These motor themes indicate areas with robust research activity and strong interconnections, where topics are both important and well-developed. In the top-left quadrant (niche themes), terms like non-destructive analysis, health condition assessment and pavement maintenance are specialised themes that are well-developed but have lower relevance to the broader field. These niche areas are advanced but remain marginal. The bottom-right quadrant (basic Themes) contains core concepts like Building Information Modelling, road infrastructure, road digitalisation, road information modelling, collaboration, and management. These are highly relevant topics that form the foundation of the research field, though they may not yet be as fully developed as motor themes. Lastly, the bottom-left quadrant (emerging or declining themes) includes terms like BIM road infrastructure, facility management and digital twins, suggesting these areas are emerging as new research edges in research interest. In summary, to advance the field, future research should focus on integrating Digital Twins, GIS, and AI-driven systems into the broader framework of BIM for road asset management, addressing interoperability challenges and enhancing data-driven decision-making. Additionally, exploring automation in road construction and improving pavement maintenance techniques using real-time data and non-destructive analysis methods will contribute to long-term infrastructure sustainability.

Thematic Evolution Analysis for BIM in Road Infrastructure Management

Thematic evolution analysis is illustrated in Figure 10 below to highlight the Evolution of themes, keywords or terms over time within a dataset between 2019 and 2023. BIM is core in this network, which is well-connected to themes such as asset management and road infrastructure, with the prominence of its significance in infrastructure digitalisation and management. In the early years of 2019 to 2020, research primarily focused on foundational aspects like Geographic Information Systems (GIS), digital twins, and asset management, reflecting a growing interest in integrating digital tools and spatial data management, particularly within the road and civil infrastructure sectors. As the timeline progressed to 2021, more specific applications of BIM emerged, including transportation infrastructure, collaboration, and management, indicating an expansion from general digital management tools to focused applications within specific infrastructure areas. The importance of digital twins and the Internet of Things (IoT) also became more prominent during this period. In the most recent years, 2022 to 2023, research shifted towards advanced topics such as digitalisation, infraBIM, road information modelling (RIM), and BIM infrastructure, suggesting a keen interest in fully integrating BIM with broader digital transformation technologies. Overall, visualisation demonstrates a thematic shift from general BIM applications to more specialised and advanced uses and how BIM can enhance real-time infrastructure management through integration with emerging technologies like AI, IoT and digital twin. Thematic evolution analysis highlighted research that evolves from conceptual explorations to practical implementations.



(Extracted from VOSviewer)

Figure 10. Thematic Evolution Analysis

In summary, government organisations, contractors, consulting firms, and infrastructure managers should adopt BIM and emerging digital technologies to address challenges of ageing infrastructure, data inefficiency, limited collaboration, safety and environmental issues, and enhance sustainability, efficiency and productivity of road infrastructure management, as well as to make data-driven decisions for countries' socioeconomic development.

Limitations of The Research

This study presents a comprehensive bibliometric review of BIM for road infrastructure management. However, it is not without limitations. The analysis is limited to the Scopus database due to the bibliometric tools used, such as VOSviewer and Biblioshiny, relying on data imported from single sources. While Scopus is one of the comprehensive and largest academic literature databases, this limitation excludes potentially relevant articles indexed in other sources. The study utilised bibliometric tools to map publication trends, co-authorships, and thematic analyses. Nevertheless, bibliometric methods may overlook qualitative insights, such as practical challenges, case studies, and stakeholder perspectives on BIM adoption in road infrastructure management.

The dataset is limited to publications from 2010 to August 2024, excluding recently published or ongoing research. Furthermore, the study predominantly focuses on keywords and citation metrics to identify trends and gaps, which may not fully capture the evolving interdisciplinarity of BIM with emerging technologies like artificial intelligence (AI), the Internet of Things (IoT), and Geographic information systems (GIS). Additionally, thematic analysis based on keyword co-occurrence is inherently constrained by how researchers identify and structure their publications.

Future Direction

This review underscores the growing significance of BIM for road infrastructure management through bibliometric analysis. To advance BIM adoption and effectiveness in road infrastructure management, researchers, policymakers, and practitioners should consider the following recommendations. First, future researchers should conduct a comprehensive review by integrating data from multiple databases to enable systematic literature reviews and meta-analyses, providing deeper qualitative insights and practical guidance. Second, prioritise the integration of BIM with AI, IoT, and digital twin systems, leveraging their potential to enhance data management, predictive maintenance, and real-time decision-making in road infrastructure management. Third, address regional and country-specific challenges to BIM adoption, particularly in developing nations, by funding research that identifies these challenges through stakeholder surveys, interviews, and case studies. African researchers, policymakers, and practitioners should start international collaborations with established BIM research communities that can accelerate innovation and adoption, enabling the region to address critical infrastructure gaps using sustainable, technology-driven solutions. Policymakers should also create enabling environments through supportive regulations, capacity-building programs, and public-private partnerships to ensure the successful implementation of BIM for socio-economic growth and sustainable development in the countries.

CONCLUSIONS

This bibliometric review contributes to knowledge by highlighting a comprehensive review of the current research trends, gaps, and encouragements for future studies in BIM for road infrastructure management. The findings underscore BIM's transformative potential to enhance efficiency, collaboration, and sustainability of road infrastructure management. In conclusion, the bibliometric review on utilising BIM for road infrastructure management has shown notable insight into annual publication growth, most influential articles, international collaboration, production by authors and countries and the conceptual structure of the topics. The following lessons can be drawn:

- The annual publication growth rate of 134 documents published from 2013 to 2024 is 23.83%; this indicates a significant growing interest in BIM for road infrastructure management. This trend also highlights an expanding research interest that implies the continued growth of this research area.

- The most influential paper shows the foundational works and paves the way for future research. So, Costin et al. (2018) (A Costin et al., 2018) and Chong et al. (2016) (Chong et al., 2016) have significantly influenced the research landscape, with citations reaching 346 and 129, respectively. The high citation numbers emphasise the critical role these studies have played in shaping the discourse on BIM and its applications for Road infrastructure management.

- The author's co-authorship and the country's co-authorship Analysis highlight strong international collaborations, with 16.42% of documents featuring cross-border collaborations. Authors such as Salvatore Antonio Biancardo and Gianluca Dell'Acqua are central figures in the research network and production, while

countries like China, Italy, and the USA lead global research output. These collaborative efforts have strengthened the intellectual connectivity of the field, fostering knowledge sharing across borders and institutions. However, in Africa, research aimed at the adoption of BIM for road infrastructure management is limited compared to developed nations, which highlights the need for more region-specific research.

- The co-occurrence, thematic map, and thematic Evolution analysis highlight several emerging research themes within road infrastructure management, including digitalisation, road data management, asset management, and integrating BIM with Fourth Industrial Revolution technologies like AI, IoT and digital twins. The research has evolved towards advanced technological applications, with recent trends focusing on sustainability, real-time data integration, and AI-driven innovations. Emerging concepts like digital twins and AI, identified in thematic Evolution, point toward the future of BIM research, emphasising the need for more data-driven, automated, and sustainable approaches to road infrastructure management.

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CRITICAL SUCCESS FACTORS FOR EFFECTIVE TECHNOLOGY TRANSFER IN DIGITAL CONSTRUCTION: A SYSTEMATIC LITERATURE REVIEW

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Abstract

Transfer of Technology (TOT) is one (1) of the processes that ensure knowledge and information as modern-day resources are effectively shared to create a competitive advantage for stakeholders. Despite the increase in TOT activities, there has yet to be an agreement among existing stakeholders, especially industry-academia collaborators, to measure the actual effectiveness of TOT and how it uplifts and improves collaborating stakeholders. Thus, understanding the efficacy of TOT is crucial to boost and spur economic and social growth. Nonetheless, methods need to be established to assess the effectiveness of TOT, especially in Malaysia's digital construction industry. Thus, this study aims to investigate the Critical Success Factors (CSFs) to ensure effective TOT. Using the BOOLEAN search string, a systematic literature review using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) technique is conducted across Scopus databases. The searches yielded 309 articles, which, upon screening, a total of 31 article journals were carefully chosen and thoroughly reviewed and later coded using NVIVO software into seven main themes and 39 subthemes. The study revealed seven main themes, politics, economics, social, technology, policies, legal, and environment, as the main success factors for effective TOT. Future directions of research that focus on CSFs as the parameters to be measured will add to the existing literature on the topic. This study intends to guide construction organisations to navigate the complexities of digital transformation better, achieve sustainable success, and ultimately create a better business opportunity that leads to economic growth.

Keywords: *Transfer of Technology; TOT; Critical Success Factors; Systematic Review; Digital Construction*

INTRODUCTION

Many companies lack the planning and execution to adopt new technology. This includes the lack of well-defined technology integration strategies, inadequate personnel training, and a failure to understand the transfer of technology (TOT) adequately. (Bezuidenhout and Bean, 2022). Besides that, TOT errors can delay projects, increase costs, and compromise safety. This division makes using new technologies inefficient and wastes capital. (MOSTI, 2021). As technology advances swiftly, the sector must keep up, which could lead to a loss of competitive edge and economic downfall. (World Economic Forum, 2019; Ministry of Works (KKR), 2022).

Notwithstanding these barriers, there is optimism. Utilising organised frameworks for TOT, such as creating specialised teams for technology integration, offering ongoing employee training and development, and cultivating an environment encouraging innovation, can greatly enhance results. Moreover, adopting proven methodologies from prosperous case studies and tailoring them to fit specific organisational circumstances can facilitate seamless

transitions. Implementing pre-emptive measures can reduce the risks connected with TOT, hence guaranteeing that the industry can fully capitalise on the advantages of digital innovations (OECD/Eurostat, 2018; Sun, 2021).

Conversely, the success of TOT depends on other aspects. Effective TOT in digital construction requires addressing critical success factors (CSFs) to avoid failure and achieve desired results. By identifying its weaknesses and adopting strategic solutions, the construction sector may successfully manage the digital transformation, improving productivity and sustainability. Financial, organisational, and regulatory variables are crucial to measuring TOT. (Roszkowska, 2013). On top of that, learning from existing project experience helps in understanding technology capabilities and limitations, especially as with many technologies, further research is needed to understand the advantages and drawbacks of technologies fully (Hanif et al., 2023). Through understanding and leveraging these factors, stakeholders can optimise their TOT strategies and maximise the impact of their innovations on society and the economy of the construction industry itself.

Nevertheless, current research on TOT CSFs and TOT in digital construction is sparse. Thus, this study seeks to identify the CSFs of effective TOT to illuminate the factors that later affect digital construction technology transfer. This initiative will promote digital construction research and expand field expertise.

METHODOLOGY

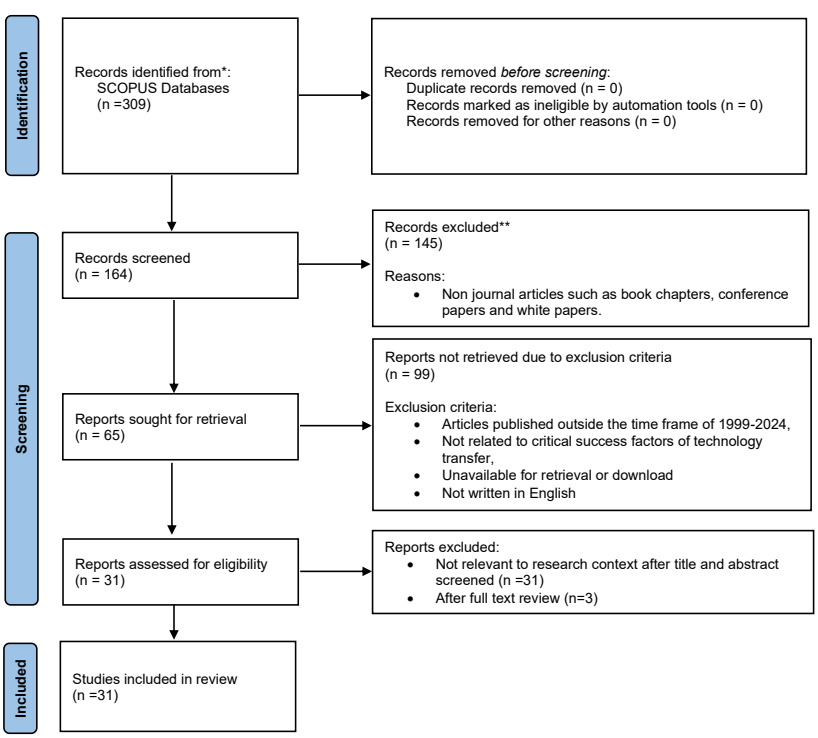

Figure 1. SLR Prisma Flowchart

A systematic literature review (SLR) was utilised for this research. SLR summarise field information in detail. They propose future research goals, answer issues that individual studies may have missed, identify persistent difficulties that future studies can address, and produce or evaluate hypotheses explaining events (Page et al., 2021). Following PRISMA guidelines, there are four main stages of SLR processes as follows: (1) Identification of journals, (2) Screening process; (3) Eligibility check; and (4) Inclusion of finalised journals This study used an SLR of earlier research conducted about the CSFs of effective TOT, as the current body of knowledge is still lacking in understanding the right way of assessing the impact of TOT (Joshi et al., 2021). Figure 1 portrays the SLR process that funnelled the study from the initial 301 articles to 31 articles over the three structured layers of the screening process.

This process begins by identifying article journals through SCOPUS databases. SCOPUS was chosen as the search engine because of the clear list of indexed content and its extensive library of publications covering more than 15,000 articles and journals from more than 4,000 publishers from different industries, including management, engineering, business, and construction (Radzi, Rahman and Doh, 2023). A systematic desktop search using search string of "TITLE-ABS-KEY (critical AND success AND factors AND of AND technology AND transfer) AND PUBYEAR > 1998 AND PUBYEAR < 2024 AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (EXACTKEYWORD, "Technology Transfer")) AND (LIMIT-TO (SRCTYPE, "j"))" was conducted on SCOPUS databases and 309 articles were retrieved initially by January 2024. IDuring the screening stage, journal articles are filtered to ensure data dependability and accuracy. Of the 309 publications, 145 were omitted because they were book chapters, conference papers, informal documents, or white papers. The second screening step excluded 99 articles using distinctive exclusion factors, leaving 65 articles. The parameters were established in Table 1. Abstract and full manuscript text checks are conducted to ensure the final papers are eligible for analysis. This process is important for a more detailed evaluation of journals. It involves an in-depth assessment of the contents to ensure that data and insights are reliable, high-quality, and relevant to the research topic. Only 31 of 65 screened papers were chosen for further analysis in this study.

Table 1. Exclusion & Inclusion Criteria

Inclusion Criteria	Weightage of Criteria	Justification
Articles published in peer-reviewed journals	25%	Peer-reviewed articles undergo rigorous evaluation by experts in the field, which enhances the validity of the findings
Studies focusing on Critical Success Factors (CSF) or Transfer of Technology (TOT)	25%	Articles were evaluated on their direct relevance to the topic of CSF or TOT
Publications in English	10%	Ensure ease of accessibility and accurate understanding.
Exclusion Criteria	**Weightage of Criteria**	**Justification**
Articles not related to CSF and TOT	10%	Maintain the study's focus on factors impacting the effectiveness of TOT
Articles published outside the time frame of 1999-2024	10%	Capturing the most relevant and recent developments in the field
Non-peer-reviewed publications, such as conference papers and reports	15%	Non-peer-reviewed publications are excluded to ensure credibility and reliability
Articles are not available for retrieval or download	5%	Inaccessible articles were excluded to ensure a thorough review and analysis

Thematic Analysis is a well-proven method widely used in theoretical research that allows researchers to focus on identifying the themes and developing analysis cohesively, conducting knowledge-building and theory-generating qualitative SLRs (Joshi et al., 2021). In this investigation, NVIVO software assisted with data analyses. Key criteria, such as critical elements for effective TOT, research methodology, conclusions, and future directions, were coded from the selected papers. The analysis found seven primary themes: Political, Economic, Social, Technology, Policies, Legal, and Environment aspects of effective TOT success.

RESULTS AND DISCUSSION

This study analysed publication data using Thematic Analysis. Thematic Analysis describes data patterns and observations. Qualitative coding organises data by assigning codes. It involves developing a thorough list of ideas or subjects that best represent a data compilation (Toyon, 2021). Figure 2 illustrates the analysis findings of 31 articles that have been further classified into seven main themes: Politics, Economics, Social, Technology, Legal, Policies and Environment, with a total of 39 subthemes that were found to be potential CSFs for effective TOT.

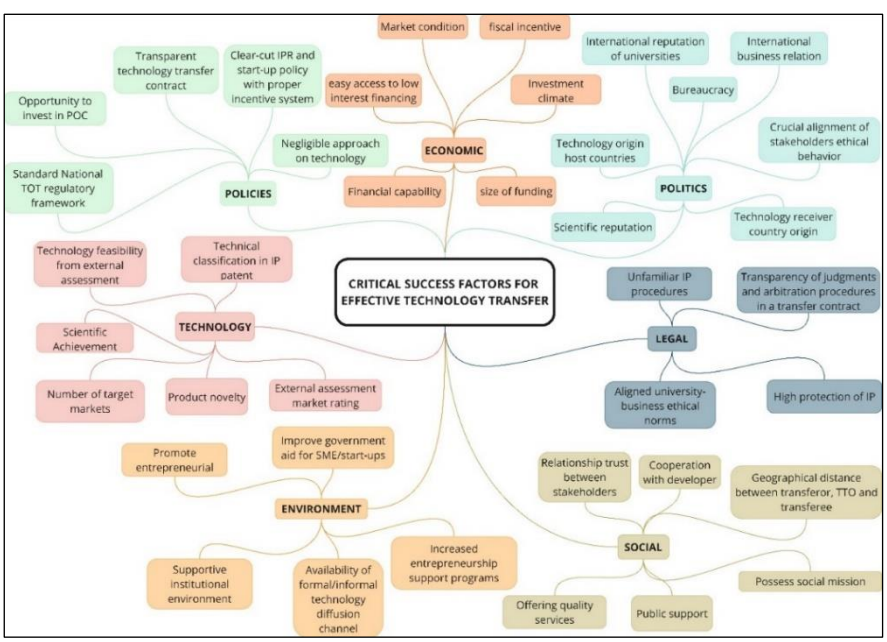

Figure 2. Author's Illustration on SLR Finding Mind Map

Politics

Politics often impact TOT, as governments may regulate it to protect national interests, enforce international agreements, or stimulate domestic innovation. (Shahebrahimi et al., 2022). Moreover, the importance of maintaining good political relationships between countries (Sun et al., 2023) and maintaining political stability (Mazher et al., 2018) are among key highlights of how politics benefit the accomplishment of the TOT process as rewards indicators (Barbolla and Corredera, 2009). Interestingly, the ever-changing political paradigm poses several uncertainties that could threaten TOT and success. (Farrukh Bashir et al., 2013).

Scientific Reputations

From another perspective, TOT must emphasise scientific reputation. Trusted universities and organisations with good research outputs will likely obtain international collaborations and funding. A high scientific reputation increases technology uptake and commercialisation, facilitates negotiations, and boosts credibility. (Schiller and Brimble, 2009; Sun, 2021; Toledano, Gessa and Sanchez-Herrera, 2022).

International Reputation of The Universities

Private companies seeking reputable partners may also be drawn to colleges with a good international reputation for TOT. (López-Mendoza et al., 2020). These institutions have stronger networks, visibility, and resources for TOT. Their global status attracts outstanding academics, researchers, and students, creating a vibrant intellectual atmosphere for innovation and collaboration. (Munari, Sobrero and Toschi, 2017).

Ethical Alignment of Stakeholders

TOT depends on stakeholder ethics. This alignment ensures that all parties follow fair practices, respect intellectual property rights, and support the transfer's mutual benefits. Ethical behaviour builds trust, which is essential for teamwork. TOT projects might fail due to disagreements, legal issues, and ethical misalignment. (López-Mendoza et al., 2020; Messina et al., 2022).

Bureaucracy

TOT can be hampered by bureaucracy. Bureaucracy delays raise expenses and deter investors and partners. (Munari, Sobrero and Toschi, 2017). TOT requires transparent and streamlined bureaucracy. Simplifying regulations and cutting red tape can attract domestic and international stakeholders. (López-Mendoza et al., 2020).

International Business Relations

TOT requires strong international business relationships. These partnerships can open new markets, encourage cross-border cooperation, and share expertise and resources. TOT is affected by diplomatic and trade interactions. TOT agreements are more common in countries with good business climates and international contacts (Sun et al., 2023).

Technology Origins

The technological origin of the host country's policies and infrastructure affects TOT. Countries with innovation, research, and development policies foster transferable technology. Technology sharing and transfer require legal protections for inventors and investors, including intellectual property laws. Technology recipient country readiness and capabilities are equally crucial. Country infrastructure, workforce skills, regulatory climate, and commercial opportunity. Education, infrastructure, and economic and political stability help countries embrace and employ transferred technologies. Government support and incentives for technology adoption can also boost TOT success. (Weikl and Grotz, 1999; Farrukh Bashir et al., 2013).

Economic

From an economic perspective, TOT can stimulate growth by allowing countries or corporations to acquire sophisticated technologies without the need to invest significant time and resources in developing them from the beginning (Sun et al., 2023). Economic integration between transferor-transferee countries has improved productivity and operation efficiencies and elevated competitiveness for both organisations and their workers (Nguyen, Nguyen and Do, 2024). The process can include licensing agreements, joint ventures, and foreign direct investment (Quitzow, Huenteler and Asmussen, 2017; Shahebrahimi et al., 2022).

Market Condition

Additionally, market conditions greatly impact technological transfer. Stable and growing markets attract investment and foster new technology. (Lane, Leahy and Bauer, 2003). Tax breaks, grants, and subsidies from the government can also enhance technological transfer. These incentives make investing in new technology more appealing by lowering the cost burden. Fiscal incentives can also encourage foreign corporations to transfer their technologies to the incentivising country, boosting economic growth and technology. (Sun, 2021; Toledano, Gessa and Sanchez-Herrera, 2022).

Financial Capability

TOT also depends on the receiving entity's resources. Financial stable companies can absorb and implement advanced technology, giving them a competitive edge and operational efficiency. (Lane, Leahy and Bauer, 2003; Toledano, Gessa and Sanchez-Herrera, 2022).

Investment Climate

Additionally, a good investment climate is needed to attract TOT funding. Positive investment climates encourage domestic and international investors to fund TOT efforts, increasing their chances of success. (Munari, Sobrero and Toschi, 2017). In contrast, (Sun et al., 2023) indicated that TOT activities require a good business model to make revenues. A lack of awareness of corporate culture and understanding has hindered TOT's success. (Passarelli et al., 2020). Conversely, a volatile market can deter investors and impede the adoption of new technologies(Jung, Lee and Lee, 2015).

Easy Access to Low-Interest Financing Rates

Easy access to funding, especially at low interest rates, is essential for technological transfer. Companies can invest in new technologies with affordable finance. When borrowing costs are low, corporations are more eager to invest in new technology, which can boost innovation and adoption. (Mazher et al., 2018).

Social

Socially, TOT can impact societies by improving the quality of life through the introduction of new technologies (López-Mendoza et al., 2020). The diffusion of technology can reduce inequalities by providing access to modern tools and information, though it can also widen the gap if access is uneven (Pornpongtechavanich et al., 2022).

Cooperation With Developers

Successful TOT requires developer participation. Developers contribute technical expertise and innovation, while partners provide infrastructure and market access. (Mohammadi, Dahooie and Khajevand, 2021). Strong collaboration ensures that the technology is adapted to meet the specific needs of the recipient organisation, leading to smoother implementation and higher adoption rates (Messina et al., 2022). Nonetheless, (Schiller and Brimble, 2009) also highlighted that cooperation between stakeholders is essential but is hindered by institutional barriers such as university autonomy and governmental bureaucracy.

Relationship Trust Between Stakeholders

Beyond that, stakeholder trust is essential for TOT. It lowers uncertainty and encourages open communication, aligning stakeholders towards common goals. Trust promotes transparency and information sharing, which helps troubleshoot and optimise technology during transfer. (Barbolla and Corredera, 2009; Passarelli et al., 2020).

Offering Quality Services to People

Providing high-quality services is also essential for public and stakeholder support for TOT programs. When technology improves service quality, it increases credibility and sustains stakeholder investment and engagement. (Mohammadi, Dahooie and Khajevand, 2021). Quality services also enhance the reputation of both the technology provider and the recipient, promoting future collaborations.

Public Support

TOT also benefits from public support. Awareness campaigns and showing the benefits of new technologies can improve public acceptance. Public support can influence policy and encourage government and private sector TOT investments. (Munari, Sobrero and Toschi, 2017).

Geographical Distance Between Transferor, TOT and Transferee

The geographical distance between a firm and a university research centre or department can impact the success of TOT (López-Mendoza et al., 2020). Proximity makes communication, collaboration, and problem-solving simpler. It allows academic experts to provide greater hands-on guidance, improving the transfer process. (Passarelli et al., 2020).

Possess Social Mission

Finally, socially conscious organisations are more inclined to transfer technology. A social mission links TOT aims to societal advantages, which can attract financing and support from stakeholders. It also guarantees that transferred technology meets essential social demands, boosting its relevance and influence. (Toledano, Gessa and Sanchez-Herrera, 2022).

Technology

TOT involves sharing scientific and technical knowledge. Research has examined patent licensing, collaborative research, and commercialising inventions as TOT CSFs. (Barbolla and Corredera, 2009). The goal is to apply new technologies in practical settings, leading to real-world applications and benefits.

Product Novelty

Furthermore, product uniqueness is vital to TOT. New technologies often solve issues or create new markets. Potential adopters may be drawn to the product's uniqueness, making transfer easier. Novel items can swiftly build a market presence due to less direct competition. (Lane, Leahy and Bauer, 2003; Messina et al., 2022; Sun et al., 2023). Then again, it is also highlighted that novel technologies also face different barriers to being commercialised, especially ensuring the product is market-ready (Sun et al., 2023).

Scientific Achievement

Beyond that, scientific achievement helps a new technology's credibility and reliability. Scientific excellence, shown by peer-reviewed publications and awards, boosts technology value. Recognition can attract investors and partners, making TOT easier. (Messina et al., 2022).

Number of Identified Target Markets of New Technology

Previous researchers highlighted that the identification of multiple target markets by inventors can significantly boost the success of TOT (Messina et al., 2022). A broader market application increases the technology's commercial potential, attracting more stakeholders and resources (Lane, Leahy and Bauer, 2003; Passarelli et al., 2020). This adaptability makes the technology adaptable across industries, improving adoption and integration. Nevertheless, finding the correct market channels and segmentations remains the major obstacle to TOT success. (Sun, 2021).

External Assessment Market Rating

Additionally, IP experts must analyse the practicality of the new technology. These assessments guarantee that the technology is feasible and scalable. (Passarelli et al., 2020). Feasibility studies cover technological, economic, and legal issues to assess the technology's potential and limitations. Positive feasibility ratings decrease risks and uncertainties, promoting stakeholder support for the transfer. (Barbolla and Corredera, 2009). Nonetheless, (Passarelli et al., 2020) highlight that determining the feasibility of a new technology is always tricky, and it is difficult to predict its outcome precisely.

Technology Feasibility from External Assessment

In addition, external assessments or ratings by industrial experts provide an objective evaluation of the technology's market potential (Sun et al., 2023). These assessments can highlight the competitive advantages and potential barriers the technology may face in the

market. Positive ratings from recognised innovation brokers can significantly boost stakeholder confidence and attract investment, facilitating smoother TOT (Passarelli et al., 2020).

Technical Classification in IP Patent

Finally, the IP patent's technical categories show the new technology's scope and prospective uses. More classes indicate a wider technology's applicability and versatility (Jung, Lee and Lee, 2015). This can attract more industries and improve TOT. Comprehensive patent classifications can strengthen intellectual property protection, encouraging stakeholders to transfer.

Legal

Laws and regulations control TOT across businesses and borders. Intellectual property rights (IPR) like patents, trademarks, and copyrights protect inventors and facilitate the secure transfer and commercialisation of ideas. (Pornpongtechavanich et al., 2022).

Transparency of Judgements and Arbitration Procedures

TOT success requires clarity in judgements and arbitration procedures in transfer contracts. Transfer contracts that clearly explain arbitration procedures and assure fair and transparent judgements build stakeholder trust (Munari, Sobrero and Toschi, 2017). Transparent processes reduce misunderstandings and disagreements, making transfer negotiations and execution easier (Bezuidenhout and Bean, 2022). Transparency helps parties understand their rights and responsibilities, lowering legal issues and improving TOT success. (Ratinho and Henriques, 2010).

High Protection of IP

TOT must prioritise IP protection (Barbolla and Corredera, 2009). Patents, trademarks, and copyrights protect technology developers and owners from unauthorised use and replication (Sun, 2021). IP protection gives inventors and businesses the confidence to share their technologies since their rights are protected. This protection encourages research and investment in new technologies, facilitating TOT (Joshi et al., 2021; Shahebrahimi et al., 2022). However, (Schiller and Brimble, 2009) noted that strong intellectual property requirements hinder TOT stakeholders' contact.

Unfamiliar IP Procedures Systems

Furthermore, navigating unfamiliar intellectual property (IP) procedures and systems is a significant barrier to TOT (Shahebrahimi et al., 2022). Differences in IP laws, regulations, and practices across countries can create barriers to successful TOT (Sun et al., 2023). Patentable products in one jurisdiction may not be in another, complicating innovation protection. Understanding and strategically navigating these IP ecosystems is essential for TOT. IP professionals can advise on local IP systems and help design robust patent applications that meet regulatory criteria. (Munari, Sobrero and Toschi, 2017; Joshi et al., 2021). Additionally, misunderstandings or lack of knowledge about local IP procedures can lead to legal disputes, delays, and even loss of IP rights (Barbolla and Corredera, 2009). Thus,

universities and enterprises must transfer technology to educate their workforce in IP. Clear standards and procedures that allow for international IP variations can reduce risks and ease TOT across borders. (Joshi et al., 2021).

Aligned University-Business Ethical Norms

Lastly, aligning ethical norms between universities and businesses is critical for the success of TOT (Toledano, Gessa and Sanchez-Herrera, 2022). Ethical congruence ensures that both stakeholders share a common understanding of practices and standards, fostering trust and cooperation (Lopez Mendoza and Mauricio, 2021). When universities and businesses have aligned ethical norms, they are more likely to engage in transparent and fair negotiations, leading to mutually beneficial agreements (Messina et al., 2022). Ethical alignment includes respect for intellectual property rights, fair license terms, and agreed-upon research and development procedures. TOT attempts might fail due to ethical differences, mistrust, and conflict.(Toledano, Gessa and Sanchez-Herrera, 2022). A university may value open research access, while a company may value private control and commercialisation. Such issues must be resolved to guarantee a smooth transfer (Lopez Mendoza and Mauricio, 2021).

Policies

TOT policies are government or organisation instructions and rules streamlining TOT. These rules encourage inventiveness, fair competition, and national security. These projects often include research and development aid, tax incentives, and public-private collaborative mechanisms. (Bezuidenhout and Bean, 2022).

Transparent TOT Contract

Transparent TOT contracts are essential to TOT success. Well-written agreements help parties understand their rights, duties, and expectations. (Sun, 2021). Transparency in contracts mitigates potential conflicts and fosters a cooperative environment conducive to innovation (Lop et al., 2024). Contracts usually specify the transfer, payment terms, confidentiality, and dispute settlement. These factors must be transparent to develop trust and ensure that TOT goes smoothly. (Munari, Sobrero and Toschi, 2017; Bezuidenhout and Bean, 2022; Shahebrahimi et al., 2022).

Clear Intellectual Property Rights (IPR) and Start-Up Policy

TOT relies on IPR. Well-defined IPR rules with strong safeguards and a compelling incentive structure encourage creativity and inspire inventors and organisations to commercialise their inventions. An explicit IPR policy helps resolve ownership and royalty/profit issues. Academics and businesspeople are encouraged to collaborate in TOT. (Barbolla and Corredera, 2009; Munari, Sobrero and Toschi, 2017; Quitzow, Huenteler and Asmussen, 2017; Sun, 2021). On the contrary, (Schiller and Brimble, 2009) also highlighted that IPR regulations can also be seen as an additional wall of obstruction to encourage interaction between stakeholders. Effective TOT regulations should also handle start-up establishment, administration, and equity distribution. Clear policies in these areas structure technology commercialisation through new ventures. (Quitzow, Huenteler and Asmussen,

2017). These policies should address startup formation, governance, finance, and equity allocation. Universities and research organisations may help start-ups succeed and develop by creating a transparent framework and improving the TOT environment. (Messina et al., 2022). On top of that, (Ratinho and Henriques, 2010; Joshi et al., 2021; Sun, 2021) also urged universities to offer a first right of refusal to invest in their researchers and a professional reward and merit system to stimulate start-ups.

Standard National TOT Regulatory Framework

A standard national TOT regulatory framework is essential for systematic and efficient TOT. This methodology ensures TOT consistency across industries and regions. In addition, industry-specific technology policies can address industry challenges and opportunities, fostering the development and commercialisation of breakthrough technologies. Combining TOT programs with specific industrial strategies boosts efficiency. (Joshi et al., 2021; Lopez Mendoza and Mauricio, 2021; Shahebrahimi et al., 2022).

Opportunity to Invest in POC Programs

Previous researchers also suggested that policymakers should consider investing in Proof of Concept (POC) programs to bridge the gap between research and commercialisation (Jung, Lee and Lee, 2015; Munari, Sobrero and Toschi, 2017). POC programs provide critical funding and support to validate the feasibility and market potential of new technologies (Mankins, 2002). By investing in these programs, policymakers can help de-risk early-stage innovations, making them more attractive to investors and industry partners (Passarelli et al., 2020). This investment can accelerate the development and commercialisation of cutting-edge technologies, contributing to the success of TOT efforts (Sun, 2021).

A Negligible Approach to Technology is Believed to be A Luxury Investment

Finally, enterprises, governments, and research institutions may overlook or underinvest in cutting-edge technologies because they are too expensive or impractical. In environments that prioritise short-term profits over long-term strategic gains, this happens. Prioritising vital technology over luxury expenditures can help allocate scarce resources to meet critical demands. By avoiding high-cost investments in innovative technologies, companies can lower financial risks, especially in uncertain markets or economic downturns. (Passarelli et al., 2020; Shahebrahimi et al., 2022). Dismissing modern technologies as luxuries can miss the potential for improvements and competitive advantages. Innovation stagnation can cause companies to slip behind competitors who are more eager to adopt and integrate advanced tools, leading to inefficiencies over time. (Jung, Lee and Lee, 2015; Quitzow, Huenteler and Asmussen, 2017; Mazher et al., 2018). Successful growth and technological advancement require recognising the potential of these sophisticated technologies and proactively incorporating them into the transfer process.

Environment

TOT's success depends on its surroundings. An ecosystem conducive to TOT requires supportive institutional frameworks, entrepreneurship support programs, an entrepreneurial climate, technology diffusion channels, and government funding for technology start-ups.

Supportive Institutional Environment

Successful TOT requires institutional backing. Universities and research groups must provide strong TOT frameworks. This requires dedicated TOT offices, transparent policies, and sufficient resources to commercialise inventions. (Munari, Sobrero and Toschi, 2017; Joshi et al., 2021; Pornpongtechavanich et al., 2022).

Increased Entrepreneurship Support Programs

In addition to the above, entrepreneurship support programs are essential in promoting the TOT (Sun et al., 2023). Incubators, accelerators, and mentorship programs help entrepreneurs launch new technologies. They provide cash, business assistance, and networking opportunities for TOT efforts.

Promote Entrepreneurial Climate/Environment

For innovation and TOT, an entrepreneurial climate is essential. Create an environment that encourages risk-taking, innovation, and collaboration. Educational institutions and governments promote this climate by including entrepreneurship in courses and offering innovation opportunities. (Ratinho and Henriques, 2010; Munari, Sobrero and Toschi, 2017; Joshi et al., 2021; Sun, 2021; Toledano, Gessa and Sanchez-Herrera, 2022).

Availability of Formal/Informal Technology Diffusion Channel

Formal and informal technology diffusion channels greatly affect TOT. Formal channels include structured programs and efforts; informal channels include networking, industry collaborations, and knowledge sharing. These channels spread technical advancements across sectors and geographies. (Jung, Lee and Lee, 2015). Yet, clarity and distinction must be clear between TOT and technology diffusion to facilitate industry understanding of the matter (Sun et al., 2023).

Improve Government Aid for SMEs/Start-Ups

Small and Medium-sized Enterprises (SMEs) often face significant barriers to accessing and adopting new technologies despite the argument that the role of SMEs role in transnational TOT is still unknown (Weikl and Grotz, 1999). Kumar et al. (2015) Click or tap here to enter text.proposed a TOT model for SMEs with broader input factors. Government aid in the form of grants, subsidies, and tax incentives can help mitigate these barriers(Schiller and Brimble, 2009). By supporting SMEs, governments can enhance their capacity to engage in TOT activities, thereby driving economic growth and innovation (Weikl and Grotz, 1999). A multifaceted approach is needed to transfer technology in a complicated ecosystem. technological transfer success depends on supportive institutional frameworks, entrepreneurship assistance programs, an entrepreneurial atmosphere, technological diffusion channels, and government help for SMEs. By addressing these variables, stakeholders can improve TOT initiatives and boost innovation and growth.

CONCLUSION

This study concludes with an SLR on TOT CSFs. Further investigation revealed a limited understanding of how effective TOT is regardless of the industry the technology is embedded into, especially in the construction industry. This study sheds some light on the limitations and adds to the existing knowledge database to adapt the determining factors to Malaysian Digital Construction. A total of 31 article journals were carefully selected and reviewed, then divided into two primary themes and 11 subthemes. This study only covered CSFs from 7 themes: Politics, Economics, Social, Technology, Policies, Legal, and Environment due to its complexity and limitations. This study helps identify knowledge gaps in the TOT body of knowledge and guides the industry in understanding effective TOT elements to maximise advantages and profitability for all stakeholders.

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FACTORS INFLUENCING BLOCKCHAIN INTEGRATION FOR SUSTAINABLE MATERIAL HANDLING IN THE MALAYSIAN CONSTRUCTION INDUSTRY

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Abstract
The construction industry in Malaysia is a key driver of economic growth but faces significant challenges in achieving sustainability, particularly in material handling processes. Inefficient material management often results in excessive waste, increased costs, and environmental degradation, impeding efforts toward sustainable development. Blockchain technology, with its decentralised, transparent, and secure features, has been identified as a potential solution for enhancing efficiency and accountability in material handling. However, its adoption in the Malaysian construction sector remains limited. Therefore, this study aims to identify the key factors influencing blockchain technology integration in Malaysian construction industry. Semi-structured interviews are employed using both modes, such as face-to-face or online interviews, with selected 21 respondents from various backgrounds in the construction industry. Thematic analysis was applied to the collected data to uncover insights. The findings of this research identified five critical factors influencing the adoption of blockchain technology: 1) Social, 2) Educational, 3) Technical, 4) Political, and 5) Financial. The results of the study show that factors that need to be considered are awareness of blockchain, lack of professional workforce, and government support in leveraging the use of blockchain. The findings offer a solid foundation for informed decision-making among policymakers, industry practitioners, and researchers, thereby facilitating the adoption of blockchain technology, particularly in the context of material handling within the Malaysian construction industry.

Keywords: *Blockchain Technology; Factor, Sustainability; Material Handling; Construction Industry*

INTRODUCTION

Sustainable development has become a priority in an organisation by emphasising the economy, politics, social, and environment (Ministry of Works, 2019). The rapidly developing construction sector has led to uncontrolled use of resources, slow operations, and unsystematic management and has created difficulties for organisations to improve sustainable practices (Prasetyo et al., 2024). The main goal of sustainable development is to ensure prudent use of resources, increase efficiency, and reduce side effects on the environment.

Material handling can be defined as reducing manufacturing costs and improving material handling process efficiency by transferring the appropriate material to the appropriate location at the appropriate time, in the appropriate quantity, in the appropriate order, and in the appropriate condition (Tadesse et al., 2020).

Blockchain has the unique characteristics of being able to make decentralised decisions, ensuring that each data cannot be changed, and smart contracts can automate the agreement between two parties if the conditions of both parties are met (Singh et al., 2023). Decentralised means that all operations do not depend on a single entity, middleman, or organisation; instead, they can operate by themselves (Çolak & Kağnicioğlu, 2022). Immutable means once a new block is added, any changes and modifications cannot be made to the blockchain

(Alqarni et al., 2023). Nick Szabo says a smart contract is a computerised transaction protocol that executes the contractual term of an agreement where traditionally the agreement is given verbally, or words are converted to a digital form stored in the computer (Szabo, 1996).

Material handling has been the biggest problem in the Malaysian construction industry for the last several years, and its indicators are data losses (Bello et al., 2024), non-real-time monitoring (Wang et al., 2020), and security issues (Wu et al., 2022). Because blockchain technology can identify these issues, it can be utilised to enhance the material flow and organisational sustainability of companies. However, if blockchain technology is to be used successfully in sustainable material handling, certain conditions must dominate, including technological preparedness, economics, and the availability of qualified manpower.

This study aims to address the following research questions: What are the factors that need to be considered for the adoption of blockchain technology towards sustainable material handling in the Malaysian construction industry? To answer this, the study seeks to identify the key factors influencing the adoption of blockchain technology in sustainable material handling within the Malaysian construction industry.

LITERATURE REVIEW

Blockchain Technology Integration in The Malaysian Construction Industry

The construction industry uses smart contracts to replace physical and verbal agreements with digitisation technology. Some of the work in the construction sector requires manual observation, such as material quality inspection, storage of hazardous materials, inspection of the total quantity of materials ordered, and situations that require person in charge (PIC) judgment for each work done. This process requires a lot of document storage, such as authority verification, amendment documents, and more. Smart contracts will help make it easier for the company or organisation to conduct an audit because if there is an unwanted incident, such as a building collapsing or cracking, then the authorities can find out who is responsible for confirming a work situation without following the correct procedure (Luo et al., 2019).

Blockchain is a technology that is transparent, secure, and can verify transactions through a peer-to-peer network (Ariff et al., 2024). There are several studies in the construction industry to identify the capabilities of blockchain to solve issues related to tendering, transparency, and supply chain. Tendering is the process of awarding a contract to a contractor who is eligible to carry out the project according to the offer that has been agreed between the two parties (Weerawardana & Madubashini, 2020). The weakness of traditional tendering depends on the use of a lot of paper, and central authority makes it vulnerable to fraud. This article (Ahmadisheykhsarmast et al., 2023) uses blockchain in the tendering process to ensure each transaction is safer and a smart contract that can automate the entire process without the involvement of middlemen.

The construction supply chain is a complex sector because it involves stakeholders with different backgrounds, work activities that are different from each other and require different resources and machines to make a construction project a success (Heydari & Shojaei, 2025). This makes it difficult for the construction sector to achieve harmony and effective

communication with the stakeholders involved. This researcher discusses the impact of using blockchain on the construction supply chain has had a positive impact; where the results of the integration of important information and data can ensure that the construction supply chain is organised and runs smoothly, as well as give practical guidelines to the construction sector for the implementation of blockchain into their respective organisations (Wang et al., 2025).

The deficiencies found in conventional construction information storage, unsystematic tendering systems, and fragmented construction supply chains are the main factors for the integration of blockchain with existing systems. Blockchain features can launch operations because they are decentralised, immutable, and can operate digitally; that is, with the help of smart contracts, they can overcome the risk of fraud, unsystematic document management, and poor communication. However, to ensure this implementation is successful, several factors need to be taken into account, namely the level of awareness of the construction sector towards blockchain, government support in making the use of blockchain successful, information resources, and skilled professional energy must be sufficient to spread the benefits and potential of blockchain in the construction industry.

METHODOLOGY

This study employs a qualitative method, allowing respondents to express their opinions and views more openly and in greater detail compared to the limited scope typically found in articles or journals (Azmi et al., 2022). Interviews provide a platform for respondents to share more comprehensive insights. There are several steps that need to be followed, such as the quantity of the number of respondents, the determination of the sample, the need to get the consent of the respondent, the equipment used during the interview, and how to analyse the data obtained. Figure 1 shows the methodology flow chart in this study.

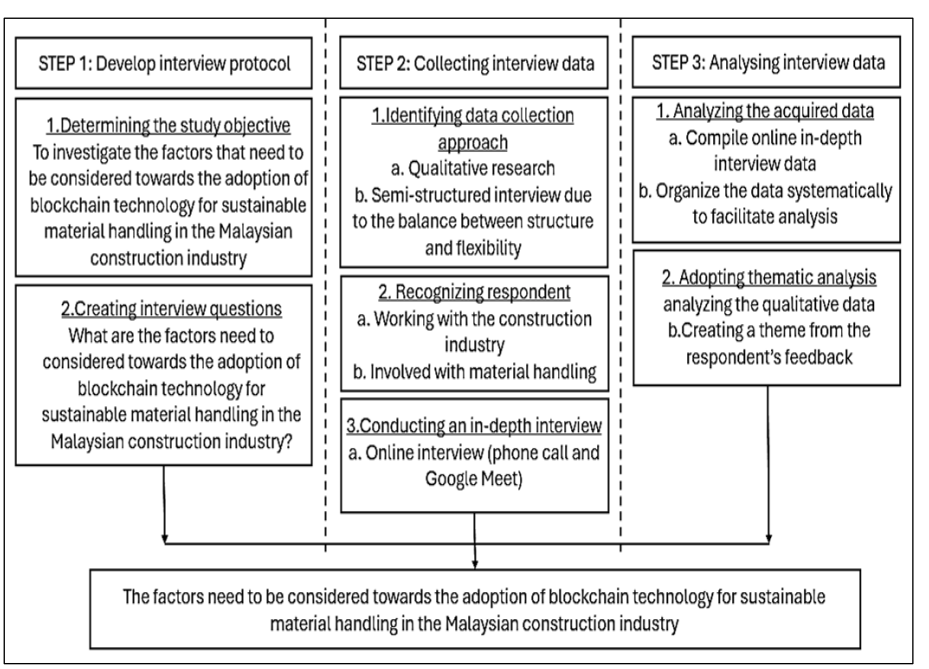

Figure 1. The Methodology Flow Chart

Research Approach: Semi-Structured Interviews

Data collection for this study was carried out through semi-structured interviews with 21 respondents from diverse professional backgrounds, including project managers, site engineers, site supervisors, inspectors of work, safety and health officers, and procurement executives. The purpose of selecting respondents from different professions was to capture a range of perspectives, as each profession involves different scopes of work, methods, and levels of technology use depending on their respective companies. The article (Bekele & Ago, 2022) suggested that 20 to 60 respondents are sufficient to explore the factors that need to be considered for the adoption of blockchain in sustainable material handling. The interviews were conducted via phone calls, Google Meet, and face-to-face meetings, as many respondents faced time constraints for in-person interviews. This online approach facilitated greater participation and allowed respondents to fully cooperate in answering the questions relevant to the ongoing study.

Sampling Method: Purposive Sampling

Table 1. Respondent's Demographic

No of Respondent	Stakeholder	Current Position	Years of Industrial Experience
R1	Main contractor	Site Engineer	9
R2	Subcontractor	Site Supervisor	6
R3	Main contractor	Safety & Health Officer	7
R4	Consultant	Inspector of Work	32
R5	Developer	Assistant Project Manager	14
R6	Subcontractor	Project Manager	8
R7	Consultant	Site Engineer	7
R8	Consultant	Inspector of Work	31
R9	Main contractor	Procurement Executive	10
R10	Main contractor	Project Manager	26
R11	Subcontractor	Instrumentation Engineer	12
R12	Subcontractor	Project Manager	15
R13	Main contractor	Site Safety Supervisor	5
R14	Main contractor	Site Engineer	5
R15	Government	Civil Engineer	9
R16	Subcontractor	Site Engineer	6
R17	Developer	Site Supervisor	6
R18	Main contractor	Safety & Health Officer	10
R19	Main contractor	Manager, Co-Developer cum Quantity Surveyor	5
R20	Main contractor	Procurement Executive	7
R21	Government	Site Engineer	9

Respondents were selected using purposive sampling based on specific criteria, including individuals with more than 5 years of experience in the Malaysian construction industry and extensive skills and expertise in on-site material handling. According to data released by (Kamarul & Sebri, 2023), once a developer signs the Sale and Purchase Agreement (SPA) issued by KPKT, the developer is required to complete the project within a specified timeframe. Landed projects must be completed within 2 years, while strata projects, such as condominiums and apartments, must be completed within 3 years. Therefore, individuals with more than 5 years of experience in the construction industry are likely to have been directly

involved in developer-related projects, as such projects typically take 2 to 3 years to complete. Thus, respondents with more than 5 years of experience are deemed sufficient to answer the questions related to the study. The purpose of using purposive sampling is to ensure that the selected respondents possess specific experience in on-site material handling, providing more relevant and informed responses compared to a random selection of respondents (Caron & Markusen, 2016). Table 1 above presents the demographic of 21 respondents who were being interviewed.

Data Analysis: Thematic Analysis

This research uses thematic analysis to identify appropriate themes related to the information provided by the respondents. The information obtained is very extensive and diverse; therefore, classifying and separating the data according to appropriate groups or themes will facilitate the process of translating the data obtained. Figure 2 below demonstrates the steps of thematic analysis in this study. Finally, the process concludes with the creation of a comprehensive report (Nowell et al., 2017). Overall, the factors to be considered for the adoption of blockchain technology in sustainable material handling were categorised into sub-themes and themes accordingly.

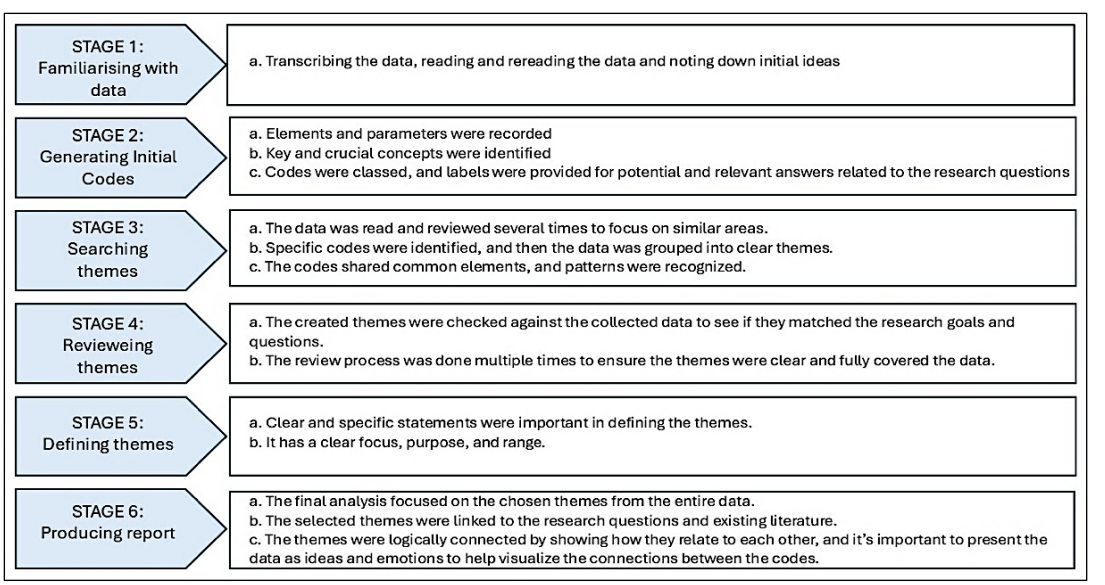

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Figure 2. Steps of Thematic Analysis in This Study

RESULTS

This study presents the findings from interviews with 21 highly experienced respondents in the Malaysian construction industry, particularly in on-site material handling. Figure 3 below provides a summary of the themes and sub-themes related to the factors that need to be considered for the adoption of blockchain technology in sustainable material handling within the Malaysian construction industry. There are five main themes: technical, social, educational, political, and financial. The details of each theme and its sub-themes will be discussed in the following subsection.

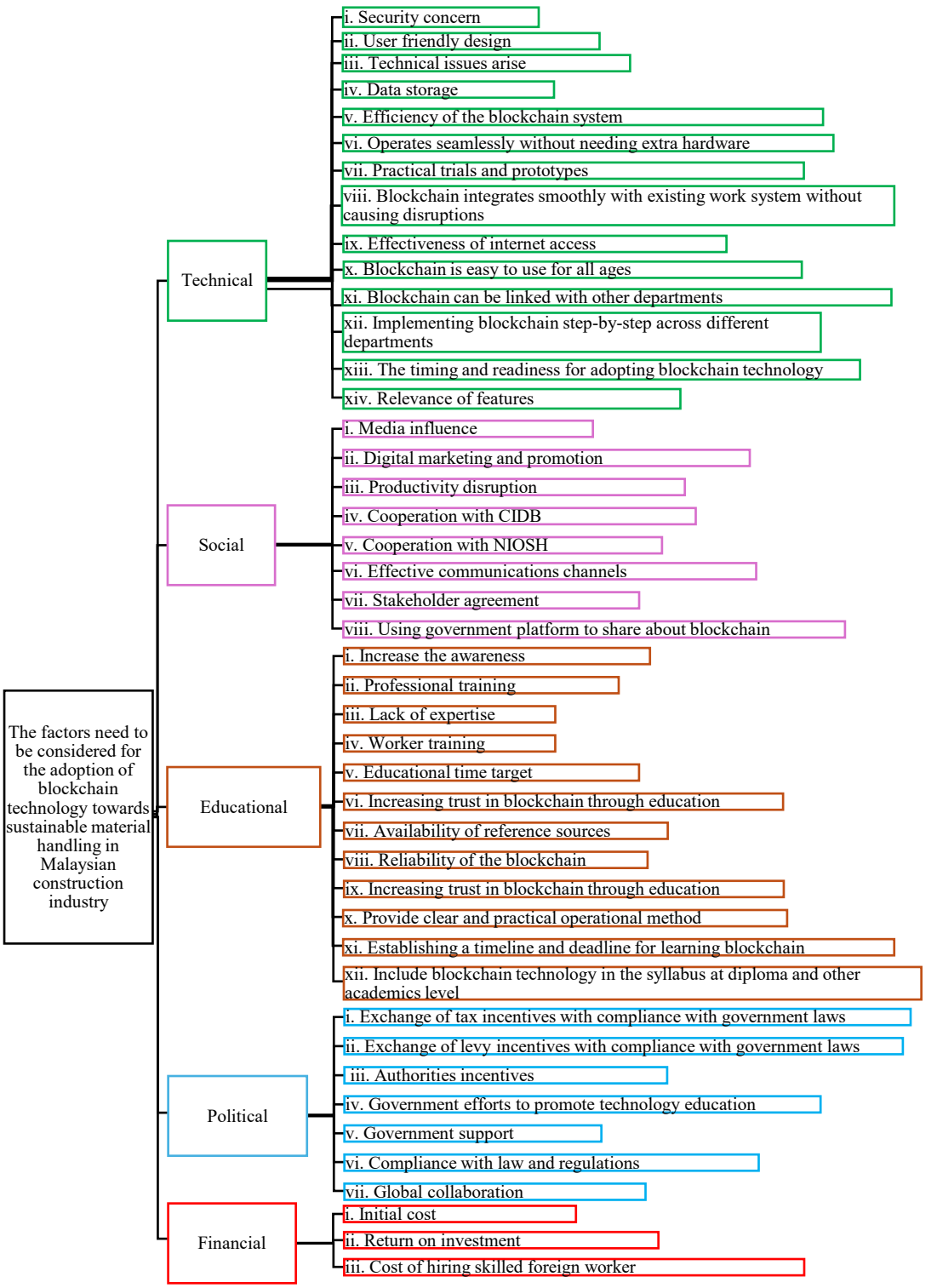

Figure 3. The Phases of Identifying the Themes and Sub-Themes for The Adoption of Blockchain Technology for Sustainable Material Handling in Malaysian Construction Industry

DISCUSSION

Technical

The use of blockchain for material handling within the context of sustainable practices may lead to several technical challenges. These challenges arise due to the nature of blockchain and the need to transition from traditional methods to new approaches. Some of the key technical issues that could significantly impact the use of blockchain in sustainable material handling include:

Operates seamlessly without needing extra hardware. Typically, the PIC is an individual who works on-site without a fixed location and frequently moves between sites to monitor progress. If blockchain cannot be easily accessed via mobile phones, it will create difficulties for the PIC in using it efficiently. A blockchain system that can be accessed through a mobile phone or a simple application would not only make it easier for the PIC to use but also increase the likelihood of organisational adoption. Additionally, it would reduce the company's costs for providing ongoing technical support. A summary of the interview is provided as an example below:

> *"Making blockchain technology easily accessible through smartphones, ensuring functionality without the need for additional hardware." (Respondent 5)*

Implementing blockchain step-by-step across different departments. Awareness of blockchain in the construction industry remains low compared to other sectors (Zilin et al., 2023), which means that organisational acceptance may take time as a deeper understanding of blockchain is required. To facilitate smoother adoption, gradual changes should be introduced to each department rather than implementing drastic shifts all at once. This approach provides flexibility, allowing non-critical materials to continue being handled conventionally while critical materials transition to blockchain. A summary of the interview is as follows:

> *"Only certain departments use blockchain to save the company, so there is no need to invest heavily in this blockchain for departments that can still carry out manual and uncomplicated management."* (Respondent 12)

Social

The social factor is the simplest and most effective way to ensure that the benefits and potential of blockchain are widely communicated within the construction industry.

Cooperate with the Construction Industry Development Board (CIDB) Malaysia. Blockchain has not yet gained significant attention in the Malaysian construction industry compared to Building Information Modelling (BIM). The promotion of BIM in Malaysia began in 2007 when the Director of the Public Works Department (JKR) introduced it to the construction industry. Additionally, the CIDB has conducted several seminars across Malaysia aimed at fostering an understanding of BIM and promoting its benefits within construction organisations (Syed Jamaludin et al., 2022). This indicates that to facilitate the rapid dissemination of blockchain, the involvement of platforms like CIDB, along with

support from authorities and the government, is crucial. A summary from the interview with the respondent is as follows:

> *"Collaborate with CIDB to help spread blockchain technology into the construction sector."* (Respondents 8 and 13)

Educational

Dissemination of information through educational channels is the most effective way and does not require high costs but requires skilled instructors on the blockchain technology to be delivered:

Include blockchain technology in the syllabus for diplomas and other academic levels. By incorporating blockchain technology into the Malaysian education syllabus, students will graduate with a foundational knowledge of blockchain. As they enter the construction industry, where blockchain is practised in organisational operations, they will be better prepared to utilise this technology in their daily work, which will be implemented indirectly. This initiative can help the country overcome the barrier of a lack of experienced professionals in the field of blockchain. The government has enhanced Technical Vocational Education and Training (TVET) at the secondary school level to ensure that students can balance the theoretical knowledge gained in the classroom with practical applications. The purpose of TVET at the secondary school level is to ensure that students engage with real projects based on the theoretical knowledge they acquire, deepening their understanding and expertise. Encountering challenges while working on actual projects allows students to address and overcome these issues using their skills and abilities (Isa & Azid, 2021). Students who are exposed to blockchain knowledge from the high school level will develop creative and critical thinking skills, making them competitive in technological advancements alongside their counterparts in developed countries. Furthermore, any shortcomings of blockchain can be identified early and addressed swiftly before implementation in the construction industry. A summary from the interview with the respondent is as follows:

> *"Include blockchain technology in the academic curriculum to educate students from an early stage. Adding blockchain to the diploma syllabus helps students build essential knowledge and skills for their future careers."* (Respondent 20)

Political

The involvement of authorities or the government is crucial to ensure the successful implementation of blockchain in the construction industry, particularly in material handling. Several political factors must be considered, including:

Global collaboration. The implementation of blockchain in Malaysia remains at a low level. To ensure its successful adoption, global cooperation is essential, particularly with countries like China, the USA, the UK, and Australia that have effectively utilised blockchain in their organisations (Sun et al., 2023). This international collaboration allows for the exchange of skills and knowledge related to blockchain, especially in the context of sustainable material handling operations. Malaysia has extensive interactions with foreign countries to secure essential on-site materials, such as machinery, rebar, and more. Therefore,

it is crucial to establish strong bilateral relations with these partnering nations to ensure a smooth and systematic supply of materials. A summary from the interview with the respondent is as follows:

> *"Right now, many mega projects in Malaysia have a joint venture with overseas companies. This technology should be able to be accessed not only in Malaysia but also by other countries."* (Respondent 21)

Financial

In the construction industry, finance is a crucial component. Effective financial management may guarantee that the budgetary allotment for every project is regulated and stays within the predetermined expenses. The following are some financial considerations that must be made for blockchain technology to be adopted for sustainable material handling in the Malaysian construction industry:

Initial cost. Organisations must be fully aware of all the expenses associated with using blockchain, including the cost of new software and hardware, as well as the necessity to buy or rent the blockchain because there are many factors to consider, including development, maintenance, troubleshooting, updating, and many more. This upfront cost may help the organisation predict how much money will be needed to implement blockchain technology. The following is a synopsis of the respondent interview:

> *"Companies need to clearly understand the costs associated with using blockchain in their organization."* (Respondent 5)

Cost of hiring skilled foreign workers. The construction industry is becoming more complex and complicated, so the conventional way of material handling is no longer relevant. Companies are in dire need of skilled workers with blockchain, but the competition to have such individuals is very high, and it is certain that the price to be offered to such skilled individuals is too high (Kumar Singh et al., 2023). Blockchain, which is gaining attention, especially for material handling, causes companies to keep up with the development of this modern technology, and to overcome the shortage of skilled workforce, blockchain causes employers to hire skilled foreign workers to fill the shortage. The cost of accommodating skilled foreign workers is very high compared to local ones because they must be paid according to the foreign currency exchange. So, the probability of companies rejecting the use of blockchain in the organisation is very high. The summary of the interview with the respondent is as follows:

> *"Foreign currency exchange involving skilled workers from foreign countries to teach about this blockchain."* (Respondent 14)

Limitations

Among the limitations encountered during the conduct of this study is during data collection to obtain feedback from respondents because most professionals are busy carrying out essential tasks and ensuring that the interview schedule with essential tasks does not clash is not an easy task due to time constraints.

Study Implications

This study has contributed to a very valuable view of the factors that need to be considered in the adoption of blockchain technology towards sustainable material handling in Malaysian construction. The results of this study reveal that implementing blockchain step-by-step across different departments, educational time targets, government support, and initial cost are factors that need to be paid more attention to. Professional bodies in the construction industry can use this factor as a practical preliminary plan before it is officially introduced into the organisation. Policymakers can use the findings of this study to formulate policies that are in line with industry standards and regulations. The findings of this study can not only be used by the construction industry in Malaysia, but other countries can also use it as a guide by adapting these findings according to the requirements of the laws and standards of their respective countries

CONCLUSION AND RECOMMENDATIONS

This study successfully identifies the critical variables for the use of blockchain technology for sustainable material handling in the Malaysian construction industry. Conventional methods of material handling are disadvantaged by cost and time overruns, inefficiency, material theft, and disorganised storage and handling practices. There are five important factors that need to be considered in ensuring that the implementation of blockchain is done well and planned: 1) Social, 2) Technical, 3) Educational, 4) Financial, and 5) Political.

The five elements mentioned above play a very important role, especially for policymakers, developers, government, and researchers, in understanding the requirements before they are implemented into the organisation. This study has also supported Sustainable Development Goal 9 (Industry, Innovation, and Infrastructure), which is to encourage the construction industry to apply technology in the work process to be more efficient and effective.

Furthermore, the government of Malaysia can adopt public-private partnerships to promote the implementation of blockchain by addressing issues concerning data privacy, data storage, education timelines, and global collaboration. Apart from that, grant or subsidy financial assistance programs can be launched, particularly for SMEs that have challenges with the costly nature of implementation.

The main goal of this study is to identify the factors that influence the use of blockchain, so future studies need to consider obstacles and solutions for the use of blockchain in other construction sectors apart from the handling of sustainable materials such as workforce management, machinery handling, procurement, or others.

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BIM FOR SAFETY VIOLATIONS IN HIGH-RISE CONSTRUCTION: ASSESSING CURRENT IMPLEMENTATION AND CHALLENGES

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Abstract
This study examines the integration of Advanced Construction Modelling (BIM) as a proactive tool for enhancing adherence to safety regulations in multi-story construction projects in Malaysia. Employing a comprehensive mixed-methods approach, the research synthesises survey data from industry experts and practitioners with an in-depth assessment of BIM's potential to address safety risks. The investigation highlights key safety deficiencies, including insufficient fall protection measures, substandard scaffolding setups, inadequate utilisation of personal protective equipment (PPE), and poor site maintenance practices. Additionally, the study explores BIM-driven interventions, such as enhanced project visualisation, structured safety planning, and real-time hazard monitoring, which collectively facilitate the early detection of hazards and mitigation strategies. Despite its benefits, BIM adoption faces substantial barriers, including regulatory and contractual complexities, limited industry awareness, and resistance to technological shifts among industry participants. To bridge these gaps, the research proposes a strategic integration framework, advocating for robust policy reinforcement strategies, continuous professional training, cross-sector collaboration, and targeted financial incentives to accelerate BIM implementation. Ultimately, the study underscores the transformative impact of BIM technology in reshaping construction safety protocols, reducing workplace hazards, and fostering a secure and well-regulated environment for personnel in high-rise building projects.

Keywords: *Building Information Modelling; Safety Management; High-Rise Construction; Safety Violations*

INTRODUCTION

Advanced Construction Modelling (BIM) has emerged as a transformative technology in the Architecture, Engineering, and Construction (AEC) industry, offering enhanced visualisation, coordination, and collaboration capabilities throughout a project's lifecycle (Ali et al., 2022). Studies have shown BIM's potential to improve safety outcomes by identifying clashes, simulating construction sequences, and facilitating continuous project oversight on projects (Abosaq & Batool, 2024). However, research specifically addressing the mitigation of breaches of safety standards in high-rise buildings, where the risks are amplified due to height and complexity, remains limited.

Despite the promising potential of BIM to improve safety outcomes, multi-story building projects continue to be plagued by breaches of safety standards, resulting in accidents, injuries, and fatalities. This persistence can be attributed to several interconnected factors, including the lack of standardised, BIM-specific safety protocols and checklists, resistance to change due to perceived costs and complexity, and inadequate training on effectively utilising BIM for safety (Harahap et al., 2024). Furthermore, the complexity of integrating BIM data with other project information and real-time site data from sensors presents a significant obstacle to fully realising BIM's safety potential (Piniano & Iwanami, 2023). Therefore, this

study seeks to overcome existing challenges by examining the role of Advanced Construction Modelling (BIM) in enhancing adherence to safety regulations and reducing violations in multi-story building projects. To achieve this, the research is structured around three key objectives: first, to systematically identify and analyse prevalent safety breaches in Malaysia's multi-story building projects sector; second, to evaluate the extent of BIM adoption alongside the barriers hindering its effective integration into the workplace safety protocols practices; and third, to develop a comprehensive, structured implementation approach that facilitates the seamless incorporation of BIM for improving risk mitigation effectiveness in these complex construction environments.

LITERATURE REVIEW

Building Information Modelling (BIM) is revolutionising the building sector by enhancing efficiency, quality, and safety. It allows for detailed planning, visualisation, and monitoring throughout a project's lifecycle (Adepoju, 2021). BIM facilitates the development of comprehensive construction documents and intelligent data that can be used from design and construction to operation and maintenance.

Research on technology's application for improving health and safety (H&S) management in construction has grown significantly. Implementing BIM goes beyond educating workers about hazard identification; it facilitates proper maintenance of industrial equipment and contributes to a safer working environment. BIM enhances safety by enabling detailed documentation and monitoring of safety protocols throughout the project. It aids in communicating project information and delivery, positively impacting site safety (Alomari et al., 2017; Umeokafor et al., 2024). By utilising BIM, stakeholders can identify and address potential safety hazards, ensuring worker well-being and overall safety.

Despite advancements in safety technology, violations remain a significant concern, particularly in high-rise projects where risks are amplified. Common violations include inadequate fall protection, improper scaffolding, and insufficient use of personal protective equipment (PPE) (Sehsah et al., 2020). These violations often result from unsafe behaviours, hazardous conditions, and deviations from safety procedures (Emuze, 2022).

BIM offers a promising solution for mitigating these violations. Its ability to generate 3D visualisations enhances communication and understanding of safety protocols (Afzal & Shafiq, 2021). Integrating BIM with real-time monitoring and safety management systems allows for proactive hazard identification and mitigation. Case studies demonstrate BIM's superiority in reducing accidents, ensuring safety protocol adherence, and improving project efficiency compared to traditional methods (Salzano et al., 2024). This proactive approach, coupled with BIM's capacity to improve collaboration, can significantly enhance construction site safety.

Addressing the challenges of BIM implementation is crucial. Several factors contribute to safety violations, including inadequate safety training, ineffective communication, and insufficient risk assessment procedures. The rapid pace of urbanisation and increasing complexity of construction projects necessitate adopting advanced technologies like BIM to address these challenges. The adoption of BIM offers substantial advantages, particularly in remote construction projects, by enhancing management efficiency and communication while

addressing challenges such as construction quality control, material logistics, and strategic project planning to ensure seamless execution and resource optimisation (Igba et al., 2024).

Table 1 identifies the gaps in existing research on factors influencing construction safety management.

Table 1. Comparison of Gap Analysis

No.	Title	Reference	Findings	Research Gap	Research Focus
1	Bibliometric Survey for Adoption of Building Information Modelling (BIM) in Construction Industry – A Safety Perspective	(Hire et al., 2022)	The research found that BIM adoption for construction safety in India is still emerging, with limited awareness and solutions for identifying scaffolding hazards.	The research gap is the lack of adoption of BIM for safety management in high-rise construction projects in India, as there is a lack of knowledge and solutions for identifying hazards related to construction.	BIM, Construction, India, Scaffold, Scaffolding
2	BIM and Modular MEP Systems for Super-Tall and Mega – Tall Buildings	(Samarasinghe et al., 2017)	The research found that BIM enhances safety in high-rise construction by identifying and resolving MEP conflicts, reducing hazards and inefficiencies.	The research gap is the lack of research on the integration of BIM for safety violation analysis in high-rise construction projects that involve prefabricated MEP systems.	MEP, High-rise, Modular, Prefabricated, BIM
3	Improving Construction Safety with Virtual – Design Construction Technologies – A Review	(Afzal et al., 2021)	The research showed that BIM enhances construction safety through hazard identification, safety training, and planning, reducing risks and improving worksite safety.	The research gap is the lack of research on the integration of BIM with other technologies, such as VR, AR, and GIS, for safety purposes in high-rise construction projects.	Virtual design construction (VDC); BIM; augmented reality (AR); virtual reality (VR); geographic information system (GIS); 4-D BIM; construction safety; digital design technology
4	Key Factors Affecting the Application of Building Information Management (BIM) in Management of High – Rise Building Construction Volume	(Nguyen et al., 2021)	The study confirmed that BIM enhances the accuracy and efficiency of volume management in high-rise construction by optimising spatial analysis and material estimation, leading to better project coordination and resource utilisation.	The research gap is the lack of research on the integration of BIM with other technologies for safety purposes and detecting safety violations in high-rise building construction projects.	Construction volume, BIM, high-rise building, Vietnam
5	Development of Construction Site Safety Monitoring Techniques Using Worker Positioning and BIM	(Mun et al., 2023)	The study found that BIM can be used to improve safety by tracking the location of workers and equipment on construction sites.	The research gap is the lack of research on the integration of BIM with other technologies for safety purposes and real-time safety violation monitoring in high-rise construction projects.	Safety Management, Inertial Measurement Unit (IMU), Ultra–Wideband (UWB), Kalman Filter, Digital Twin

No.	Title	Reference	Findings	Research Gap	Research Focus
6	Challenges to the Implementation of Building Information Modelling (BIM) for Sustainable Construction Projects	(Kineber et al., 2023)	The study found that there are a number of challenges to the implementation of BIM for sustainable construction projects, including a lack of awareness and training, high cost, and lack of government support.	The research gap is the lack of research on the specific challenges of implementing BIM for safety management in high-rise construction projects.	Partial least square structural equation modelling; barriers; Nigeria; BIM; exploratory factor analysis; project lifecycle
7	Construction Safety on Scaffolding: Building Information Modelling (BIM) and Safety Management - A Systematic Review	(Rebelo et al., 2019)	The study found that BIM can be used to improve safety on scaffolding by identifying and preventing hazards.	The research gap is the lack of research on the integration of BIM with other technologies for safety purposes and automated hazard identification in high-rise construction projects that involve scaffolding.	Construction, Safety, BIM, Scaffold, Scaffolding.
8	Survey Evaluation of Building Information Modelling (BIM) for Health and Safety in Building Construction Projects in Malaysia	(Alaloul et al., 2023)	The study found that BIM can be used to improve health and safety in building construction projects by identifying and preventing hazards and by improving safety communication.	The research gap is the lack of research on the integration of BIM with other technologies for safety purposes and real-time hazard identification in high-rise construction projects.	BIM; traditional safety planning; health and safety; framework; Malaysian construction industry
9	BIM–based fall hazard ontology and benchmark model for comparison of automated prevention through design approaches in construction safety	(Winther Johansen et al., 2022)	The study found that BIM can establish an ontology of fall hazards and mitigation strategies, allowing for the automation of hazard identification and prevention in construction safety.	The research gap is the lack of research on the integration of BIM with other technologies for safety purposes and automated prevention of safety violations in high-rise construction projects.	Construction safety, Digital Twins, Prevention through Design, Building Information Model, Benchmark Model
10	Exploring the Role of BIM in Construction Safety in Developing Countries: Toward Automated Hazard Analysis	(Akram et al., 2022)	The study found that BIM can be used to develop a safety management framework that covers the entire lifecycle of a construction project in a developing country.	The research gap is the lack of research on the integration of BIM with other technologies for safety purposes and automated hazard identification in high-rise construction projects.	Construction safety; safety management; BIM; automation; process map
11	BIM–Based Automated Code Compliance Checking System in Malaysian Fire Safety Regulations: A User-Friendly Approach	(Ismail et al., 2023)	The study found that BIM can be used to develop an automated code compliance checking system that is user–friendly and accessible to AEC professionals.	The research gap is the lack of user–friendly and accessible BIM-based code compliance checking systems that can be used to identify and prevent safety violations in high-rise construction projects.	BIM; compliance checking; semantics; knowledge representation; visual programming language

No.	Title	Reference	Findings	Research Gap	Research Focus
12	BIM-Based Safety Leading Indicators Measurement Tool for Construction Sites	(Dadashi Haji et al., 2023)	The study found that BIM can be used to develop a safety–leading indicators measurement tool that can help to identify and prevent hazards on construction sites.	The research gap is the lack of a comprehensive, proactive approach for assessing safety violations in high-rise construction projects based on active safety-leading indicators.	BIM; safety leading indicator; knowledge base; safety management system; construction safety
13	BIM Approach in Construction Safety – A Case Study on Preventing Falls from Height	(Rodrigues et al., 2022)	The study found that BIM can be used to develop a safety plan for preventing falls from height on construction sites.	The research gap is the lack of a practical approach for integrating safety measures into construction planning to prevent safety violations in high-rise construction projects.	BIM; construction safety; planning; safety elements; construction site management; falls from height
14	Reducing Falls from Heights through BIM: A Dedicated System for Visualising Safety Standards	(Tariq et al., 2023)	The study found that BIM can be used to develop a dedicated system for visualising safety standards, which can help to improve safety on construction sites.	The research gap is the lack of a system that can help to improve the implementation of safety standards on construction sites, specifically for preventing falls from heights in high-rise construction projects.	Falls from height; OSHA; health and safety in construction; BIM; application programming interface; safety clause
15	Application of BIM in construction site safety: Systematic review	(Shukri et al., 2023)	The study found that BIM can be used to improve safety on construction sites by providing a platform for visualising and analysing safety hazards.	The research gap is the lack of a systematic review of the literature on the application of BIM in construction site safety, specifically for high-rise construction projects.	Building Information Model; construction safety; co-occurrence analysis; VOSviewer

RESEARCH SCOPE

This research investigates the factors contributing to breaches of safety standards in multi-story building projects in Malaysia and explores how BIM can be integrated to mitigate these issues. The study focuses on understanding the current state of safety practices, the prevalence of BIM adoption, and the challenges and opportunities associated with its implementation. Key industry participants participating in the research include the Department of Occupational Safety and Health (DOSH), the Construction Industry Development Board (CIDB), Safety Officers, and Site Safety Supervisors. The research employs a quantitative approach, utilising questionnaires to gather data from these industry participants on their perceptions and experiences regarding breaches of safety standards, BIM usage, and the perceived benefits and barriers to BIM adoption.

RESEARCH METHODOLOGY

This study adopted a mixed-methods research design to examine the integration of Advanced Construction Modelling (BIM) in reducing breaches of safety standards within

multi-story building projects. By incorporating both quantitative and qualitative gathering of empirical insights techniques, the research aimed to develop a comprehensive understanding of the subject. This research design was selected to capitalise on the strengths of both paradigms, enabling a more thorough and multidimensional analysis of the issue.

The literature review played a crucial role in informing the research methodology. It helped identify key themes, variables, and potential research gaps, which in turn guided the development of the research instruments and the selection of appropriate gathering of empirical insights and analysis techniques. The literature review also provided a theoretical framework for interpreting the study conclusions and situating them within the broader context of existing knowledge.

This study integrated mixed-method research strategies, supported by a comprehensive literature review, to produce rigorous and insightful findings that advance the understanding of BIM's role in improving safety within multi-story building projects.

Pilot Survey

An initial research phase was conducted to test the clarity, reliability, and validity of the research instruments. A draft questionnaire was reviewed by a panel of experts, including safety professionals and BIM specialists, to assess its content, clarity, and relevance to the research objectives. A small-scale survey was conducted with a group of industry experts and practitioners to gather feedback on the questionnaire and identify any areas for improvement. The questionnaire was revised in response to the feedback received, ensuring improved clarity, precision, and effectiveness in capturing the necessary data for the study.

Preparation for Data Collection

The primary objective of gathering empirical insights is to obtain empirical insights into the effectiveness of Advanced Construction Modelling (BIM) in reducing breaches of safety standards and improving risk mitigation effectiveness in multi-story building projects. To achieve this, the study will adopt a mixed-methods approach, integrating quantitative data from a questionnaire survey with qualitative insights gathered through semi-structured interviews. This aligns with the research objective of assessing the current state of workplace safety protocols, identifying common violations, and evaluating the potential of BIM to address these challenges. Through an extensive literature review, pertinent factors influencing risk mitigation effectiveness and BIM adoption have been identified and categorised into four main groups: (1) Technological factors (e.g., BIM functionalities, interoperability, data accuracy), (2) Organisational factors (e.g., leadership commitment, safety culture, communication), (3) Individual factors (e.g., worker competency, safety awareness, risk perception), and (4) Regulatory factors (e.g., safety regulations, BIM standards, enforcement).

Interview

Key industry participants participated in semi-structured interviews to provide in-depth qualitative insights into safety practices in multi-story building projects and the potential role of BIM in mitigating breaches of safety standards. These interviews explored industry participants' perspectives, experiences, and professional viewpoints, offering a

comprehensive understanding of safety challenges and BIM's impact on improving workplace safety protocols. This qualitative research approach proved valuable in providing in-depth insights into the complex relationship between the challenges and opportunities presented by BIM integration for workplace safety protocols. An interview protocol utilising open-ended questions was employed to facilitate detailed discussions, encouraging participants to share their nuanced insights and practical experiences freely. Participants included safety officers, BIM managers, and project managers, all of whom possess direct experience with high-rise building projects in Malaysia. Interviews were conducted either in person, at the participants' convenience, or remotely via secure online platforms, accommodating participant availability, location, and preference to maximise participation while minimising disruption to their schedules. The collected interview data is currently undergoing thematic analysis to identify recurring themes related to challenges in BIM implementation, perceived benefits of BIM for safety, and best practices for workplace safety protocols in multi-story building projects. This process involves verbatim transcription of interviews, iterative refinement of themes through discussion and comparison, and interpretation of the identified themes in relation to the research questions. This rigorous analytical approach will contribute to a comprehensive understanding of the factors influencing BIM adoption and its effectiveness in mitigating breaches of safety standards within the context of Malaysian multi-story building projects.

Questionnaire

A total of 35 questionnaires were distributed to industry experts and practitioners engaged in high-rise projects in Malaysia, including contractors, consultants, and safety officers. The questionnaire was carefully developed based on an extensive literature review, incorporating key factors essential for effective workplace safety protocols in multi-story building projects. With a 100% response rate, the high level of participation underscores strong industry interest in the research and enhances the reliability of the collected data. The findings revealed that most respondents acknowledged the significance of adherence to safety regulations and demonstrated a positive perspective on BIM's potential to improve safety efficiency, minimise workplace risks, and prevent construction-related accidents and injuries.

Data Analysis

Following the collection of data through questionnaires and interviews, the subsequent stage involves a comprehensive analysis of this information. The data gathered will undergo a thorough evaluation and summarisation to extract meaningful insights into the current state of workplace safety protocols within multi-story building projects, the prevalence of breaches of safety standards, and the potential of Advanced Construction Modelling (BIM) to effectively address these challenges.

To analyse the survey results, this research will use a few methods, namely the Relative Importance Index (RII), mean scores, standard deviation and Cronbach's Alpha. These methods facilitate the ranking and prioritisation of factors influencing risk mitigation effectiveness. They are calculated as follows:

Relative Importance Index

The questionnaire data has been analysed using SPSS software, employing descriptive statistical methods such as mean and standard deviation to assess central tendencies and data variability. Furthermore, the Relative Importance Index (RII) will be computed to prioritise factors affecting risk mitigation effectiveness and evaluate their relative significance in workplace safety protocols within multi-story building projects (Alhazmi & Alhassan, 2014).

$$\text{Relative importance} = \frac{\sum W}{AN}$$

Where: W represents the weighting given to each factor by the respondents (ranging from 1 to 5); A is the highest weight (in this case, 5); N is the total number of samples.

Cronbach's Alpha Using SPSS Software

Cronbach's alpha is a statistical measure used to assess the internal consistency of a set of items in a questionnaire or scale. It measures how closely related the items are as a group, with values ranging from 0.0 to + 1.0. A Cronbach's alpha value closer to 1 indicates a higher degree of internal consistency, suggesting that the items are measuring the same underlying construct.

RESULT AND DISCUSSION

The Reliability of The Questionnaire

A reliability test was conducted to evaluate the consistency and stability of the measurement instrument, employing Cronbach's alpha, a widely accepted metric for reliability assessment. A Cronbach's alpha value above 0.60 is generally considered acceptable, while values exceeding 0.70 indicate good reliability, and those surpassing 0.90 are deemed excellent.

As presented in Table 2, all five variables analysed in the questionnaire exhibited a high level of internal consistency, with reliability coefficients ranging from 0.711 to 0.975. These results confirm that the questionnaire serves as a reliable and valid instrument for measuring the key factors influencing workplace safety protocols in multi-story building projects.

Table 2. Reliability Statistics for Variables

Variables	Cronbach's Alpha	No. of items	Reliability
State of affairs in the current construction safety management processes	0.763	10	Reliable
Safety violation incidences commonly committed in construction	0.975	30	Reliable
Challenges in implementing BIM for construction safety	0.711	9	Reliable
Application of BIM for construction safety	0.815	12	Reliable
Strategy to profile BIM in construction safety	0.778	8	Reliable

The Analysis of Data

This chapter provides a comprehensive analysis of the data gathered from questionnaires and interviews, structured around four key areas. Firstly, it examines the demographic profile of respondents, offering insight into the characteristics of the sample group. Secondly, it evaluates the occurrence of breaches of safety standards in multi-story building projects, detailing the types and frequency of incidents. Thirdly, it assesses the current utilisation of Advanced Construction Modelling (BIM) in construction safety, examining its level of integration into workplace safety protocol strategies. Lastly, it investigates the challenges associated with BIM implementation, identifying key barriers that hinder its widespread adoption in the construction sector.

Characteristics of The Respondents

As detailed in Table 3, the respondents were predominantly male (91.4%), with the most common age bracket being 35-40 years (48.6%). The majority held a Bachelor's degree (74.3%). Engineers comprised the largest professional group (37.2%), followed by Site Supervisors (20%) and Safety Officers (17.1%). Over half the respondents (51.4%) possessed more than 10 years of working experience and had been engaged in their current project for over 3 years.

Table 3. Respondents' Profile

Gender		**Age**		**Academic Qualification**	
Male	91.4%	18-24 years	-	Bachelor's Degree	74.3%
Female	8.6%	25-30 years	28.6%	Diploma	25.7%
		35-40 years	48.6%		
		> 40 years	22.8%		
Role		**Working Experience**		**Engagement to Project**	
Engineer	37.2%	1-3 years	2.9%	<6 months	-
Director	14.3%	3-5 years	28.6%	6-12 months	27.1%
Project Manager	8.6%	5-10 years	17.1%	1-2 years	22.9%
Safety Officer	17.1%	>10 years	51.4%	2-3 years	28.6%
Site Engineer	14.3%			>3 years	21.4%
Site Supervisor	20.0%				

The Exploration of RII & AI in Assessing The Factors Involving Safety Violation Incidents Commonly Committed in Construction

This section examines the prevalence of breaches of safety standards in multi-story building projects based on the responses to the questionnaire. Respondents rated the frequency of encountering various breaches of safety standards on a 5-point Likert scale, ranging from 'Never' to 'Very Frequently. ' As tabulated in Table 4, the most commonly observed violations include 'Lack of eye and face protection' (A1) with the highest RII (0.988) and 'Lack of fall protection at height (safety harness)' (A4) ranked fourth (RII = 0.892) This highlights the critical need for stricter enforcement and awareness regarding personal protective equipment (PPE) usage, especially in high-risk activities like working at height. These findings align with observations in existing literature that emphasise the importance of adequate fall protection in multi-story building projects (Samad et al., 2024). Interestingly, while 'Lack of proper electrical wiring' (A11) and 'Lack of general machine guarding' (A12)

also ranked high in terms of RII (0.982), their AI values were relatively low (0.507) "This suggests that while these violations are recognised as important, their actual occurrence might be less frequent compared to PPE violations.

Further analysis reveals that violations related to 'Lack of trench/excavation safety' (A8) and 'Lack of scaffold safety' (A13) also ranked high (RII = 0.892), indicating potential areas for improvement in construction site workplace safety protocols. These findings are consistent with the critical role of safety culture and leadership commitment in ensuring worker safety in high-rise projects, particularly in areas with potentially hazardous conditions like trenches and scaffolds (Sankar et al., 2023).

Moreover, the relatively high prevalence of violations such as 'Lack of risky, near-miss and accident reporting' (A6) with an RII of 0.982 suggests a potential underreporting of safety incidents, which could hinder the identification of safety hazards and the implementation of preventive measures. This emphasises the need for a transparent and proactive safety reporting culture to facilitate continuous improvement in risk mitigation effectiveness.

Table 4. Descriptive Statistics of Safety Violation Incidences Commonly Committed in Construction

Code	Factors	RII	AVI	Rank
A1	Lack of eye and face protection	0.9880	0.3400	1
A2	Lack of respiratory protection	0.8980	0.5600	2
A3	Lack of foot protection	0.8980	0.5600	2
A4	Lack of fall protection at height (safety harness)	0.8920	0.6600	4
A5	Lack of stairway or elevator shaft safety	0.8860	0.5600	5
A6	Lack of risky, near-miss and accident reporting	0.8800	0.6500	6
A7	Lack of crane safety	0.8800	0.6500	6
A8	Lack of trench/excavation safety	0.8060	1.0100	8
A9	Lack of elevated storage surfaces safety	0.7880	0.3400	9
A10	Lack of fire protection	0.6980	0.5600	10
A11	Lack of proper electrical wiring			
A12	Lack of general machine guarding			
A13	Lack of scaffold safety	0.9820	0.5070	1
A14	Lack of health moratorium in the workspace and living space	0.9820	0.5070	1
A15	Lack of Logout/Tagout (LOTO) procedures during servicing and maintenance activities	0.9820	0.5070	1
A16	Lack of proper electrical systems design	0.9820	0.5070	1
A17	Lack of order and hygiene in the workspace and living space	0.9820	0.5070	1
A18	Lack of head and hearing protection	0.9820	0.5070	1
A19	Lack of torso protection	0.9820	0.5070	1
A20	Lack of hand protection	0.8920	0.5670	8
A21	Lack of wall/floor openings safety	0.8920	0.6570	8
A22	Lack of on-the-level storage surfaces safety	0.8920	0.6570	8
A23	Lack of hazard communication	0.8920	0.6510	8
A24	Lack of chemical inventory and care in handling	0.8860	0.7780	12
A25	Lack of care in performing site clearance and walkthrough	0.8800	0.6510	13
A26	Lack of care in handling high voltage overhead/ underground power lines	0.8800	0.6510	13
A27	Lack of employee health screening	0.8800	0.6510	13
A28	Lack of Powered Industrial Truck (PIT) safety (forklift)	0.8800	0.6510	13
A29	Lack of ladder safety	0.8000	1.0570	17
A30	Lack of building material inventory and care in handling	0.7880	0.3380	18

The Exploration of RII & AI in Assessing The Factors Involving The Application of Building Information Modelling (BIM) for Construction

This section presents the analysis of the Relative Importance Index (RII) and Average Index (AI) for the twelve factors involving the application of Advanced Construction Modelling (BIM) for construction, as shown in Table 5. 'Enhanced planning and design' (B1) and 'Hazardous material management' (B2) emerged as the most significant factors (RII = 0.988), highlighting the perceived importance of BIM in these areas. This aligns with findings that emphasised the benefits of BIM in improving collaboration and clash detection during the planning and design phases (Ramya & George, 2022).

Interestingly, 'Ergonomics and workforce safety' (B4) and 'Safety documentation and compliance' (B5) received relatively lower rankings (RII = 0.886), suggesting that the potential of BIM in directly enhancing worker safety and ensuring compliance might be underutilised. This observation resonates with the research gap for further investigation into the specific impact of BIM on various breaches of safety standards and the development of standardised BIM-based safety protocols.

Furthermore, the low ranking of 'Construction site monitoring' (B12) with an RII of 0.600 indicates a potential area for improvement in BIM implementation. While BIM offers capabilities for real-time site monitoring and progress tracking, its adoption for this purpose seems limited. This aligns with the findings that highlighted the need for further exploration of BIM's applications beyond specific hazards to address a wider range of breaches of safety standards in multi-story building projects (Devaiah & Keshav, 2022).

Table 5. Statistical Summary of Factors Involving The Application of Building Information Modelling (BIM) for Construction

Code	Factors	RII	AVI	Rank
B1	Enhanced planning and design	0.9880	0.3400	1
B2	Hazardous material management	0.9880	0.3400	1
B3	Maintenance and facility management	0.8980	0.5600	3
B4	Ergonomics and workforce safety	0.8980	0.5600	3
B5	Safety documentation and compliance	0.8860	0.5600	5
B6	Site logistics and access planning	0.8060	1.0100	6
B7	Visualisations and simulations	0.7940	0.1700	7
B8	Collaboration and communication	0.7940	0.1700	7
B9	Safety training and education	0.7940	0.1700	7
B10	Clash detection and risk reduction	0.7880	0.3400	10
B11	Incident investigation and analysis	0.7020	0.5100	11
B12	Construction site monitoring	0.6000	0.0000	12

The Exploration of RII & AI in Assessing The Factors Involving Challenges in Implementing BIM for Construction

This section explores the challenges encountered in implementing BIM for construction, particularly in relation to workplace safety protocols, based on the data presented in Table 6. 'Legal and contractual considerations' (C1) emerged as the most significant challenge (RII = 0.898), followed by 'Limited awareness and understanding' (C2) with an RII of 0.892. This highlights the need for clear legal frameworks and contractual provisions that support BIM

adoption, as well as comprehensive training and awareness programs to promote its benefits and address misconceptions. These findings are consistent with those that identified similar challenges in a case study on BIM implementation for workplace safety protocols in multi-story building projects (Alotaibi et al., 2024).

Interestingly, 'Skill and competency gap' (C5) exhibited a high AI value (1.057) despite a relatively lower RII (0.800). This indicates a strong consensus among respondents regarding the lack of skilled professionals capable of effectively utilising BIM for workplace safety protocols. This challenge resonates with the observations of the importance of BIM-based safety training to improve workers' safety knowledge and behaviour.

Conversely, 'Cost and resource considerations' (C9) received the lowest ranking (RII = 0.600), suggesting that while cost is a factor, it may not be the primary barrier to BIM adoption. This contrasts with the findings that identified high costs as a significant barrier. This difference could be attributed to the increasing affordability of BIM software and the growing recognition of its long-term cost benefits, particularly in enhancing safety and reducing accidents.

Table 6. Statistical Summary of Factors Involving Challenges in Implementing BIM for Construction

Code	Factors	RII	AVI	Rank
C1	Legal and contractual considerations	0.8980	0.5620	1
C2	Limited awareness and understanding	0.8920	0.6570	2
C3	Change management and resistance	0.8800	0.6510	3
C4	Scalability and industry adoption	0.8800	0.6510	3
C5	Skill and competency gap	0.8000	1.0570	5
C6	Data management and standardisation	0.7940	0.1690	6
C7	Collaboration and coordination	0.7940	0.1690	6
C8	Integration with existing workflows	0.7880	0.3380	8
C9	Cost and resource considerations	0.6000	0.0000	9

Development of Framework for Navigating the BIM-Safety Landscape in Challenging Environments

Figure 1, derived from the categorised factors in Tables 3, 4, and 5, presents a three-phase framework ("Needs, Vision, Action") for integrating BIM to enhance safety in challenging construction environments. This framework guides the process of identifying safety needs, establishing a BIM implementation strategy, and utilising BIM for enhanced planning and workplace safety protocols.

Needs Phase: This initial phase focuses on identifying and understanding the specific safety needs and challenges within the construction project or organisation. It involves analysing existing safety practices, identifying common violations, and assessing the potential root causes of these issues. This needs-based assessment ensures that BIM implementation is targeted and relevant to the specific safety concerns at hand. For example, if a project involves frequent fall hazards, the "Needs" phase would highlight the importance of BIM-enabled fall protection solutions.

Vision Phase: Once the safety needs are identified, the "Vision" phase involves establishing a clear BIM implementation strategy. This includes defining goals, objectives, and key performance indicators (KPIs) for BIM adoption. It also involves considering the various factors that influence BIM adoption and risk mitigation effectiveness, such as technological, organisational, individual, and regulatory aspects. This holistic approach ensures that the BIM implementation strategy is comprehensive and considers the broader context in which the project operates. For instance, if a project involves a large number of subcontractors, the "Vision" phase would emphasise the importance of collaboration and communication platforms within the BIM environment.

Action Phase: The "Action" phase focuses on translating the vision into concrete steps. This includes developing BIM execution plans, implementing BIM-enabled safety solutions, and utilising BIM for enhanced planning and workplace safety protocols. It also involves continuous monitoring and evaluation of the BIM implementation process to ensure its effectiveness and adapt to evolving safety challenges. This action-oriented approach ensures that the BIM implementation strategy is not just a theoretical concept but a practical tool for enhancing workplace security. For example, the "Action" phase might involve using BIM to create 3D visualisations of construction sites to identify potential hazards or to track safety inspections and incident reports.

This cyclical framework promotes continuous improvement by allowing industry participants to adapt and address evolving safety challenges. Its need-based and holistic approach ensures that BIM implementation is targeted and relevant and considers various factors influencing adoption and risk mitigation effectiveness. The framework's action-oriented approach emphasises translating the vision into concrete steps, realising BIM's full potential in enhancing safety. Its cyclical nature ensures that BIM remains relevant and effective in addressing evolving safety challenges through continuous monitoring and adaptation.

The framework's veracity is further supported by its alignment with effective workplace safety protocol principles, its comprehensive consideration of factors influencing BIM adoption, and its emphasis on continuous improvement. By incorporating these elements, the framework provides a practical roadmap for construction industry participants to navigate the BIM-safety landscape and create a safer built environment.

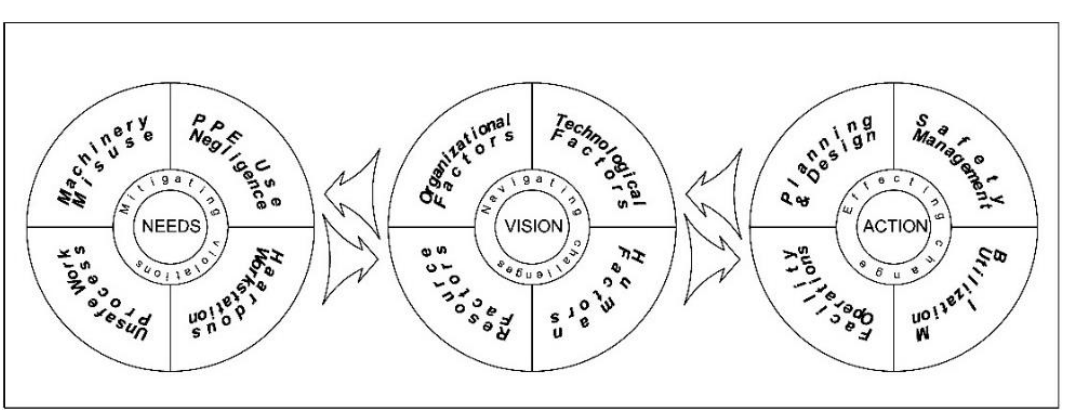

Figure 1. A Framework for Navigating The BIM-Safety Landscape in Challenging Environments

CONCLUSION

This research has successfully fulfilled its objectives by analysing the prevalence of breaches of safety standards in multi-story building projects, assessing the current state of BIM adoption for workplace safety protocols, and identifying the challenges hindering its wider implementation. The proposed "Needs, Vision, Action" framework provides a practical roadmap for construction industry participants to effectively integrate BIM and address evolving safety challenges. The findings underscore the need for increased awareness and training, proactive workplace safety protocols, and continuous improvement to maximise the benefits of BIM in creating a safer and more sustainable built environment.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support provided by grant YUTP-FRG 1/2022 (015-LC0-405).

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STRENGTH OF CONCRETE CONTAINING COMBINATION OF STEEL AND POLYPROPYLENE FIBERS

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Abstract
Fibres are primarily used as alternatives to conventional reinforcement in non-structural applications to increase the tensile strength and reduce cracking. These advantages have led to a broader application of fibres in structures, especially those with lower reliability levels, such as slabs and walls. The integration of fibres into the overall structural design of structural applications is steadily increasing. Thus, the performance of a steel and polypropylene (PP) fibre combination in concrete is the main focus of this study. The design incorporated fibre additions of 0%, 0.5%, 1.0%, and 1.5% for both types of fibres. The findings showed that adding fibres to concrete improved its strength behaviour, especially when fibres were combined, which showed a notable improvement in both compressive and cracking tensile strengths. This research significantly obtained an optimum mix combination of 1.0% PP and 1.5% steel fibre with increased compressive strength by 35.7% compared to the control specimen for compressive strength. With an increased strength of 58.8% in comparison to the control specimen, this trend persisted in splitting tensile strength. The results demonstrated that, in comparison to a low fibre combination ratio, PP and SF created superior composites. According to the study's findings, adding combination fibres to the concrete mix improved the composite's compressive and split tensile strengths.

Keywords: *PP Fibre; Steel Fibre; Workability, Strength*

INTRODUCTION

In the third quarter of 2024, Malaysia's construction industry grew by 17.3% (Daim, 2024). In place of water, concrete is the second most widely used building material worldwide (Ahsan et al., 2023). Concrete's strength, workability, and affordability make it an essential building material. Cement, aggregates, water, and additives are usually its constituents. Concrete's tensile strength and crack resistance are typically improved by adding synthetic fibres like polyester, nylon, and others (Abubakar, Akçaoğlu & Marar, 2020). Steel fibres are also used for similar purposes. These additions improve concrete's performance without compromising its existing qualities. However, the use of synthetic fibres raises concerns about waste management and environmental impact, given their non-biodegradable nature. Long-term contamination is due to synthetic fibres because they last longer in landfill areas for hundreds of years. Large areas of landfill are occupied with these waste synthetic fibres. Malaysia will reach maximum capacity for solid waste disposal at landfills by 2050 (International Trade Administration, 2024). In addition, the degradation of synthetic fibres generates microplastic particles that bring about environmental pollution. The aquatic life and soil conditions are affected by the entrance of these particles through soil erosion and surface runoff (Liou, 2021). Proper disposal and recycling methods are essential to mitigate these issues. New production of synthetic fibres can be reduced, and more landfill areas can be saved. Research indicates that optimal percentages of synthetic fibres (around 0.5%) can significantly enhance concrete's strength without affecting its workability. Combining synthetic fibres with steel reinforcement further enhances concrete's durability and structural

integrity. This combination reduces the need for excessive steel while improving overall performance, cost-effectiveness, and sustainability in construction projects. Research by Abu Bakar et al. (2020), Patel, Desai and Desai (2012), and Qi, Weiss and Olek (2003) significantly found a contribution to improving the toughness of concrete by fibre. Therefore, the incorporation of steel and polypropylene (PP) fibres in concrete addresses these issues and improves overall strength. Synthetic fibres are widely utilised for reinforcing concrete. Abu Bakar et al. (2020) claimed that adding fibres to concrete offers several benefits, including preventing sudden failure, increasing fracture energy, reducing crack width, minimising shrinkage, and enhancing flexural, tensile strength, and toughness. The inclusion of a range of 1.0% to 1.5% of PP fibre volume improved the concrete's split tensile, flexural, and compressive strength (Qi et al., 2003). Research by Qi et al. (2003) found that adding steel fibres generally enhanced the ductility and toughness of the concrete. In fact, Qi et al. (2003) addressed that while synthetic fibres improved the behaviour of fresh concrete and minimised plastic shrinkage cracking.

Adding steel fibre as bridging tensile matrix concrete significantly enhances the toughness and strength properties of concrete, increasing both compression and tensile strength by approximately 20% (Karya, Sameera & Keshav, 2022). Steel fibres distribute loads uniformly across concrete structures, extending their lifespan. The curing period of concrete influences its compressive strength, with longer drying periods generally resulting in greater strength and cohesion (Irwan et al., 2013; Irwan et al., 2014). The effectiveness of steel fibre depends on factors such as its blended well dispersion within the concrete (homogeneous mix) and the optimal selection of volume fibre over the volume of concrete. Steel fibres outperform other materials like polyester, polyethene, and nylon due to their high aspect ratio, low water absorption, improved impact and abrasion resistance, and overall durability (Zhong et al., 2021). High volumes of steel fibres (exceeding 2% of concrete volume) can achieve robust mechanical properties without additional continuous reinforcement, enhancing compressive strength and crack prevention by evenly distributing loads and stresses through the concrete. In practical applications, the spacing between steel fibres and their physical parameters (such as shape, thickness, and length density) are critical for assessing concrete's features and resistance. Misri et al. (2018) claimed an increment of 79.1% in the tensile strength of concrete compared to control and concrete containing 2.0% fibre. However, smaller volumes of steel fibre, which is less than 0.5%, may not significantly improve tensile strength. All things considered, steel fibre reinforcing enhances the post-cracking behaviour of lightweight, high-strength concrete, which lowers costs by lowering the requirement for extra crack control techniques. Steel fibres are also beneficial in other fields of civil engineering, such as road components, instead of making concrete. Steel fibres can be added to stone mastic asphalt and porous asphalt to improve the stability and strength of the roads. Jasni et al. (2020) indicated the optimum percentage of 0.4% had effectively minimised the loss of binder, thus reducing the voids of aggregate structure. Higher fibre content resulted in greater stiffness, making the asphalt more durable to be used under high loads for a period of time. The use of steel fibres prevented the asphalt mixture from deforming. According to Radzi et al. (2020), the engineering qualities of porous asphalt were improved by the use of steel fibres. In the LA abrasion test, steel fibres with a percentage of 0.6% demonstrated the best results. For 0.5% steel fibres, the greatest resilient modulus values were 15% at 25°C and 10% at 40°C. The density and Marshall stability were considerably improved by adding 0.2% of steel fibres.

The objective of this study was to examine the mechanical characteristics of concrete that contains PP and steel fibres in both fresh and hardened states. Combining synthetic fibres with steel reinforcement further enhances concrete's durability and structural integrity. This combination reduces the need for excessive steel while improving overall performance, cost-effectiveness, and sustainability in construction projects. High manufacturing of steel fibres leads to the depletion of natural resources. Iron ore and coal are the primary resources for the production of steel fibres. Steel consumption achieved 7.9 million metric tonnes in 2023, which developed by 4.5% for the third consecutive year (Malaysia Investment Development Authority, 2024). Reduction of a new production of steel fibres can conserve natural resources. Other than that, minimising the fabrication of steel fibres also reduced landfill operation and waste management costs. Malaysia's government used up around 5.24 billion USD annually in solid waste management (Pentas Flora, 2022). Reusing steel fibres in the construction industry reduces the financial burden on the government.

In conclusion, integrating PP and steel fibres in concrete produces advantages in terms of long-lifetime structure, durability, and economy. This study is concerned with environmental-friendly, economic, and social benefits. The utilisation of steel and PP waste fibres as additional materials in concrete is considered sustainable construction since the waste fibres are resource-efficient. At the same time, a healthy environment protects the human and all other organisms in the world. Various costs can be saved, such as construction costs and waste management costs. This approach represents a promising direction for constructing resilient and long-lasting infrastructure.

EXPERIMENTAL SET UP

Materials

The Ordinary Portland Cement (OPC), a maximum of 20mm coarse aggregate and a maximum of 5mm fine aggregate, were used. The steel and PP fibres, as shown in Figure 1 and Figure 2, were added to the concrete mixture as supplementary fibre materials. The characteristics of both fibres utilised for this research are shown in Table 1.

Table 1. Specification of Fibres

Fibres	Specification				
	Type	Diameter (m)	Length (m)	Tensile strength (N/mm^2)	Young's modulus (N/mm^2)
Steel	Hooked-end	0.00075	0.06	1100	205000
PP	-	0.001	0.05	-	-



Figure 1. Hooked-end Steel Fibres



Figure 2. PP Fibres

Methods

In this research, the volume of fibre used was 0%, 0.5%, 1.0%, and 1.5% for both PP and steel fibres. Research made by Khalid et al. (2018) has been used as a reference for the mixture design of concrete. Other than that, the water-cement ratio in this research was 0.5. Table 2 shows the percentage of fibre design in total mixed concrete by volume. A total of 90 specimens were produced, including 60 cubes with dimensions 100 mm × 100 mm × 100 mm and 30 cylindrical moulds with dimensions 100 mm × 200 mm. Three tests were conducted, namely a slump test following ASTM C143, a compressive strength test following BS EN 12390-3:2019, and a splitting tensile strength test according to ASTM C496.

Table 2. Mixture Proportion for $1m^3$ of Concrete

Mix Designation	PP Fibre (%)	Steel Fibre (%)	Cement (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)	Water (kg/m^3)	PP Fibre (kg/m^3)	Steel Fibre (kg/m^3)
Control	0	0	390	975	800	195	0	0
P 0.5 - S 0.5	0.5	0.5					10.93	39.8
P 0.5 - S 1.0	0.5	1.0					10.93	79.6
P 0.5 - S 1.5	0.5	1.5					10.93	119.4
P 1.0 - S 0.5	1.0	0.5					21.86	39.8
P 1.0 - S 1.0	1.0	1.0					21.86	79.6
P 1.0 - S 1.5	1.0	1.5					21.86	119.4
P 1.5 - S 0.5	1.5	0.5					32.79	39.8
P 1.5 - S 1.0	1.5	1.0					32.79	79.6
P 1.5 - S 1.5	1.5	1.5					32.79	119.4

Slump Test

The slump test was conducted in accordance with ASTM C143 to evaluate the workability of fresh concrete, and it must be done immediately after mixing concrete. First, the concrete was placed in the cone and made sure the cone was placed on the flat floor. Second, the concrete sample was then divided into three layers before being placed into the cone. Each layer was blown with a steel rod 25 times. Third, the slump cone was taken out upwardly and then the mixture of concrete moved by itself without any vibration. Finally, the reading of the slump was taken. The slump test control sample is depicted in Figure 3.



Figure 3. Slump Test for Fresh Concrete with PP and Steel Fibres

Compressive Strength Test

The compressive strength of the concrete was assessed based on BS EN 12390-3:2019. A compression machine was used to provide static compression loading to 100 mm × 100 mm × 100 mm cubes at 7 and 28 days of age for each mix. First, the concrete cube samples were taken out from the curing tanks, and the excess moisture was wiped off. Second, the concrete cube sample was placed onto the Automatic Compression Machine (ATM) and c with respect to the lower platen. The constant loading rate of 0.6±0.2MPa/s was used. Third, the concrete cube sample was subjected to a load perpendicular to the casting direction until it failed. Lastly, the maximum load was noted, and the compressive strength for each mix design was calculated.

Splitting Tensile Strength Test

The purpose of this test was to ascertain the concrete's tensile strength. The process used cylindrical moulds of 100 mm in diameter and 200 mm in length, which were evaluated after 28 days in accordance with ASTM C496. The cylindrical samples of concrete were first removed from the curing process, and the surplus moisture was cleaned off. Second, a jig was used to position the cylindrical concrete sample in the centre of the Automatic Tension Testing Machine. The loading pieces and packaging strips were positioned along the top and bottom of the samples' loading plane. During loading, the top and lower platens were parallel. They set the stress rate at 0.05±0.01 MPa/s. Third, the load continued until the sample failed. Ultimately, the highest load was noted, and the tensile splitting strength was evaluated.

RESULTS AND DISCUSSION

Slump Test

The selected slump value was ranged in between 60 and 180 mm. The slump values dropped from 70mm to 60.1mm in this research. Among fibre-reinforced concrete, the 0.5% PP and 0.5% steel fibres had the best workability, with a slump value of 64.1mm. It demonstrated that the workability of the concrete decreased with the addition of fibres to the slurry. This is due to the fibres' ability to distribute moisture. As seen in Figure 4, the slump value for the control specimen was 70 mm, showing great workability. The slump value of concrete with steel and PP fibres was lower than that of control concrete. Nevertheless, the slump value of the concrete with extra fibres was still within the range allowed for a true slump. This implies that the slump value somewhat dropped as the concrete's fibre volume rose.

It demonstrates how adding fibres reduces the fluidity of the material and, consequently, the concrete's workability. Concrete's rheological properties were improved, which reduced the structure's segregation (Patel & Kulkarni, 2013). The results demonstrated that with 1.0% PP fibre and 1.5% steel fibre, the slump reading remained above 60 mm. However, when a higher combination of these fibres was used, particularly with a 1.5% mix of both fibres, the lowest recorded slump value was 60.1 mm. The workability of the concrete decreased much more as the proportion of steel and PP fibres increased. This reduction in workability, especially with higher PP fibre content, is due to more air being trapped in the voids, making it harder to compact the mix (Patel & Kulkarni, 2013; Zaki et al., 2020). Fibres' geometry

also interrupted the viscosity of concrete mixtures (Yaqin et al., 2024). Additionally, steel fibres tend to clump for various reasons, such as pre-existing clumps before mixing and the use of high-volume fibres (Patel & Kulkarni, 2013).

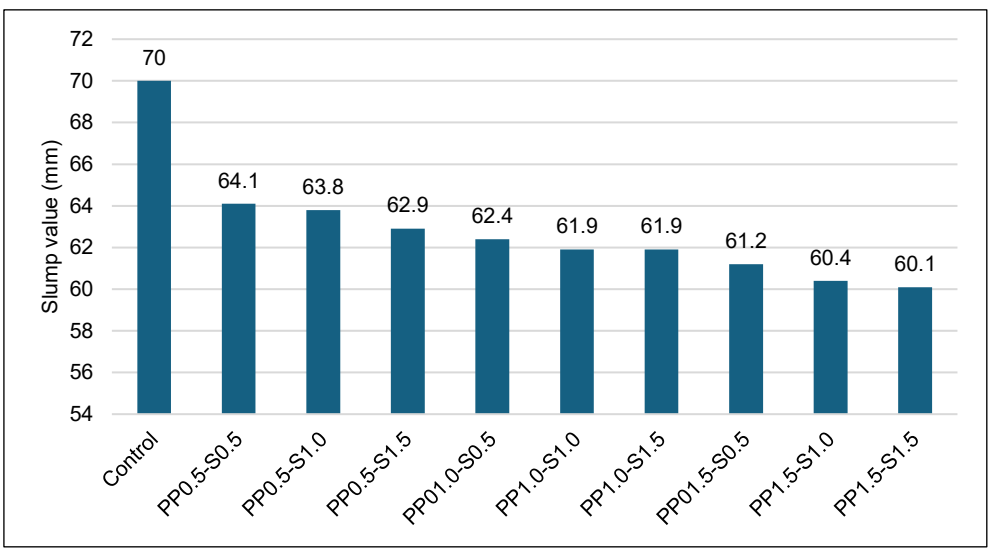

Figure 4. Slump Test Results

Compressive Strength

After 28 days, the average compressive strength of regular concrete was 31.1 MPa, which was the desired compressive strength. After 28 days, the best mix was determined to be concrete with 1.0% PP fibres and 1.5% steel fibres, which increased strength by 35.7% above the control, as seen in Figure 5. At 28 days, this sample's compressive strength of 42.2 MPa was the greatest. Its compressive strength of 31.1 MPa was marginally greater than that of the control specimen at 28 days. After 28 days, the concrete mix containing 0.5% PP fibres and 0.5% steel fibres had the lowest compressive strength, 33.5 MPa. The 1.0% PP fibre sample had the highest compressive strength among the top three. The compressive strength of each sample at day 28 was higher than at day 7.

Beyond the optimal mix classification, the strength trend did, however, indicate a modest decline. It is clear that the strength of fibre-containing concrete rose somewhat from the fibre-free mix (PP 0% to S0%) to the PP1.0% to S1.5% mix. Previous studies have demonstrated that PP fibres delay the onset of initial cracking and help resist crack development (Sun & Xu, 2009). The bonding of concrete was boosted with the addition of fibres (Ahsan et al., 2023). However, a higher volume of PP fibres reduces the concrete's strength, as they interfere with its cohesiveness (Ahmed et al., 2022). Inadequate PP fibre dispersion and hydrophobic characteristics prevented the PP fibres from adhering to the cement and aggregates in the concrete, which resulted in low cohesiveness (Ahmad et al., 2022; Popa et al., 2023). The occurrence of a weakened strength enhancement effect if there is an excessive volume of fibres leads to low compact concrete (Li et al., 2024). Additionally, the results show that steel fibres add more toughness than polypropylene fibres. More specifically, hooked-end steel fibres improve concrete's hardness more than other fibre kinds (Blazy & Blazy, 2021).

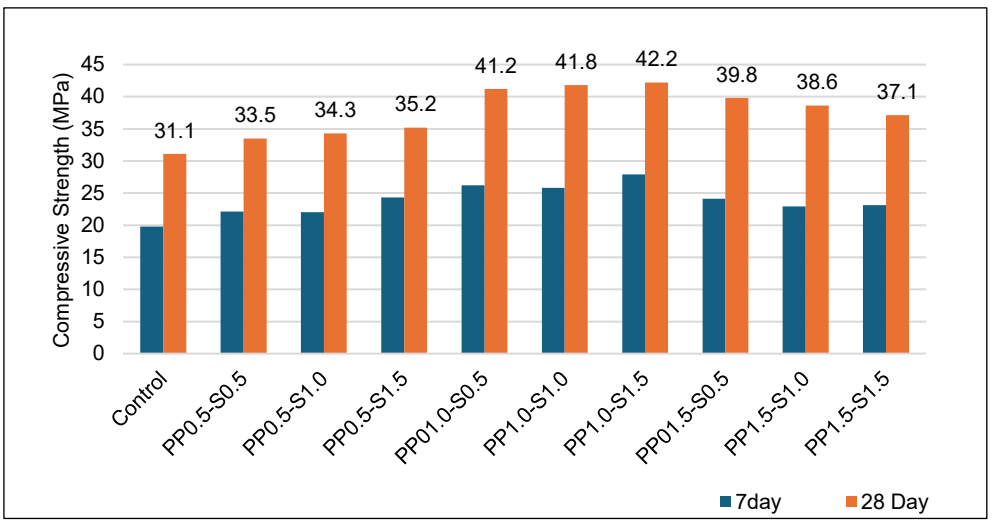

Figure 5. Compressive Strength Results

Splitting Tensile Strength

Figure 6 displays the findings of the splitting tensile strength test for the control and steel and PP fibre-containing concrete. The control concrete's average strength after 28 days was 2.11 MPa. Since all of the fibre-reinforced concrete's tensile strengths were higher than 2.11 MPa, the material's tensile strength significantly improved. Concrete with 1.0% steel fibres and 1.0% PP fibres was the best combination fibre design. This mix design produced an average strength of 3.35 MPa, a considerable increase of almost 58.8% above the control. The findings unequivocally demonstrate that the split tensile strength was increased by adding steel and PP fibres to the concrete mixture. As demonstrated by the mixes PP 1.5% and steel fibres 0.5%, PP1.5% and steel fibres 1.0%, and PP1.5% and steel fibres 1.5%, which had tensile strengths of 3.01 MPa, 3.09 MPa, and 3.00 MPa, respectively, the tensile strength somewhat declined in comparison to an ideal mix design when the PP fibres content surpassed 1.0%. The fibre-reinforced concrete containing 0.5% PP and 0.5% steel fibres had the lowest tensile strength, measuring 2.89 MPa.

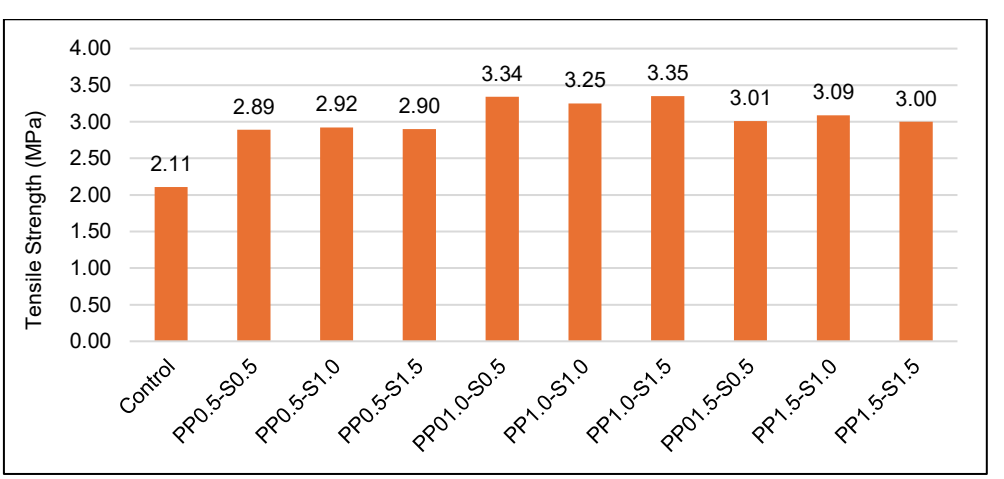

Figure 6. Splitting Tensile Strength Test Results

The problem of low tensile strength was successfully resolved by adding steel and PP fibres to the concrete mixture. It was observed that PP fibres contribute to bridging the fractures, absorbing internal tensile stresses, and slowing down the propagation of cracks once microcracking has started (Blazy & Blazy, 2021). A comprehensive network was formed by the uniformly distributed fibres within concrete (Li et al., 2024). When there was only little fibre content, the strengthening effect was hard to reach (Li et al., 2024). However, the results indicate that increasing the PP fibre content above 1.0%, especially at 1.5%, resulted in a drop in strength, proving that the idea that tensile strength always rises with increased fibre volumes is not totally accurate. The strength decreased as a result of the fibre-matrix adhesion being weakened by an excessive amount of fibre (Gigante et al., 2024). Poor stress is dispersed throughout the matrix and into individual fibres (Ismail & Ishak, 2018). The variety of fibre bundles also resulted in the formation of inter-fibrillar spaces.

However, by interfering with the cohesiveness of the concrete, a larger amount of PP fibres weakens the material (Mazenan et al., 2018). The results suggest that steel fibres enhance toughness more effectively than PP fibres, with hooked-end steel fibres being particularly effective at improving concrete toughness compared to other fibre types (Blazy & Blazy, 2021). According to Fathilah and Tan (2016), the addition of steel fibres to normal concrete matrices improves their mechanical qualities by bridging cracks and residual tensile strengths.

CONCLUSION

The purpose of this study was to evaluate the workability, compressive strength, and splitting tensile strength of concrete that contains steel and PP fibres in a concrete matrix.

- Although the higher fibre percentage has an impact on fresh concrete's workability, it is still within an acceptable range for a real slump. The slump for the fibre-containing concrete and the control concrete, which had a value of 70 mm, varied between 60.1 and 64.1 mm, indicating a medium degree of workability.
- The concrete's compressive strength was raised by the addition of steel and PP fibres.
- The problem of low tensile strength was successfully resolved by adding steel fibres and PP to the concrete in increasing volumes. By acting as fibre bridging, the addition of steel and PP fibres enhanced its performance and tensile load resistance.
- 1.0% PP and 1.5% steel fibres are the most appropriate and ideal ratio of combined fibres in concrete since they demonstrated the highest compressive and tensile strength while maintaining workability within the chosen slump value.
- While adding additional steel and PP fibres can increase the strength of the concrete, adding more than 1.0% PP may result in a minor decrease in strength, even though it is still higher than that of regular concrete.

ACKNOWLEDGEMENTS

This research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through GPPS (Q788). The assistance from the Research Management Centre (RMC), is greatly appreciated.

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THE CLIENT'S ROLE IN PREVENTION THROUGH DESIGN UNDER THE CONSTRUCTION WORK DESIGN MANAGEMENT REGULATIONS 2024 IN MALAYSIA

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Abstract
The Malaysian construction industry continues to struggle with high injury and fatality rates, largely due to the late integration of safety measures in project lifecycles. Prevention through Design (PtD) addresses this issue by embedding safety considerations from the design phase. In response, the Department of Occupational Safety and Health (DOSH) introduced the Occupational Safety and Health (Construction Work) (Design and Management) Regulations 2024 to promote PtD adoption. However, compliance remains low, primarily due to insufficient client involvement in safety management. This study develops a conceptual framework emphasising the critical role of clients in implementing PtD under the new regulations. Through an extensive review of key legislation, including the Occupational Safety and Health (Amendment) Act 2022, the framework was validated by expert panels. The findings highlight that clients play a central role in ensuring regulatory compliance and fostering a proactive safety culture among project stakeholders. The framework underscores the importance of client leadership in early-stage risk management and interdisciplinary collaboration, offering significant implications for improving safety performance, project sustainability, and operational efficiency. By providing structured guidance, this framework supports clients in aligning their responsibilities with safety regulations, ultimately enhancing project safety and overall success.

Keywords: *Client; Duties; Compliance*

INTRODUCTION

From 2017 to October 2023, statistical data indicates that the Malaysian construction industry recorded the highest fatality rate among all sectors, with 548 fatal incidents, surpassing the 427 in manufacturing (DOSH, 2024). The peak of these fatalities occurred in 2018, with 118 cases, up from 111 in 2017. Although the fatality rate has been declining in recent years, it remains far from the zero-accident target set by the AEC industry (Labadan et al., 2022). In this case, researchers have increasingly highlighted the potential for significantly reducing construction-related injuries by incorporating safety measures during the design phase rather than limiting safety efforts to the construction stage (Toole et al., 2016). This emphasis stems from evidence that a considerable number of construction accidents and fatalities result from design deficiencies that overlook safety considerations for construction, maintenance, and demolition (Driscoll et al., 2008; Haslam et al., 2005; Hossain et al., 2023; Xiahou et al., 2018). Consequently, proactive risk management at the design stage is essential to eliminating hazards before they emerge on-site (Tuan Hai & Ngoc Tu, 2024), aligning with the approach of PtD.

In general, PtD is a comprehensive approach focused on reducing or eliminating the risk of accidents, injuries, and health hazards by proactively identifying and addressing potential dangers during the initial design stages of a project (Che Ibrahim & Belayutham, 2020; Gambatese, 2019; Goh & Chua, 2016; Guo et al., 2021; Samsudin et al., 2022). It encourages designers, such as architects, as well as civil and structural engineers, to proactively address risks from the outset by considering the safety of site workers and the full lifecycle of the building, including construction, operation, maintenance, and demolition, in their architectural and structural designs (Che Ibrahim & Belayutham, 2020; Toole et al., 2016).

Accordingly, a prime example of PtD principles in action is the success of the London Stadium project. By integrating safety considerations from the earliest stages of design, the project achieved zero fatalities, even on a project of its immense scale. The collaborative approach facilitated by the New Engineering Contract (NEC), which emphasised early engagement and communication among project partners, allowed potential risks to be addressed during the design phase rather than during construction, thus aligning with PtD's goal of minimising hazards through proactive planning (Blamire-Brown, 2010). However, the conventional divide between design and site safety, where architects and engineers remain detached from safety responsibilities, which are predominantly assigned to contractors, continues to hinder the effective implementation of PtD (Karakhan & Gambatese, 2017; Mohd et al., 2020). Therefore, clients, who are the building owners or developers, play a crucial role in promoting PtD implementation in construction projects.

To strengthen the role of clients in ensuring safety and health in the construction industry, Malaysia has integrated client responsibilities into the Occupational Safety and Health (Construction Work) (Design and Management) Regulations 2024, enforced under the Occupational Safety and Health (Amendment) Act 2022. In this context, a client refers to any entity or individual commissioning a project. These regulations mark a significant shift by prioritising safety and health considerations across the entire project lifecycle, particularly during the crucial design phase. This approach aligns Malaysia with international best practices, such as the United Kingdom's Construction (Design and Management) Regulations and Singapore's Design for Safety framework, both of which have been instrumental in reducing workplace hazards and fatalities. However, the successful implementation of the regulations hinges on a comprehensive understanding of stakeholder duties, particularly those of clients, who now hold a legal and ethical mandate to advocate for safety from the outset of a project. Therefore, considering the high-risk nature of Malaysia's construction industry and its troubling history of workplace fatalities, there is an urgent need to bridge the knowledge gap and equip clients with the tools and guidance to fulfil their roles effectively.

Nevertheless, despite the introduction of the regulations, research on PtD in Malaysia remains limited due to the regulations being in their early stages of enforcement. Existing studies primarily focus on barriers to PtD implementation (Azmi & Misnan, 2013), awareness among stakeholders (Abas et al., 2020; Che Ibrahim & Belayutham, 2020; Christermaller et al., 2022; Samsudin et al., 2022, 2023), the duties of designers (Samsudin et al., 2021), and designer competency (Ibrahim et al., 2022). However, there is a notable gap in research addressing the critical role of clients in PtD implementation.

To address this gap, this study aims to develop a comprehensive conceptual framework that underscores the critical role of clients in facilitating the implementation of PtD in construction projects. Specifically, the objectives are twofold: first, to identify the duties of clients as defined by the Occupational Safety and Health (Amendment) Act 2022 and the Occupational Safety and Health (Construction Work) (Design and Management) Regulations 2024, and second, to develop a structured framework to guide clients in integrating PtD principles into their projects. This framework not only ensures compliance with the new legislation but also contributes to fostering a safer, more sustainable construction environment.

LITERATURE REVIEW

The literature review explores the PtD implementation in the Malaysian construction industry, focusing on its integration through the Occupational Safety and Health (Amendment) Act 2022 and the Occupational Safety and Health (Construction Work) (Design and Management) Regulations 2024. A key emphasis is placed on the roles and responsibilities of clients in effectively adopting and embedding PtD within their construction projects. This analysis is guided by the identification of critical clauses within the Act and Regulations, which specifically outline client duties and align with the study's objectives. Ultimately, these critical clauses serve as the foundation for developing a conceptual framework that underscores the pivotal role of clients in ensuring PtD implementation.

Application of Prevention Through Design (PtD) in The Malaysian Construction Industry

In response to the pressing need to improve Occupational Safety and Health (OSH) in the local construction industry, DOSH has adopted the PtD concept into industry practices. This initiative is inspired by successful frameworks from countries such as the United States, United Kingdom, Singapore, Australia, and South Korea, where legislation clearly defines the roles and responsibilities of construction stakeholders, such as designers, contractors, and clients, to prioritise safety from the pre-construction stage by mitigating risks during the design phase (Ismail et al., 2022). Accordingly, the updated PtD legislation includes regulations, such as the Construction (Design and Management) Regulations 2015 in the United Kingdom (Ndekugri et al., 2023) and Workplace Safety and Health (Design for Safety) Regulations 2015 in Singapore (Toh et al., 2016). Other legislation includes PtD guidelines, such as ANSI/ASSP Z590.3-2021 in the United States (Popov, 2016) and the Design Safety and Health Ledger System in South Korea (Shin et al., 2023). Furthermore, there is also a code of practice for PtD in Australia, which is the "Code of Practice: Safe Design of Structures" (Toh et al., 2016). Therefore, DOSH has also strengthened the legislation for PtD in the Malaysian construction industry with the enforcement of the Occupational Safety and Health (Construction Work) (Design and Management) Regulations 2024 on 1st June 2024, including amendments to the Occupational Safety and Health Act 1994, which is known as the Occupational Safety and Health (Amendment) Act 2022. These initiatives aim to elevate OSH standards in the Malaysian construction industry by encouraging a proactive approach to risk management, with a strong emphasis on the design phase. Consequently, under the newly implemented legislation, clients now assume a key responsibility in ensuring that safety and health regulations are upheld and sustained throughout the entire project lifecycle. By actively promoting a culture of safety and regulatory compliance, clients facilitate the early

integration of risk mitigation strategies, ensuring that all stakeholders prioritise OSH requirements from the initial design stage through to project completion.

Occupational Safety and Health (Amendment) Act 2022 (Act A1648)

The Occupational Safety and Health (Amendment) Act 2022 (OSHA (A) 2022) serves as an important update to the original Occupational Safety and Health Act 1994 (OSHA), which has been a cornerstone of workplace safety legislation in Malaysia. Enforced by DOSH, the original OSHA 1994 consists of 15 parts, 67 sections, and three schedules, clearly outlining the responsibilities of employers, employees, and the government in maintaining high workplace safety standards (Abdullah, 2013). As the expectations surrounding workplace safety evolve, effective management of OSH has become increasingly critical, including the integration of PtD principles. Hence, OSHA (A) 2022 introduces significant updates and modifications to strengthen workplace safety provisions, including the removal of two sections, amendments to 35 sections, and the addition of 27 new sections and two schedules, resulting in a comprehensive framework of 92 sections and five schedules. Ultimately, while OSHA 1994 laid the groundwork for OSH in Malaysia, OSHA (A) 2022 enhances the law to address contemporary workplace challenges, broaden its scope, and implement stricter enforcement measures to better protect workers' safety and health.

Accordingly, OSHA (A) 2022 underscores the principle that those who create the risks are responsible for managing them. In this context, Section 18 of the amended act highlights the critical roles of clients, designers, and contractors in assessing and managing safety and health risks associated with construction hazards. In this case, clients are primarily responsible for ensuring compliance with OSHA provisions across all stakeholders, including contractors and designers, while also creating a safe work environment from the initial design stage to the project's final completion. Furthermore, clients must appoint qualified personnel to oversee safety practices, facilitate clear communication and coordination among project teams, and allocate adequate resources for implementing safety measures. Ultimately, clients are now expected to actively implement preventive strategies in their construction projects while continuously monitoring and reviewing safety procedures. This proactive approach is essential for maintaining compliance among project stakeholders and fostering a robust culture of safety throughout the entire project lifecycle. Therefore, key provisions of the OSHA (A) 2022 include six critical clauses: Section 15, Section 18A, Section 18B, Section 20, Section 29A, and Section 31, each of which the client plays a vital role in ensuring that all project stakeholders adhere to.

Table 1 summarises the six clauses of OSHA (A) 2022 that require the client's facilitation. For instance, Section 15 establishes a general duty of care, obligating the client to ensure all necessary safety measures are in place. Sections 18A and 18B emphasise the importance of involving qualified personnel, such as the principal designer and contractor, to conduct and implement thorough risk assessments. Furthermore, Section 20 requires collaborative efforts among stakeholders to ensure the design and equipment planned for use in the project are safe for the workers on-site. Moreover, Section 29A outlines the role of an OSH coordinator, who supports the client in ensuring a safe and healthy work environment. Meanwhile, Section 31 requires that all workers receive sufficient safety and health training before starting on-site activities. Together, these clauses reinforce the client's role as a key facilitator in embedding

a culture of safety at every level of project execution. Below is Table 1, which presents an overview of client-specific clauses within OSHA (A) 2022.

Table 1. Critical Clauses in Occupational Safety and Health (Amendment) Act 2022

OSHA (A) 2022 Clauses	Context	Description
Section 15	General duties of employers	Employer refers to any individual or entity that has entered into a service contract to hire another person as an employee. The duties include: • Ensure a safe working environment for all employees. • Ensure safe plant and systems of work. • Ensure employees receive sufficient information, guidance, training, and supervision on safety and health practices. • Provide welfare facilities. • Establish and enforce protocols to manage emergencies that may occur during employees' working hours.
Section 18A	Duties of principal	Principal refers to an individual or entity, such as a developer or project owner, who engages a contractor or subcontractors to carry out all or part of the construction work. The duties include: • Ensure a safe working environment for the contractor, sub-contractor or indirect sub-contractor, and employee employed by such contractor or sub-contractor at work. • Ensure safe plant and systems of work. • Allocate sufficient time, budget, and resources. • Ensure employees receive sufficient information, guidance, training, and supervision on safety and health practices. • Ensure safe maintenance of the place of work. • Establish and enforce protocols to manage emergencies that may occur during employees' working hours.
Section 18B	Duty to conduct and implement risk assessment	Mandates that employers, self-employed individuals, or principals conduct risk assessments and implement risk control measures in the workplace. The duties include: • Conduct hazard identification. • Conduct risk analysis or risk evaluation. • Implement risk control.
Section 20	General duties of manufacturers, etc., as regards plant for use at work	Assign responsibility to designers, manufacturers, importers, or suppliers of workplace equipment. The duties include: • Ensure the plant is designed and constructed to be safe. • Carry out testing and examination necessary for the performance of the plant. • Ensure sufficient information is provided regarding the intended use of the plant and the testing it has undergone. • Provide sufficient revisions of information provided for any new risks. • Eliminate and minimise risks to safety and health in accordance with the design or plant. • Ensure a safe working environment.
Section 29A	Occupational safety and health coordinator	Impose the need to appoint an employee to act as an Occupational Safety and Health Coordinator (OSH-C) to assist employers in coordinating OSH legislation and OSH programs in the workplace.
Section 31	Occupational safety and health training course	Impose the need for a certain "class or description of persons" to attend prescribed OSH training to ensure those prescribed employees gain enough exposure and knowledge before performing work activities.

Occupational Safety and Health (Construction Work) (Design and Management) Regulations 2024

Following the adaptation of OSHA (A) 2022, the Occupational Safety and Health (Construction Work) (Design and Management) Regulations 2024 (CDM Regulations, 2024) were enacted by DOSH on the 1st of June 2024. This regulation is part of a comprehensive update to OSHA aimed at improving safety and health standards in the local construction industry by integrating risk management from the design phase onward. Its primary goal is to prevent accidents, minimise risks, and encourage early hazard identification through the PtD approach. The regulation clearly outlines the specific responsibilities of all stakeholders on OSH, including clients, designers, and contractors, ensuring their collaboration in identifying, assessing, and mitigating risks throughout the construction lifecycle. Additionally, it promotes enhanced communication and coordination among stakeholders, holding them legally accountable for maintaining a safe working environment (Miao, 2024). However, since the regulation is newly enforced, compliance remains low due to insufficient client support. In Singapore, client involvement is pivotal in driving PtD practices among designers. Clients are expected to play an active role by encouraging designers to consider OSH during the design phase, ensuring that tenders include provisions for safety and health costs, and withholding construction work until a comprehensive safety and health plan is in place (Samsudin et al., 2023). Therefore, Malaysia has adopted this approach as a best practice by emphasising the crucial role that clients play in ensuring that all project stakeholders comply with safety and health regulations.

Table 2. Client Duties in CDM Regulations 2024

Regulations	Client Duties	Description
Reg.4	Client duties in relation to project management	A client is any principal or any person for whom a project is carried out. The duties include: • Provision of adequate time, funding, and resources. • Ensure that construction work can be carried out without any risks to OSH. • Ensure welfare facilities are provided.
Reg.5	Pre-construction information and construction phase plan	The client must provide pre-construction information (PCI) before the conceptual design stage and ensure that the principal contractor or contractor prepares the construction phase plan (CPP) before the construction phase commences. • PCI plays a key role in the planning and risk management of a project by providing relevant information about potential hazards, site conditions, design considerations, and any existing Safety and Health files before construction begins. • CPP is the safety and health plan that is crucial for ensuring safety, efficient coordination, and effective risk management throughout the construction phase.
Reg.6	Compliance with safety and health	The client has the responsibility to ensure that the principal designer and principal contractor comply with safety and health regulations.
Reg.7	Appointment of principal construction work designer and principal construction work contractor	The client must appoint a competent principal designer to control the pre-construction phase and also appoint a principal contractor. This appointment is to ensure safety coordination from the design phase through to the construction phase.
Reg.8	Notification	The client must notify the Director-General of DOSH before the construction phase begins.
Reg.9	Application to domestic client	A domestic client is someone who has a project built or carried out for personal reasons not related to any business activity. For this reason, all duties of the client under regulations 4, 5, 6, and 8 will be carried out by the contractor, principal contractor, or principal designer.

Table 2 highlights the duties of the client based on the CDM Regulations 2024 in Malaysia, including effective project management, preparation of PCI, ensuring stakeholder safety compliance, appointing qualified principal designers and contractors, and submitting required project notifications. These duties position the client as a central figure in promoting structured safety and regulatory compliance throughout the project lifecycle. The following presents Table 2 for client-specific clauses within CDM Regulations 2024.

FRAMEWORK DEVELOPMENT

The development of the conceptual framework builds on an extensive review of relevant literature, particularly the OSHA (A) 2022, read together with the OSHA 1994, as well as the CDM Regulations 2024. The framework is constructed by identifying and synthesising key clauses pertaining to client duties from these regulatory documents. Based on the literature review, the client's responsibilities in OSHA (A) 2022 and OSHA 1994 are derived from the employer's duties, while clauses from the CDM Regulations 2024 are drawn from "Part 2: Client Duties." Furthermore, aligned with the CDM Regulations 2024, the developed framework places the client at the core, emphasising their role in ensuring all project stakeholders adhere to safety and health obligations as stipulated by the latest regulatory standards, including OSHA (A) 2022 and OSHA 1994. This central positioning of the client underscores their influence in fostering a proactive culture of safety across the project lifecycle.

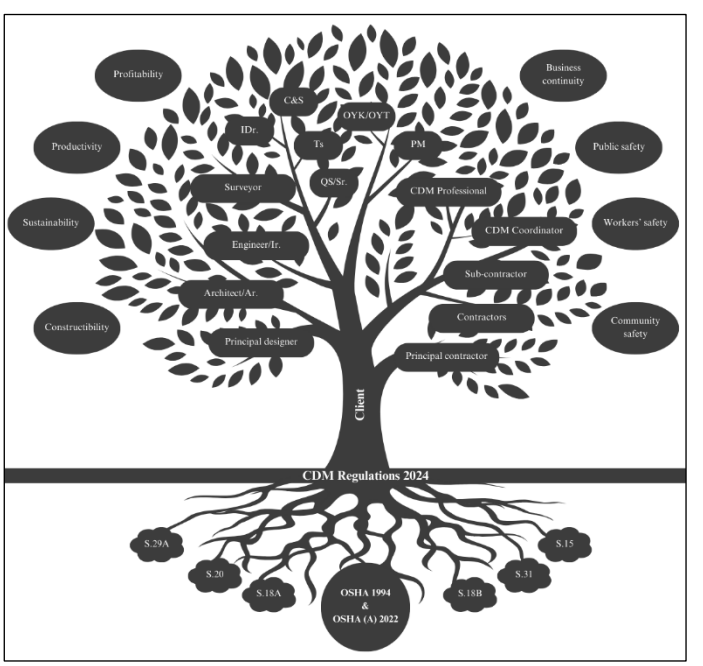

Figure 1. Client's Role to Ensure Compliance with Safety and Health

Figure 1 presents the conceptual framework, metaphorically represented as a tree. The roots symbolise the foundational commitment to safety principles and compliance, anchoring the project in the robust regulatory groundwork depicted as the soil. The trunk represents the client's pivotal role in driving the implementation of the CDM Regulations 2024, promoting a culture where safety and health considerations are integral to the project from its inception.

Extending from the trunk, the branches signify the collaborative efforts of principal stakeholders, such as the principal designer, principal contractor, consultants, and other team members, who work collectively to identify and mitigate risks while ensuring compliance with the Regulations and Acts. The framework's culmination is illustrated by the fruits, representing the tangible benefits of compliance. These include enhanced safety, sustainability, productivity, constructability, profitability, business continuity, and improved well-being for workers, the community, and the public.

In conclusion, this metaphorical representation effectively conveys the critical role of clients and highlights how a deeply rooted commitment to regulatory compliance and stakeholder collaboration fosters a safer, more sustainable, and successful construction environment. Figure 1 illustrates the framework for the role of client to ensure compliance with safety and health.

FRAMEWORK VALIDATION

The conceptual framework was validated through a panel of four subject-matter experts. This number of experts was deemed sufficient for fundamental content validation in smaller-scale studies (Yusoff, 2019). These experts were carefully selected based on their credentials as certified trainers under DOSH and their extensive knowledge and practical experience with the CDM Regulations 2024. Their active involvement in CDM training programs further ensured their familiarity with the duties of stakeholders under the regulations, especially the client.

The primary objective of the validation process was to assess the framework's reliability, relevance, and accuracy in addressing the critical duties of the client under the CDM Regulations 2024. The validation was conducted through a structured focus group discussion, where all four experts convened to collaboratively evaluate the framework. Each expert conducted an in-depth review of the framework, offering detailed feedback on its comprehensiveness, clarity, and practical applicability in real-world construction scenarios. During the discussion, the experts provided critical insights, highlighting areas that required refinement to better align the framework with the practical challenges and expectations of the construction industry. Suggestions included minor adjustments to improve clarity, emphasise the metaphor, and enhance the framework's overall usability in facilitating compliance with safety and health standards. Therefore, in response to the experts' recommendations, the framework was revised to address the identified gaps and improve its applicability. The revised version, presented in Figure 1, underscores the pivotal role of the client in ensuring compliance with safety and health requirements. It also emphasises the client's responsibility in driving the effective implementation of the CDM Regulations 2024 among project stakeholders. These revisions enhanced the framework's ability to serve as a structured protocol for achieving regulatory compliance and fostering safer construction practices.

DISCUSSION

Table 3 provides an overview of the five key layers of responsibility within the conceptual framework illustrated in Figure 1, highlighting the client's critical role in ensuring that all project stakeholders comply with safety and health regulations, specifically the CDM Regulations 2024, OSHA 1994, and OSHA (A) 2022.

Table 3. Description of Five Layers of Framework

Framework Layers	Items	Description
Roots	OSHA 1994 and OSHA (A) 2022	OSHA 1994 and the OSHA (A) 2022 serve as the foundation for compliance with the CDM Regulations 2024, reinforcing employee rights and expanding employer responsibilities for better risk management and clearer communication of workplace hazards. Together, these laws are the cornerstone of a safe working environment, with strict penalties for non-compliance, ensuring that all parties prioritise safety and health in the workplace.
Ground	CDM Regulations 2024	The CDM Regulations 2024, part of OSHA 1994 and OSHA (A) 2022, aim to enhance safety and health in construction projects by embedding risk management from project planning onward. The regulation outlines the duties of the project team, particularly the client, designers, and contractors. It emphasises the need for collaboration among all stakeholders to identify, assess, and mitigate risks across the entire construction lifecycle and imposes penalties for non-compliance to enhance enforcement and encourage better adherence to safety regulations.
Trunk	Client	Client, as the pillar of the framework, will support the adoption of CDM Regulations 2024 in their construction projects. In accordance with the adoption, the client has obligations to ensure that the entire project team complies with safety and health regulations. All in all, the client plays a pivotal role in allocating sufficient funds, time, and resources to enable the project team to execute the construction projects without any risks to safety and health.
Brunches	Project team	The project team working for the client must fulfil the client's requirements, including full compliance with OSHA and the CDM Regulations 2024. This involves close collaboration across the entire project lifecycle, particularly during the design phase, to mitigate construction risks and hazards jointly. Effective collaboration is essential to ensure clear communication of all instructions and project details, enabling the team to address safety and health concerns comprehensively and efficiently.
Fruits	Outcome	The project's success lies in the client's role to support, motivate, and ensure that the entire project team complies with CDM Regulations 2024, alongside OSHA 1994 and OSHA (A) 2022. Adhering to these legal frameworks not only enhances constructability, sustainability, productivity, and profitability but also positively impacts public safety, community well-being, and worker protection, thus ultimately contributing to long-term business continuity.

Each layer in the framework represents a distinct aspect of the client's duty to uphold regulatory standards and encourage a collaborative, safety-focused approach among project stakeholders. These layers collectively emphasise the importance of the client's leadership in fostering an environment where PtD is integrated from the earliest project phases. Through active support and motivation, the client encourages project stakeholders to align with safety provisions, creating a ripple effect that extends beyond compliance. This leads to better project outcomes, including improved safety, efficiency, and sustainability, while also positively influencing the well-being of the broader community. Table 3 provides a detailed breakdown of these aspects, illustrating how each element contributes to a comprehensive approach to safety and health in construction projects.

Accordingly, in a construction project, the commitment to safety begins with the roots, where the project team ensures compliance with the CDM Regulations 2024 through CDM workshops and necessary CDM professional certifications. Next, the soil represents the regulatory environment, where the project manager and legal team align safety protocols with the regulations and update risk management plans. Furthermore, the trunk symbolises the client's role in driving safety, appointing qualified stakeholders, and allocating resources to ensure compliance. Moreover, the branches illustrate the collaborative efforts of stakeholders like the principal designer and contractor, working together to identify and mitigate risks. Finally, the fruits represent the benefits of compliance, including fewer accidents, increased

productivity, sustainability, profitability, and long-term business continuity, all contributing to a safer, more efficient project with positive impacts on the community and the public.

Despite the introduction of the CDM Regulations 2024 and amendments to OSHA, stakeholders may face challenges in navigating the complexity of these regulations, especially during the early stages of implementation. Clients may struggle to understand their expanded responsibilities, and other stakeholders might lack clarity on aligning their practices with regulatory requirements. The absence of standardised guidelines for PtD could lead to inconsistent implementation, while traditional divisions between design and construction phases hinder the integration of safety considerations early on. To address these barriers, industry associations and regulatory bodies should collaborate to provide clear guidelines and standardised templates. Additionally, early-stage collaboration through Integrated Project Delivery (IPD) models can foster better stakeholder cooperation, while leveraging technologies like Building Information Modelling (BIM) can streamline communication and ensure safety is incorporated throughout the planning and building process.

CONCLUSIONS

The conceptual framework proposed in this study emphasises the essential role of clients in implementing PtD under the CDM Regulations 2024. Although experts have validated the framework, its practical application has yet to be tested. A notable limitation of this study is the absence of statistical data or survey findings to assess its effectiveness in real-world scenarios. Future research should focus on conducting case studies or field testing to evaluate the framework's applicability in actual construction projects, providing empirical data on the impact of regulatory compliance and the client's role in enhancing safety outcomes. Furthermore, while this study primarily centres on the client, expanding research to explore the roles of other stakeholders, such as designers and contractors, would offer a more holistic understanding of PtD implementation. Investigating the collaboration and interactions among these stakeholders will further strengthen the framework. Additionally, integrating emerging technologies like Building Information Modelling (BIM) and Artificial Intelligence (AI) could modernise PtD practices and align the framework with advancements in the construction industry. All in all, given the high-risk nature of the Malaysian construction industry and the need for regulatory compliance, this framework presents an important step towards improving safety standards and fostering a culture of risk mitigation. Industry stakeholders, including construction firms, regulatory bodies, and project managers, are strongly encouraged to implement this framework in real-world projects. By embracing a client-focused approach to PtD, they can ensure that safety remains a priority from the initial design stage to project completion, fostering a safer, more sustainable, and regulation-compliant construction environment. Addressing these research gaps and taking action to implement the framework will drive meaningful improvements in construction safety across Malaysia.

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FACTORS, RISKS AND CHALLENGES IN SELECTING IOT TECHNOLOGIES TO IMPROVE SAFETY IN SMART CAMPUSES

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Abstract
The Internet of Things (IoT) has become prevalent for safety in smart campuses, enabling interdisciplinary security collaboration throughout its lifecycle. IoT enhancing safety in smart campuses could improve the efficiency of smart campus planning and administration through a high-quality design and project safety. However, obstacles to adopting IoT technologies in the decision-making process hinder the implementation of the technologies on smart campuses. Thus, this requires an investigation into the factors influencing, the risk involved, and the challenges that play a role in decision-making in determining IoT technologies to improve smart campus safety. Therefore, this study aims to identify the factors, risks, and challenges in selecting IOT technologies to improve smart campus safety. The study interviewed 20 safety personnel who have experience in occupational health and safety management or are responsible for coordinating Occupational Safety and Health Administration (OSHA) or safety-related regulations from private and government universities. The data collected through the semi-structured interview was analysed using thematic analysis. The results of the study revealed five themes for the factor to improve safety in smart campuses, which are competency, financial, technology, infrastructure, and management; five themes of the risks, which are management, technology, safety competency, financial and infrastructure; and five themes for challenges, which are management, competency, system, human and financial. This study contributes to decision-making and strategic planning for implementing IoT technologies to enhance safety. They provide a practical foundation for policymakers and university administrators to prioritise resources and effectively address critical risks and when integrating IoT solutions into campus safety frameworks.

Keywords: *Internet of Things (IoT); Smart Campus; Safety; Decision Criteria; OSHA*

INTRODUCTION

The Internet of Things (IoT) has been rated as a critical technological leap that stands out as a notable advancement in IT, promising improved efficiency that has the potential to merge various technologies, ultimately improving the overall quality of campus life (Nord et al., 2019; Hsu & Lin, 2018: Anuar et al., 2024). Although IoT services have seen considerable growth, the factors driving sustained usage still need to be explored (Riggins & Wamba, 2015; Min-Allah & Alrashed, 2020). Nevertheless, the IoT has an impact spanning from individual users to large corporations, with implications across various sectors and different environmental levels, including educational institutions of all sizes (Min-Allah & Alrashed, 2020; Pandey et al., 2020; Rao & Prasad, 2018). Thus, integrating IoT solutions within universities promises multiple benefits for on-campus and off-campus stakeholders.

IoT is transforming education by enhancing learning and digitising traditional methods. However, selecting an optimal, smart and safe school system remains challenging. Khan et al. (2024) propose a hybrid multi-criteria decision-making (MCDM) approach, combining

Entropy and Technique for order of preference by similarity to ideal solution (TOPSIS) methods. Entropy evaluates the importance of ten educational systems based on twelve criteria, while TOPSIS ranks alternatives, identifying the most efficient IoT-based school system. The complexities of smart cities include political, technical, and socioeconomic challenges. As security, privacy, and data management concerns grow, their study synthesises key literature and develops a smart city interaction framework, covering themes like mobile security, infrastructure, healthcare, and citizen adoption of smart services (Ismagilova et al., 2022). Moghayedi et al. (2024) investigate safety and security challenges at the University of Cape Town, a campus in a high-crime area, highlighting the role of facilities management (FM). Their study reveals that past community participation efforts were ineffective and suggests that community-based FM (CbFM) and technological innovations could improve safety and security. Polin et al. (2024) explore the smart campus concept and identify a gap in evaluating campus smartness. Their narrative literature review proposes an evaluation framework to assess and improve smart campus initiatives, offering a comprehensive tool for researchers and decision-makers. Despite the growing recognition of IoT's potential in smart campus development, limited research has focused on analysing the risks, challenges, and factors influencing the successful implementation of IoT.

Furthermore, the IoT improves campus interactions and management through various procedures, creating a safer environment and proactively preventing accidents, near misses, and fatalities. However, a knowledge gap in the existing body of research on IoT security solutions within smart campuses requires a comprehensive revaluation of criteria selection. Ahmed et al. (2022) have explored stakeholders' perspectives on the criteria for smart campuses. Min-Allah and Alrashed (2020) have introduced a novel approach centred around IoT, explaining the concept of smart campuses within an IoT framework. This gap in the literature underscores the need for further research to address the practical obstacles and conditions necessary for the effective deployment of IoT technologies in smart campus initiatives. Thus, this study aims to identify the factors, risks, and challenges involved in selecting IoT technologies to improve safety on smart campuses, which will serve as a platform for the decision-making process.

METHODOLOGY

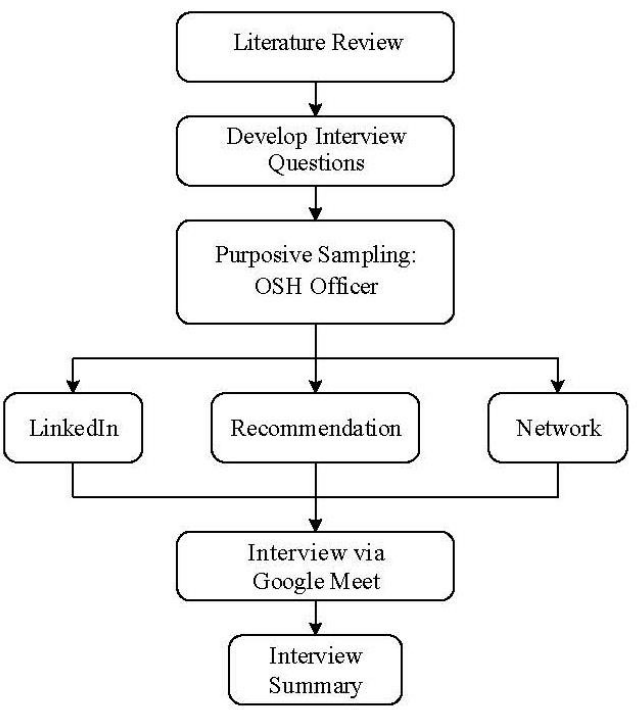
The study's methodology involves a systematic approach that begins with a literature review to establish a foundation of knowledge and identify research gaps. This is followed by a definition of the study objectives to develop the interview questions. Finally, thematic analysis was conducted to identify common themes for factors, risks, and challenges in selecting IoT technologies for improving safety in smart campuses. Figure 1 shows the methodology flowchart for this study.

Interview Questions

As shown in Figure 1, the study's methodology involves a systematic approach that begins with a literature review to establish a foundation of knowledge and identify research gaps. A definition of the study objective follows this to develop the interview questions. The primary interview questions revolved around three key areas:

1. Participants were asked to identify criteria when selecting IoT technology that would have safety implications for establishing smart campuses.
2. Participants were asked to identify the challenges to integrating safety-focused IoT technologies to pursue smart campus objectives.
3. Participants were asked to identify the risks associated with safety-related IoT technologies in the context of smart campuses.

These three questions were thoughtfully designed to extract information on various aspects of IoT adoption on smart campuses, encompassing factors, risks, and challenges.



(Source: Author, 2024)

Figure 1. Methodology Flowchart

Data Collection

Interviews were conducted with 20 construction safety professionals to gather insights on the factors, risks, and challenges involved in selecting IoT technologies for enhancing safety in smart campuses. The respondents were occupational safety and health (OSH) officers or individuals responsible for campus safety across 20 universities in both the public and private sectors in Malaysia. Participants included safety officers, OSH directors, assistant directors, IoT managers, and engineers with varying levels of expertise in OSH management-related operations. Purposive sampling was employed to select interviewees with at least five years of working experience. This sample size was considered sufficient, as similar sample sizes have been used in several other qualitative studies related to the construction industry that employ semi-structured interviews. Examples include studies with eight interviewees (Munawar et al., 2021), 16 interviewees (Loosemore et al., 2021), and 18 interviewees (Shuhaimi et al., 2024). Table 1 shows the respondent profile.

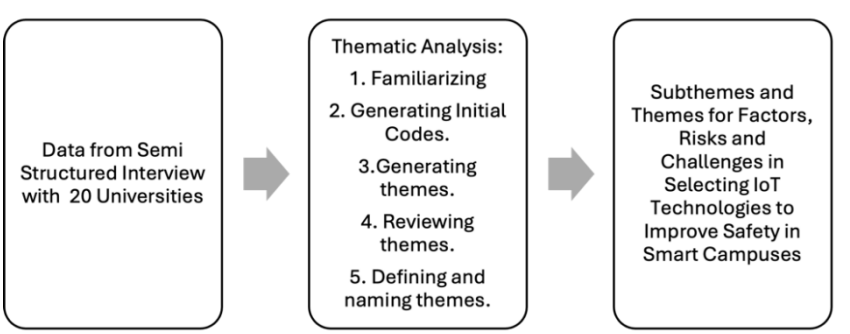
Table 3. Respondent Profile

Respondent	State	Working Experience	Designation	Type of University
RE01	Pahang	14	Assistant Director Safety Occupational Health Management	Government
RE02	Kuala Lumpur	16	Director OSHA	Government
RE03	Johor	15	OSH Officer	Government
RE04	Johor	5	Engineer OSH	Government
RE05	Melaka	5	Assistant Engineer OSH	Government
RE06	Johor	8	Engineer	Government
RE07	Pahang	5	OSH Officer	Private
RE08	Selangor	7	Competent Osh Officer	Private
RE09	Kuala Lumpur	7	PIC OSH	Private
RE10	Kedah	8	PIC OSH	Private
RE11	Selangor	9	Safety Engineer	Private
RE12	Kuala Lumpur	10	Technical safety	Private
RE13	Sarawak	8	PIC OSH	Private
RE14	Kelantan	6	OSH Facilities	Private
RE15	Selangor	7	OSHA Officer	Private
RE16	Negeri Sembilan	5	Safety Engineer	Private
RE17	Selangor	6	Technical safety	Private
RE18	Selangor	8	PIC OSH	Private
RE19	Kuala Lumpur	14	OSH Facilities	Private
RE20	Sarawak	16	OSHA Officer	Private

(Source: Author, 2024)

Data Analysis

The study employed thematic analysis to extract key insights and summarise the findings in determining the criteria, challenges, and risks from the perspectives of OSH on campuses. As shown in Figure 2, the steps taken during the analysis process are familiarising with the interview data, generating initial codes from the data, generating themes, reviewing the themes, and defining and naming the themes.



(Source: Author, 2024)

Figure 2. Thematic Analysis Procedure

Thematic analysis is a research tool used to recognise and understand patterns or themes within data sets, often leading to new insights and knowledge. It involves a systematic and iterative coding process, reducing bias by maintaining transparency in theme identification. Additionally, the iterative nature of thematic analysis allows for continuous refinement, which enhances the reliability and validity of the results (Zamani et al., 2023; Saufi et al., 2023).

The thematic analysis follows a series of procedures, including keyword and quotation selection, coding, theming, interpretation, and modelling (Bunjaridh et al., 2023; Anathan et al., 2023).

RESULTS AND DISCUSSION

The integration of IoT technologies to enhance safety in smart campuses involves various influencing factors, potential risks, and implementation challenges. Key factors include competency, financial considerations, technological aspects, infrastructure readiness, and management support, all of which influence the effectiveness and sustainability of IoT adoption. However, several risks, such as security vulnerabilities, financial uncertainties, infrastructure limitations, and governance issues, must be carefully mitigated to ensure successful deployment. Additionally, institutions face multiple challenges, including technical and human-related barriers, financial constraints, and the need for strategic management. Addressing these interconnected aspects is crucial to maximising the benefits of IoT in creating a safer and more secure campus environment.

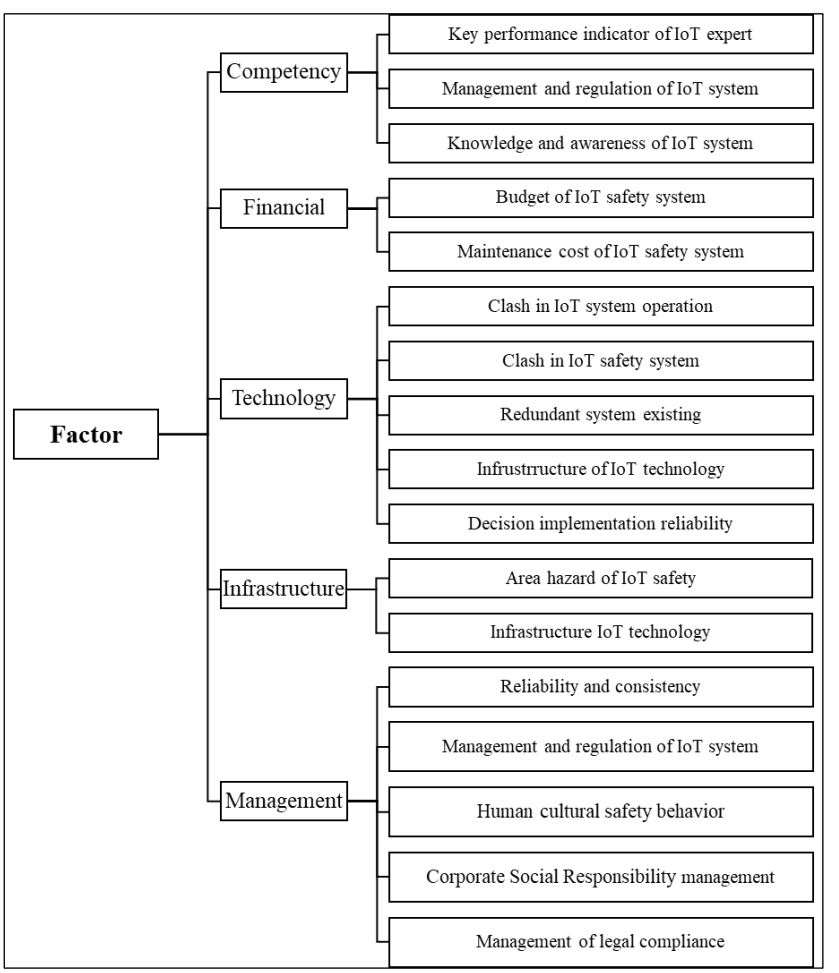


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Figure 3. Subthemes and Themes of Factors in Selecting IoT Technologies to Improve Safety in Smart Campuses

Factors

The results show that factors in selecting IoT technologies to improve safety in smart campuses can be categorised into five main themes: competency, financial, technology, infrastructure, and management, as shown in Figure 3.

Competency

Competency plays a crucial role in the successful adoption of IoT technologies for campus safety. This includes the expertise of IT staff, training programs for faculty and students, and the ability to manage cybersecurity threats (Nord et al., 2019). Skilled personnel ensure that IoT devices are properly configured, maintained, and protected against potential cyber risks. Awareness programs and continuous learning initiatives enhance the competency of campus stakeholders, ensuring the smooth integration and operation of IoT solutions (Pandey et al., 2020).

Financial

Economic considerations are pivotal in selecting IoT technologies. The initial investment costs, operational expenses, and long-term sustainability must be carefully analysed (Ullah et al., 2021; Mora et al., 2023). A cost-benefit analysis helps determine the feasibility of deployment, while financial support from government grants or private partnerships can alleviate budget constraints (Rao & Prasad, 2018). Additionally, institutions must consider the return on investment (ROI) by evaluating how IoT solutions enhance campus safety and efficiency over time (Hsu & Lin, 2018).

Technology

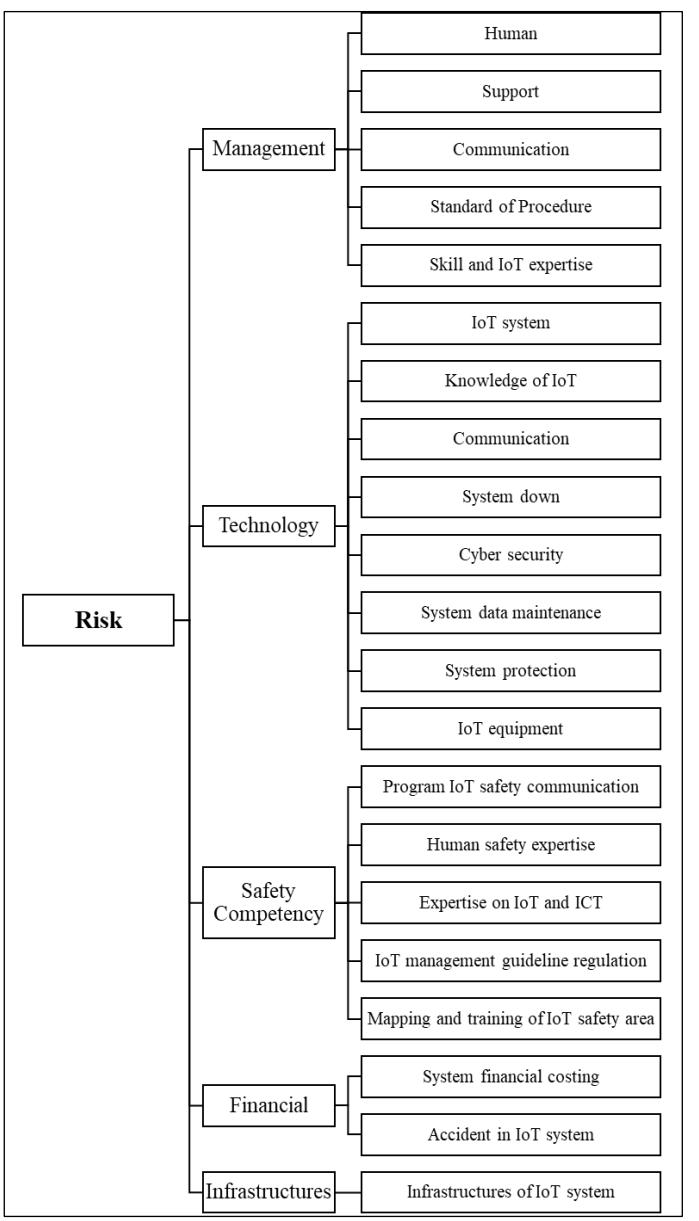
Technological factors encompass interoperability, scalability, reliability, and security. Interoperability ensures seamless communication between various IoT devices, while scalability allows for future expansion without major overhauls (Riggins & Wamba, 2015). Reliability is essential for the accurate and consistent functioning of safety systems, and robust security measures are critical for preventing cyber threats, data breaches, and unauthorised access. Institutions must prioritise selecting secure and efficient IoT solutions that align with their specific safety needs (Pandey et al., 2020).

Infrastructure

The existing physical and digital infrastructure plays a key role in IoT implementation. Factors such as network connectivity, cloud storage capabilities, and energy-efficient IoT devices impact the overall effectiveness of safety solutions (Kummitha & Crutzen, 2019). Campuses with well-established digital infrastructures can more easily integrate advanced IoT applications, while those with limited infrastructure may need to invest in foundational upgrades. Additionally, environmental conditions, such as climate and campus layout, can influence the selection of IoT technologies.

Management

Strong management support is essential for the successful adoption of IoT technologies. Institutional policies, leadership commitment, and compliance with legal regulations ensure smooth implementation (Min-Allah & Alrashed, 2020). A well-defined governance structure helps monitor and maintain IoT-based safety solutions, ensuring they remain effective and up-to-date (Lee et al., 2014; Nilssen, 2019). Management must also focus on privacy concerns, balancing the need for security with respect for individual rights (Moghayedi et al., 2024).



(Source: Author, 2024)

Figure 4. Subthemes and Themes on Risks in Selecting IoT Technologies to Improve Safety in Smart Campuses

Risks

The results show that risks in selecting IoT technologies to improve safety in smart campuses can be categorised into five main themes: management, human, competency, technology, and financial, as shown in Figure 4.

Management

Ineffective leadership, the absence of a policy framework, and poor governance can hinder the successful deployment of IoT technologies (Palis et al., 2024; Kummitha & Crutzen, 2019). Without strong managerial oversight, IoT initiatives may become misaligned with institutional goals, leading to inefficient resource allocation and compliance issues (Polin et al., 2024). Moreover, privacy concerns and ethical considerations, such as surveillance overreach, must be carefully managed to prevent institutional mistrust (Ahmed et al., 2022).

Technology

Cybersecurity threats, system vulnerabilities, and data breaches are among the most significant risks associated with IoT adoption (Ullah et al., 2021; Mora et al., 2023). Unsecured devices can serve as entry points for hackers, compromising sensitive campus data. Additionally, interoperability issues may arise when integrating multiple IoT systems, leading to communication failures and operational inefficiencies (Munawar et al., 2021). To mitigate these risks, institutions must ensure regular software updates, implement robust encryption mechanisms, and adopt standardised protocols (Loosemore et al., 2021).

Competency

A lack of technical expertise among staff and students can lead to improper handling and misuse of IoT systems. Insufficient training may result in device misconfigurations, rendering safety applications ineffective or prone to failure (Harikrishnan et al., 2021). Additionally, resistance to change among campus stakeholders may slow adoption rates and diminish the overall impact of IoT safety initiatives (Nord et al., 2019).

Financial

The high costs of initial implementation, ongoing maintenance, and software upgrades can strain institutional budgets. Unexpected expenses, such as repairs due to cyberattacks or hardware malfunctions, further increase financial burdens (Hsu & Lin, 2018). Additionally, without a clear ROI analysis, institutions may struggle to justify long-term expenditures, potentially leading to project abandonment or underfunding (Riggins & Wamba, 2015; Ullah et al., 2021; Mora et al., 2023).

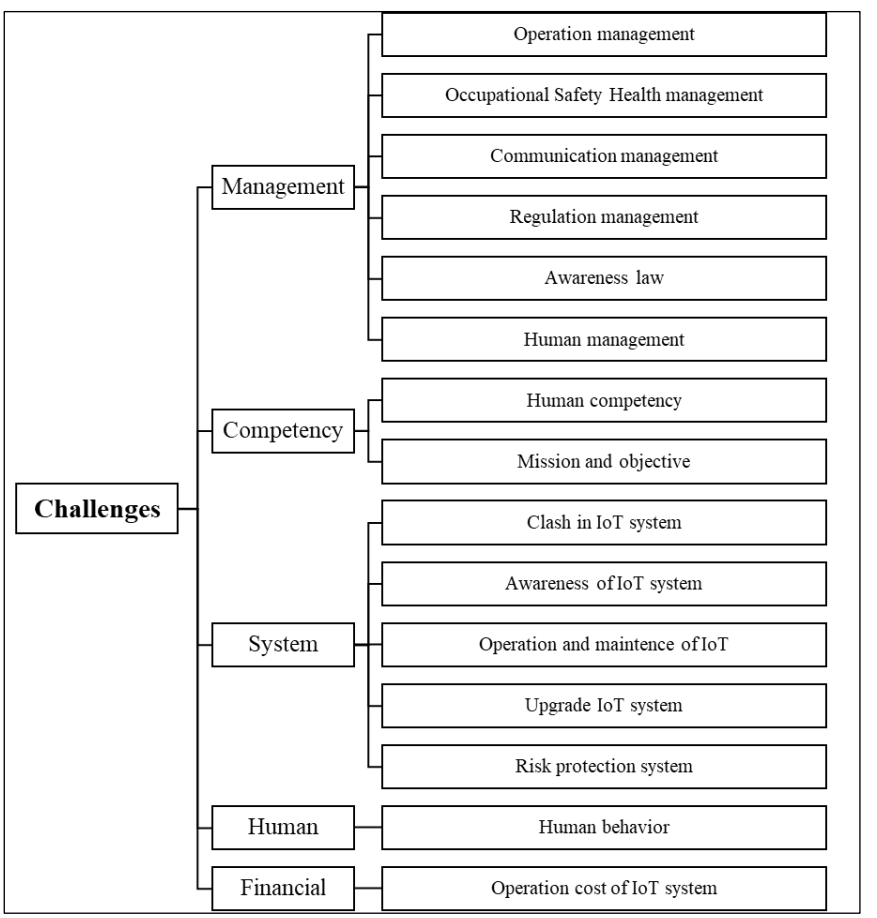
Infrastructure

Limited network coverage, poor connectivity, and inadequate power supply can hinder the effectiveness of IoT-based safety solutions (Kummitha & Crutzen, 2019; Min-Allah & Alrashed, 2020). Smart campuses require robust digital infrastructure to support IoT communication and data processing. Without sufficient bandwidth and cloud storage, real-

time monitoring and alert systems may fail, compromising campus security. Institutions must evaluate existing infrastructure and plan necessary upgrades before implementing IoT solutions (Pandey et al., 2020).

Challenges

The results show that challenges in selecting IoT technologies to improve safety in smart campuses can be categorised into five main themes: management, competency, system, human, and financial, as shown in Figure 5.



(Source: Author, 2024)

Figure 5. Subthemes and Themes on Challenges in Selecting IoT Technologies to Improve Safety in Smart Campuses

Management

IoT technologies are implemented to ensure campus sustainability. However, IoT systems introduce several challenges, including data management, stakeholder competencies, sensor-related issues, cloud network reliability, and storage limitations (Rao & Prasad, 2018). Additional challenges arise from human factors and financial constraints. Each of these categories encompasses specific obstacles that organisations must overcome to effectively utilise IoT technologies for campus security (Ismagilova et al., 2022).

Competency

Gaining management support and ensuring effective decision-making are two major obstacles to IoT implementation. Securing funding, establishing policies, and overseeing project execution all depend on leadership commitment (Moghayedi et al., 2024). Resistance to change among academics and administrators can also hinder the adoption of new safety technologies. These challenges can be addressed by implementing clear policies and fostering a culture of innovation (Polin et al., 2024).

System

Technological factors encompass interoperability, scalability, reliability, and security. Interoperability ensures seamless communication between various IoT devices, while scalability allows for future expansion without major overhauls. Reliability is essential for the accurate and consistent functioning of safety systems, and robust security measures are critical to preventing cyber threats, data breaches, and unauthorised access (Riggins & Wamba, 2015; Min-Allah & Alrashed, 2020). Institutions must prioritise selecting secure and efficient IoT solutions that align with their specific safety needs.

Human

Human factors, such as reluctance to adopt new technologies and concerns over privacy, present significant challenges. Some users may be sceptical about the effectiveness of IoT safety solutions or feel uncomfortable with surveillance technologies (Hsu & Lin, 2018; Kummitha & Crutzen, 2019; Ahmed et al., 2022). Addressing these concerns through awareness campaigns and transparent communication can enhance acceptance and engagement.

Financial

Advanced IoT solutions are expensive, and financial constraints often limit institutions' ability to invest in them. Maintenance, cybersecurity, and other operational costs further add to the financial burden (Hsu & Lin, 2018; Kummitha & Crutzen, 2019; Loosemore et al., 2021). Exploring research grants, commercial funding, or prototype grants can help mitigate financial challenges and support sustainable IoT implementation (Harikrishnan et al., 2021; Zainordin et al., 2024).

CONCLUSION

Although IoT technologies have the potential to improve campus management and safety by proactively preventing accidents, near misses, and fatalities, the criteria for selecting appropriate IoT solutions remain inadequately explored. This study aimed to identify the factors, risks, and challenges involved in selecting IoT technologies to enhance safety in smart campuses. To achieve this, the study utilised interviews with 20 safety professionals, which provided critical insights into the factors that influence IoT technology selection in smart campus environments. Thematic analysis was then employed to categorise the factors, risks, and challenges into themes and subthemes.

The findings revealed that the factors can be categorised into five main themes: competency, financial, technology, infrastructure, and management. In addition, the risks can be categorised into five main themes: management, human, competency, technology, and financial. Finally, the challenges can be categorised into five main themes: management, competency, system, human, and financial. These factors are vital in ensuring the successful adoption and effective utilisation of IoT solutions. Additionally, the study identified five primary risk categories, highlighting the complexity of deploying IoT technologies and the need for careful planning to mitigate these risks. Moreover, addressing these challenges is essential for ensuring that IoT technologies are implemented effectively and sustainably. This study provides valuable insights into the decision-making process for selecting IoT technologies to improve campus safety. By categorising the factors, risks, and challenges, the study highlights the critical areas that must be carefully considered to ensure the successful implementation of IoT solutions in smart campuses.

Recommendations

To enhance IoT adoption for campus safety, universities should focus on improving competency by providing targeted training programs for staff, faculty, and students. Financial planning is critical, so institutions should develop strategies to manage both initial costs and long-term maintenance, exploring funding from grants or partnerships. The selection of IoT technologies should prioritise interoperability, scalability, and robust security features to mitigate integration challenges. Management support is essential, and strong leadership should ensure clear policies and effective governance structures. Finally, universities must prioritise cybersecurity by implementing regular updates, encryption measures, and real-time monitoring to safeguard user data and privacy.

Future Research Directions

Future research should explore cross-institutional comparisons to understand how different types of universities approach IoT adoption. Longitudinal studies could identify trends in the long-term impact of IoT on campus safety. Research on human factors, particularly resistance to change and privacy concerns, could help improve stakeholder engagement. Additionally, exploring innovative security frameworks tailored for IoT on campuses could address cybersecurity challenges. Finally, investigating emerging technologies, such as Artificial intelligence, could reveal new ways to improve campus safety and operational efficiency.

ACKNOWLEDGEMENT

The authors would like to thank participants from the government and private universities who contributed to this study and the financial support from Universiti Malaysia Pahang Al-Sultan Abdullah under the RDU220321 Research Grant.

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PRACTICES OF DATA-DRIVEN CULTURE IN THE CONSTRUCTION

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Abstract
Previous studies have proven the existence of attributes, sub-attributes, and indicators of a data-driven culture within a construction organisation, and there are also more in-depth studies to assess the perspectives of construction industry personnel towards the indicators of a data-driven culture. However, the perspectives of construction industry practitioners are inadequate for identifying the actual practices of a data-driven culture within the organisation for the construction sector. Therefore, this study is conducted to fill the gap in the study associating the "practices" of construction industry personnel in construction organisations. The study was started by identifying indicators of data-driven culture from past researchers, then forming questionnaires, and obtaining validation from 18 expert panellists, which are clients, consultants, and contractors from construction industry stakeholders, by using Relative Importance Index (RII) analysis. The top RII values based on each sub-attribute analysed are: D4 – progress monitoring, ID3 – availability of funds, C2 – willingness to adapt to new technology, U4 – internal support, P6 –prevention, and P7 – mitigation action. The study has a significant impact towards construction industry personnel to become more competitive and relevant through documented admission of their practices as practitioners, which is in line with the upcoming Malaysian Digital Construction and Industry 4.0 Roadmap 2020-2025 and the upcoming Malaysian National Construction Plan (NCP) 2030 through "Thrust 1 – Technology as Game Changer".

Keywords: *Construction; practices; data-driven culture; relative importance index*

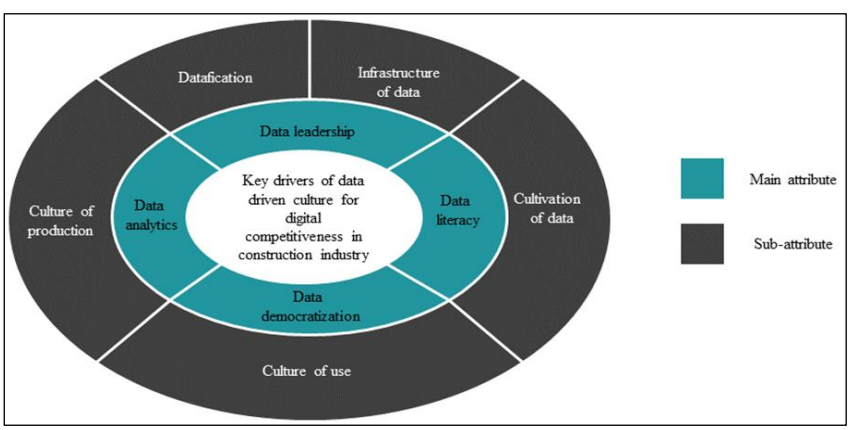
INTRODUCTION

The rapid advancement of information and communication technologies (ICTs) and digital technologies have expedited the process of digitisation, compelling enterprises to embrace a data-driven culture that improves the digitalisation process across diverse sectors. (Chaudhuri, 2023). From a financial perspective, a data-driven culture relates to Big Data Analytic Capability (BDAC), which substantially influences the integration of internal Supply Chain Finance (SCF), particularly concerning managers' ability to address unforeseen risks and challenges (Yu, 2021). Tamagusko and Ferreira (2024) assert that data-driven cultures impact the healthcare industry via knowledge management systems, information-sharing methods, and improved patient care quality. In the retail sector, a data-driven culture signifies the implementation of supply chain technologies, including blockchain, artificial intelligence (AI), analytics, robotic process automation, and data centres, necessitating business owners to adapt their supply chain strategies for improved resilience, sustainability, and cooperation among suppliers, customers, and other stakeholders (Gong, 2023). Ghafoori (2024) concurred that data-driven cultures substantially influence organisational cultures via digital transformation, including digitalisation and improved operational performance in the industrial sector. The use of digital technology and data culture in academic endeavours has been shown to improve information and knowledge management (Eshbayev, 2023).

Embracing a data-driven culture within an organisation catalyses significant business change, facilitating more precise decision-making, improving performance, and promoting innovation, therefore transforming the cultural environment (Chatterjee, 2021). Implementing big data actually assists construction businesses in management, project surveillance, and procurement (Atuahene et al., 2020).

A data-driven culture defines an organisational strategy for recognising key attributes and decision-making processes and integrating data into strategies grounded on an integrative framework (Anton, 2023). The construction industry has shown a growing interest in technologies such as cloud computing, augmented reality, Building Information Modelling (BIM), the Internet of Things (IoT), and smart buildings (Bilal et al. 2016). The integration of big data enhances construction organisations in management, project supervision, monitoring, and procurement (Atuahene et al., 2020).

Arbury et al. (2017) classify data-driven culture into four categories, which are: data leadership (datafication), data literacy (data cultivation), data democratisation (cultures of use), and data analytics (production of data), which Hashim et al. (2023) categories these categories as main attributes of data-driven culture. Acker and Clement (2019) proposed a standpoint for the main attribute of data leadership into two sub-attributes, which not only discussed datafication but also the infrastructure of data, as shown in Figure 1.



(Source: Arbury et al. (2017) and Acker et al. (2019))

Figure 1. The Framework of Data-Driven Culture Innovation

Hashim et al. (2023) suggested four main attributes of a data-driven culture in digital construction: data leadership, data literacy, data democratisation, and data analytics, with five critical areas of concern as highlighted in sub-attributes which are essential for a company's competitive capacity in the digital construction spectrum: datafication, the infrastructure of data, data cultivation, the culture of use, and culture of production, for data-driven culture process, which encompasses throughout: input (data cultivation), process (utilisation culture), and output (production culture), and governed by datafication and the data infrastructure as entities of data-driven culture management as shown in Figure 2. Acker et al. (2019) endorse their view of data culture, which encompasses data literacy (cultivate), data democratisation (use), and data analytics (production), hence being pivotal to comprehending the management of datafication and infrastructure of data.

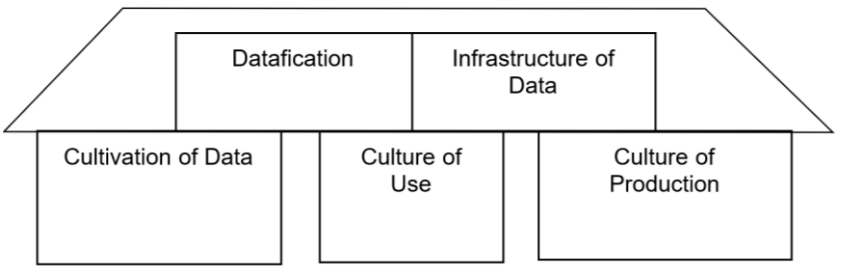
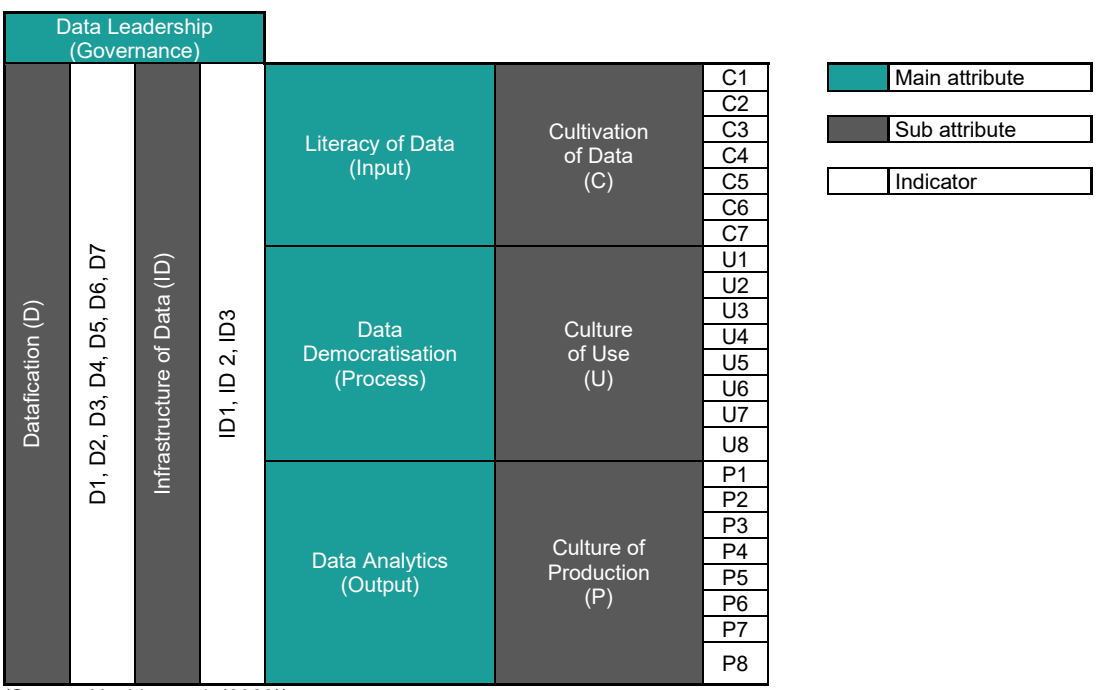


Figure 2. The Framework of Data-Driven Culture, Which Defined Datafication and Infrastructure of Data Governing The Process of Cultivation, Use and Production



(Source: Hashim et al. (2023))

Figure 3. The Framework of Data-Driven Culture Consists of 4 Main Attributes, Five Sub-Attributes and 33 Indicators

Based on Systematic Literature Review (SLR) for data-driven culture conducted by Hashim et al. (2023), the sub-attribute of datafication comprises seven indicators which are: (i) D1 - knowledge and expertise; (ii) D2 - professionalism; (iii) D3 - code of conduct; (iv) D4 - progress monitoring; (v) D5 - risk; (vi) D6 - quality; and (vii) D7 - legal. Next, the second sub-attribute of a data-driven culture in the construction digital industry referred to as infrastructure of data, consists of three indicators as follows: (i) ID1 - data security; (ii) ID2 - availability of infrastructure; and (iii) ID3 - availability of fund. The third sub-attribute, cultivation of data, has seven indicators, which are: (i) C1 - technical knowledge; (ii) C2 - willingness to adapt to new technology; (iii) C3 - ease of learning experience; (iv) C4 - competency; (v) C5 - experience; (vi) C6 - training; and (vii) C7 - coordination. Another sub-attribute of a data-driven culture in the construction industry is termed the culture of use, which comprises eight specified indicators: (i) U1 - data interoperability; (ii) U2 - compatibility with other organisations; and (iii) U3 - collaborative work processes and modelling standards; (iv) U4 - internal support; (v) U5 - external support; (vi) U6 - data

standardisation; (vii) U7 - building model reading and exploration; and (viii) U8 - availability of time to use. The last sub-attribute, referred to as the culture of production, has eight indications. These indications are identified as the specified terms, which are: (i) P1 - register-based statistic; (ii) P2 - detail data collection; (iii) P3 - information extraction; (iv) P4 - outcome expectations; (v) P5 - data estimating; (vi) P6 - prevention; (vii) P7 - mitigation action; and (viii) P8 - control strategy. Figure 3 shows the main attributes, sub-attributes and indicators of data-driven culture in the construction industry.

Even though 33 indicators of data-driven culture have been identified, negligence of these indicators, such as non-practices of data-driven culture, cause inadequate planning, ineffective communication, and insufficient teamwork, which limit productivity and project performance. (Lu et al., 2021). Berndtsson et al. (2018) claimed that organisational data-driven culture in construction must be developed and practised to effectively employ advanced analysis in construction activities. Thus, the objective of this study is to fill the gap in the study by associating the "practices" of construction industry personnel in construction organisations. To achieve the purpose of this study, the set-up methodology of this research started with the identification of attributes of data-driven culture in the construction industry, the development of questionnaires, and the selection strategy of expert panellists who qualified to share their experience in the construction industry.

EXPERIMENTAL SET UP

Identification of DDC Attributes

In order to fill the gap of research related to the practices by professionals in the construction industry, the set-up of this research utilises a Systematic Literature Review (SLR) and Focus Group Discussion (FGD) to indicate data-driven culture attributes for the construction sector. Moher et al. (2014) stated that there are four primary steps in systematic literature reviews according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology: identification, selection, eligibility, and inclusion. The intent of the systematic literature review is to offer solutions to identify the relevant attributes of DDC in the construction industry. The procedures for the systematic literature review inquiry approaches are shown in Table 1.

Table 1. Process of Systematic Literature Review

Phase	Database	Scopus
1st phase Identification	Search String: TITLE-ABS-KEY ((“data driven”) OR (“data capacity”) OR (“data culture”) OR (“big data”) OR (“data analytic”) OR (“data mining”) OR (“construction industry”))	730
2nd phase Screening	Exclude books, incomplete articles, book series, other languages, not related 5 years	535
3rd phase Eligibility	Relevant titles, keywords, and abstracts using criteria	272
4th phase Included	Full paper analysis and synthesis (articles directly related to issues of social in a construction project only)	111

1st Phase: Identification

The research used a procedure known as identification to discover related terms, variants, and synonyms of major keywords associated with data-driven culture. To start this procedure,

a literature search using the leading online database Scopus has been performed to integrate existing terms into a comprehensive search string. The decision to utilise Scopus databases as a search tool stems from the outstanding integration of studies and literature topics within Scopus compared to alternative search engines such as Web of Science (WoS), Google Scholar, and PubMed. Scopus offers a greater diversity of retrieved document types and exhibits a notable degree of overlap in indicators or keywords (Suarez, 2022). The phrases "data," "driven," "culture," "construction," and other terms included in Table 1 were used to identify the aspects present in the abstracts, titles, or keywords. The search words were concluded with an asterisk ("~") to include a broad range of results. A web search approach was used to identify the phrase "data-driven culture" from previous academic research by Hashim et al. (2023). The literature search was refined to 730 relevant articles from the Scopus database by using specific terminology for this research. The first phase of the systematic literature review was finished, whereby the primary source material consisted of various media, including research papers, books, trade magazines, and conference proceedings.

2nd Phase: Screening

The second phase of the Systematic Literature Review referred to as screening, is performed using the capabilities of the Scopus database to refine the search activities. The screening method includes the selection of logical constraints, language exclusions, and article types (David, 2023). A five-year period from the publication date was designated to maintain the relevance of research contributions about the study topic (Poojary et al. 2014). The screening procedure included selecting research papers only from journals and conference proceedings, with English as the language of publication. Saggese et al. (2015) said that concentrating on a single language in research may reduce the issue of terminological misunderstandings in the quality of research reviews. During the screening phase, 80 papers were rejected from Scopus, resulting in 535 articles from journals and conference proceedings advancing to the subsequent eligibility step.

3rd Phase: Eligibility

Eligibility is the third phase in the systematic literature review (SLR), ensuring that the author attentively examines the articles to confirm that, after the screening process, each article fulfils the established criteria. Krippendorff (2013) emphasised the significance of examining information to identify components and study their trends and patterns within a certain context. This method includes an extensive review of the title and abstract to ascertain the relevance of any publications to the selected data-driven culture. The eligibility criteria removed 263 articles from the Scopus database that did not explicitly apply to data-driven culture in construction. A total of 272 articles has met the eligibility criteria and are eligible to proceed to the final phase, which is referred to as the included stage.

4th Phase: Included

The fourth step, inclusion, involves the writers precisely analysing the text and abstracts of each article to assess the relevant research. To narrow down and reduce the overall quantity of selected literature, a series of inclusion and exclusion criteria, as outlined in Table 2, are implemented in accordance with the inclusion and exclusion methodology outlined by Beske-Janssen et al. (2015). Consequently, the researcher meticulously examined the titles, abstracts,

keywords, and general content, applying inclusion and exclusion criteria to the 111 publications. Table 2 delineates the criteria used to ascertain the inclusion or exclusion of publications in the systematic literature analysis undertaken in the study. The author will exclude articles that are not relevant to the definitional scope of construction projects since this study is confined only to digital construction. The last stage indicated that 111 research publications, including journals and conference proceedings, remain suitable for addressing the aims and research topics pertaining to data-driven culture in construction projects.

Table 2. Inclusion and Exclusion Criteria for Systematic Literature Review

Inclusion	Exclusion
• Scholarly publications and conferences that have been rigorously evaluated by domain experts and are composed in English.	• Insufficient emphasis on data-driven cultural content within the construction sector, with more emphasis on the digital economy or financial considerations instead.
• Articles that focus on the establishment of a data-driven culture in digital building projects.	• Articles only dedicated to conventional construction techniques.
• The article must concentrate only on the use of data-driven technology within the construction industry.	• Articles that use the term "construction" in general, regardless in a context not pertaining to the civil engineering domain. • Books, citations, handbooks, working papers, reports, and calls for papers related only to construction projects.

(Source: Inclusion and Exclusion Methodology Outlined by Beske-Janssen et al., 2015)

From SLR, this research identified 41 indicators related to DDC. With these indicators, the researcher conducted a Focus Group Discussion (FGD) to further identify the relevance of the DDC indicators in construction projects in Malaysia. The FGD cooperated with 18 expert panellists involved in construction across projects in Malaysia, utilising Building Information Modelling (BIM), which comprises relevant stakeholders such as clients, consultants, and contractors. Based on the FGD conducted, eight indicators indicated in earlier SLR were eliminated due to several factors, such as (1) the impracticality of indicators in Malaysia's construction industry and (2) indicators sharing the same definitions in the application of BIM in Malaysia. Thus, from 41 indicators identified based on SLR, 18 expert panellists involved in this research validate 33 indicators to be further investigated for data-driven culture in the construction industry in Malaysia.

Development of Questionnaire

A pilot study was conducted whereby the researcher developed a questionnaire in response to the attributes listed on the latest DDC (n=33) through a series of literature reviews and FGD. The description of each attribute considered the detailed explanation of each indicator in SLR and related Building Information Modelling (BIM) guidelines (e.g., BIM JKR Standard and Guidelines), laws, or specifications (e.g., BIM JKR Parameter Specification) applicable in the construction industry. There are two parts of the questionnaire, which are (1) demographic information and (2) an evaluation of the "practices" of participants in the construction industry regarding the importance of the DDC attributes. In the second part, each participant is required to evaluate each of the DDC indicators using a Likert scale to determine priority, which consists of 1 – very low; 2 – low; 3 – intermediate; 4 – high; and 5 – very high. Data analysis was performed to evaluate the information obtained from the questionnaire survey. To facilitate contributions from construction industry

participants about existing qualities, enhancements to present attributes, and a "remark" section, an additional field has been included in the second section of the questionnaire, as shown in Table 3.

Table 3. Proposed Taxonomy and Scale of Data-Driven Culture for D1 - Knowledge Application and Expertise

Description of Indicator	Fundamental Awareness	Learner	Moderate	Advanced	Expert
	1	2	3	4	5
The ability to demonstrate his/her understanding of the broad range of *knowledge and expertise among construction stakeholders* on related industry codes of practices such as; 1. BIM ISO 19650 2. BIM JKR Guideline	1. Ability to fully **understand** the common standard requirements related to digitalisation practices in the design phase (with supervision).	1. Ability to fully understand, discuss and partially comply with the common standard requirements related to digitalisation practices in the design phase (with supervision).	1. Ability to **differentiate** and fully comply with the standard requirements related to digitalisation practices in the design phase (with supervision).	1. Ability to have **mastery** over advanced knowledge standard requirements related to digitalisation practices in the design phase (without supervision).	1. Ability to **fully understand and comply** with the common standard requirements related to digitalisation practices in the design phase (with supervision).

Expert Panel Selection

For this research, the expert panels in the industry were chosen from various stakeholders in construction projects, such as contractors (n=5), consultants (n=11), and clients (n=2). The expert panellist shall have an on-job position in a construction company registered with the Construction Industry Development Board (CIDB) Malaysia 2024 with G6 and G7 grades to ensure the scale of the project is relevant to the implementation act of Building Information Modelling (BIM). The selection of expert panellists was made based on the Point System for Qualification of Expert Panellists, as shown in Table 4. Each participant must attain a minimum of 11 points according to the point system established by Hallowell and Gambatese (2010) to ensure the competency levels of industrial practitioners. There are 18 participants who have been selected and are eligible to share their views regarding their “practices” of DDC in the construction industry.

Table 4. Point System for Qualification of Experts

ID	Achievement of Experience	Point
A	Years of professional experience in the construction industry	1 point for every year
B	Advanced degree in the field of civil engineering or other related areas	Bachelor’s degree: 1 point Master: 2 points PhD: 4 points
C	Involved in any related digital data project construction	2 points for each related software used for project construction
D	Member (or chair) of professional committee(s)	Member: 1 point for each membership Chair: 3 points for each membership
E	Leading position(s) held in current/previous organisation related to digital data	3 points for each leading position
F	Publication on the topic of digital data in construction	Journal article: 4 points Book: 2 points Conference paper: 1 point
G	Attended any related digital data training in construction	1 point for each training

(Source: Adapted from Hallowell and Gambatese, 2010)

MATHEMATICAL MODELLING

To provide assurance that the "practices" concerning the indicators are quantifiably measurable, the research employs Relative Importance Index (RII) analysis, which is preferable since it provides a more significant and nuanced interpretation of subjective survey data, particularly when prioritising or comparing several criteria. It surpasses the basic average (mean) by including the relative significance or weight of each answer, rendering it especially advantageous for decision-making in contexts where the intensity of preferences is critical, as articulated by Tholibon et al. (2021). RII is a thorough analytical method capable of ranking each indicator based on its relevance, with the highest index value of 1.0 indicating the most significant indicator. The detailed calculation of RII analysis is shown in Formula Equation 1.

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

Formula Equation 1: Relative Important Index (RII)

Note: w = Mark for Each Scale; n = Number of Respondents Answered by Each Scale; A = Maximum Scale; N = Total Number of Respondent

Indicators with high values will be recognised as important indicators for promoting a data-driven culture in digital construction, whilst indicators with low values will be categorised as low-priority indicators. An example of RII calculation is shown in Table 5.

Table 5. Calculation Example for RII for D1

Data Total Surveyed, N: 18 Total Likert Scale: 5							
Step 1: Calculation Number of Respondent Agreed by Each Scale, n	**Code**	**Scale**					**Total**
		1	**2**	**3**	**4**	**5**	
	D1	2	4	10	1	1	18
Step 2: Calculation Mark of Each Scale, w	**Code**	**Scale**					**Total Mark Scale, ∑w**
		1	**2**	**3**	**4**	**5**	
	D1	2	8	30	4	5	49
Step 3: Calculation of Maximum Scale, A x Number of Respondent, N	Maximum Scale					A	5
	Number of Respondent					N	18
	Maximum Scale, A x Number of Respondent, N					AN	90
Step 4: Calculation of RII, where ∑w / AN	Total Mark Scale					∑w	49
	Maximum Scale, A x Number of Respondent, N					AN	90
	RII					∑w / AN	0.544

RESULTS AND DISCUSSION

Demographic Information

Eighteen experts from the construction industry were qualified to assess DDC indicators by exchanging their experiences on the "practices" of data-driven culture. All experts meet the criteria of the point system for expert panellists, as adopted from Hallowell and Gambatese (2010), as shown in Table 6.

Table 6. List of Qualified Experts Based on The Point System for Expert Panelists Adapted from Hallowell and Gambatese (2010)

Participant		Discipline	Position	A	B	C	D	E	F	G	Total Point
A-1	Contractor	Project Mngmt	Project Engineer	6	1	2				3	12
A-2	Contractor	Civil	Site Engineer	3	1	4				3	11
A-3	Contractor	Structural	BIM Modeller	3	1	4				4	12
A-4	Contractor	Eng. Services	BIM Modeller	3	1	2				5	11
A-5	Contractor	Civil	BIM Modeller	3	1	2				6	12
B-1	Consultant	Electrical	BIM Modeller	5	1	2				3	11
B-2	Consultant	Civil	BIM Modeller	5	1	2				4	12
B-3	Consultant	Civil	Lead Modeler	6	1	4		3		4	18
B-4	Consultant	Civil	BIM Trainer at MyBIM	28	1	4				7	40
B-5	Consultant	Civil	BIM Modeler and Coordinator	9	1	4				3	17
B-6	Consultant	Architect	Modeler	6	1	2				3	12
B-7	Consultant	Civil	BIM Modeller	3	1	4				3	11
B-8	Consultant	Civil	BIM Modeller	3	1	4				3	11
B-9	Consultant	Civil	BIM Modeller	5	2	6				1	14
B-10	Consultant	Asst Archi	BIM Modeller	4	2	4				1	11
B-11	Consultant	Civil	BIM Coordinator	12		4					16
C-1	Client	Civil	BIM Coordinator	10	2					2	14
C-2	Client	Project Mngmt	Project Engineer	4	2	2			5	1	14

The participants were classified into three main demographic groups: 1) A – Contractor; 2) B – Consultant; 3) C – Client. There are five contractors from diverse disciplines: project management (n=2), civil (n=2), and structural (n=1). They hold different employment positions, including modeller (n=3), site engineer (n=1), and project engineer (n=1). In addition to contractors, there exists a wider group of participants, including industry stakeholders known as consultants. There are a total of eleven (11) individuals from this group, representing several disciplines: civil (n=8), architecture (n=2), and electrical (n=1). The recognised employment roles include BIM modeller (n=8), BIM coordinator (n=2), and BIM trainer (n=1). The third group of participants for the data-driven culture study consists of clients involved in construction projects. Researchers identified two individuals suitable to provide their perspectives, one from project management (n=1) and the other from civil engineering (n=1), both now employed as a BIM modeller (n=1) and a project engineer (n=1) in the construction industry.

RII Analysis – Datafication

Measuring the practices of construction industry professionals in relation to the indicators associated with the sub-attribute of datafication is essential for managing a data-driven culture. Figure 4 presents the findings derived from RII analysis for the sub-attributes of datafication.

Figure 4 shows the highest RII value, which indicates the top priority of indicator in datafication, which is D4 – progress monitoring with 0.900. Experts point out that project progress monitoring within the data-driven culture of the construction organisation or projects is crucial for ensuring optimal work advancement, including the utilisation of BIM software to anticipate potential delays, maintain timely scheduling, and achieve early project completion as stated in BIM JKR Guideline (3.1.3 - Schedule and Quantities) With the

utilisation of BIM technology into construction project, the progress monitoring can be enhance through 4-D function where the time estimation takes place which able project stakeholders to predict time of completion of construction project deliverables. The second highest RII value in datafication is D5 – risk (0.567), where the researcher acknowledges the importance of implementing data culture in construction with the guidance of BIM JKR Standard and Guideline to minimise risk through activities such: (1) 30%, 60% and 90% model review; (2) clash analysis. The third highest RII value for datafication was nominated for D1-knowledge application and expertise. Experts emphasise the importance of having knowledge, application and expertise in BIM ISO 19650, BIM JKR Standard and Guidelines, BIM Specification Parameter, BIM: JKR Work Process Manual, BIM: JKR Data Management Manual, JKR: JKR Template User Manual, and BIM: JKR Green Rating Application Manual in order to fully utilise the potential of execution of data-driven culture. The lowest RII value recorded from participants on the sub-attribute of datafication is 0.322, D7 – legal.

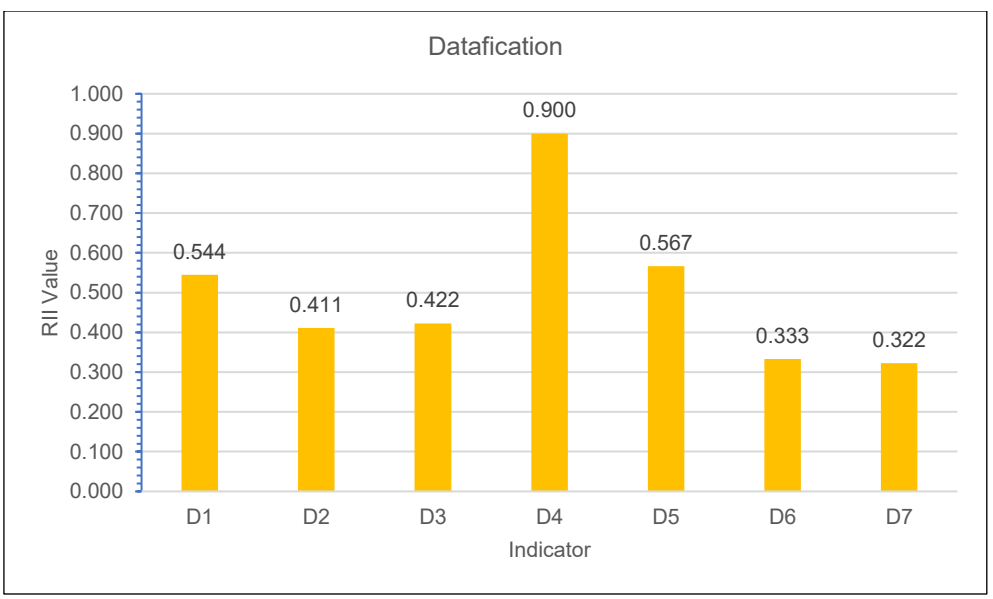


Figure 4. Obtained Results Using RII Analysis for Sub-Attributes of Datafication

RII Analysis – Infrastructure of Data

The research proceeds by assessing the practices of industry practitioners regarding the sub-attribute referred to as data infrastructure, as shown in Figure 5.

In Figure 5, indicator ID3 – availability of funds achieved the highest value of RII at 0.667. Professionals in the construction business agreed that establishing a data-driven culture inside a company requires sufficient financial resources. The allocation of expenditure of BIM infrastructure in construction projects is feasibly populated through BIM software such as CostX as stated in BIM: JKR Standard. The subsequent indicator log in the study is ID2 – infrastructure availability at 0.611. Experts express constructive opinions on the data infrastructure in construction, including the supply of modern digital infrastructures (i.e., 3D for modelling, 4D for scheduling, 5D for cost estimation, 6D for sustainability, and 7D for facility management) across various stages of building projects. The lowest documented RII

value is ID1 – data security, at 0.400. Despite ID1 being recorded as having the lowest RII value, participants underscored the significance of data security measures, such as firewall systems, in digital construction, including Personal Digital Assistants (PDA).

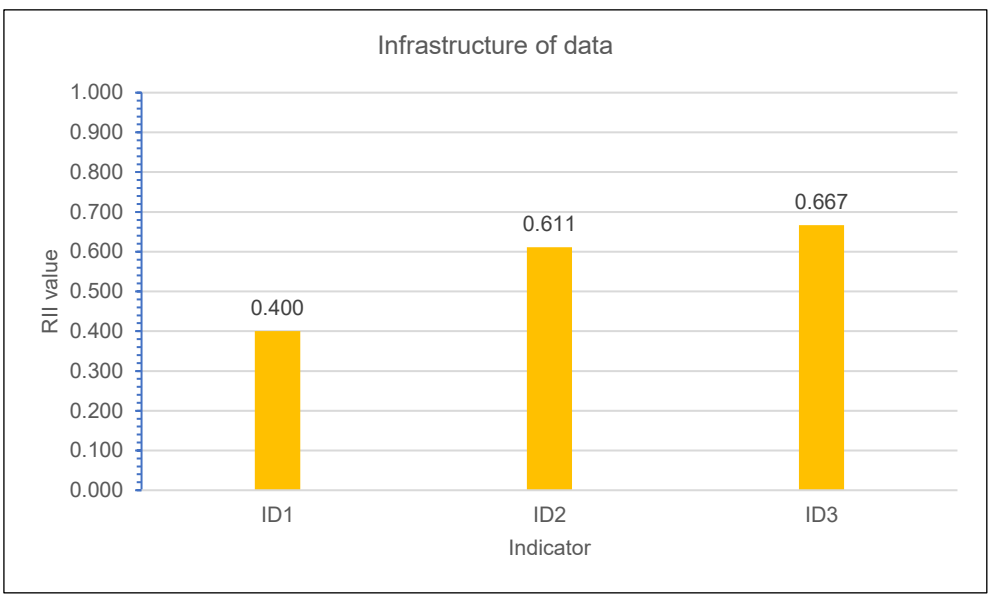


Figure 5. Obtained Results Using RII Analysis for Data Infrastructure

RII Analysis – Cultivation of Data

Fostering a data culture is crucial for data-driven practices in the construction industry. Thus, this research utilises RII analysis to validate the practices of professionals in construction organisations concerning the sub-attribute cultivation of data, as shown in Figure 6.

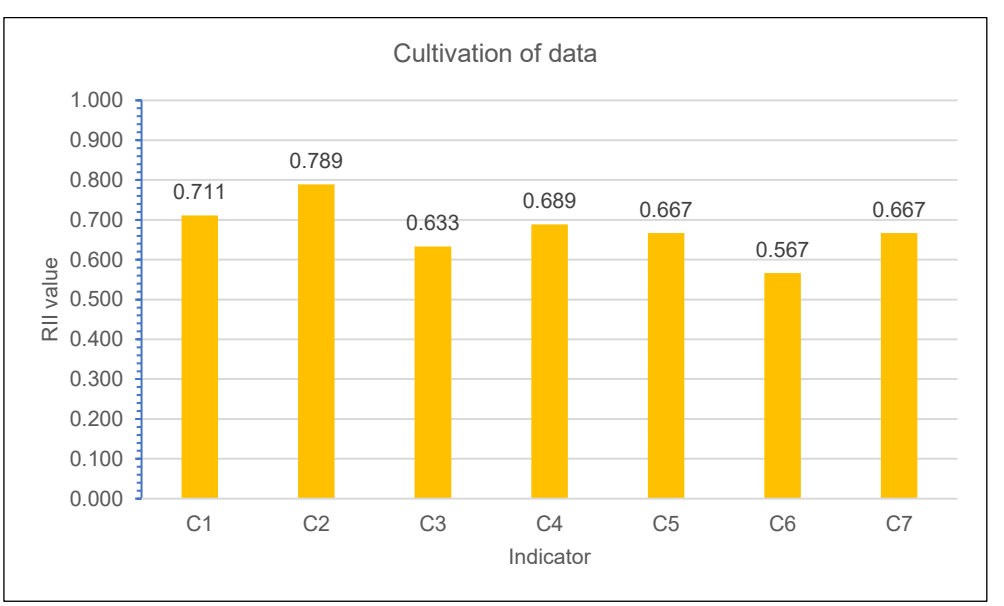


Figure 6. RII Results for Cultivation of Data

The highest RII result obtained in the sub-attribute of cultivation of data is C2 - willingness to adapt to new technology (0.789) followed by C1- technical knowledge (0.711). Research findings indicate the willingness of workers to adapt to new areas of digital construction tools such as but not limited to Computer Aid Design (CAD), Building Information Modelling (BIM), Light Detection and Ranging (LiDAR), Virtual Reality (VR), Augmented Reality (AR), Big Data Analytics (BDA), Block Chain, Internet of Things (IoT) in construction projects, will foster the development of a progressive data culture within construction projects. The third highest RII value obtained from the cultivation of data is C4 – competency (0.689). Experts highlight the importance of being competent in delivering project construction deliverables through seminars, training, and certification from professional development bodies in BIM (e.g., CIDB Certification MyBIM). In this research, the researcher acknowledges that the lowest calculated RII value is C6 – training (0.567). Research indicates a deficiency in training for the application of BIM and other digital construction technologies, regardless of whether the training is conducted internally or by other entities.

RII Analysis – Culture of Use

Culture of use is a sub-attribute of data-driven culture in the construction industry, which indicates the behaviours of construction personnel while using digital construction technologies. Figure 7. shows the practices of industry professionals concerning the sub-attribute known as culture of use.

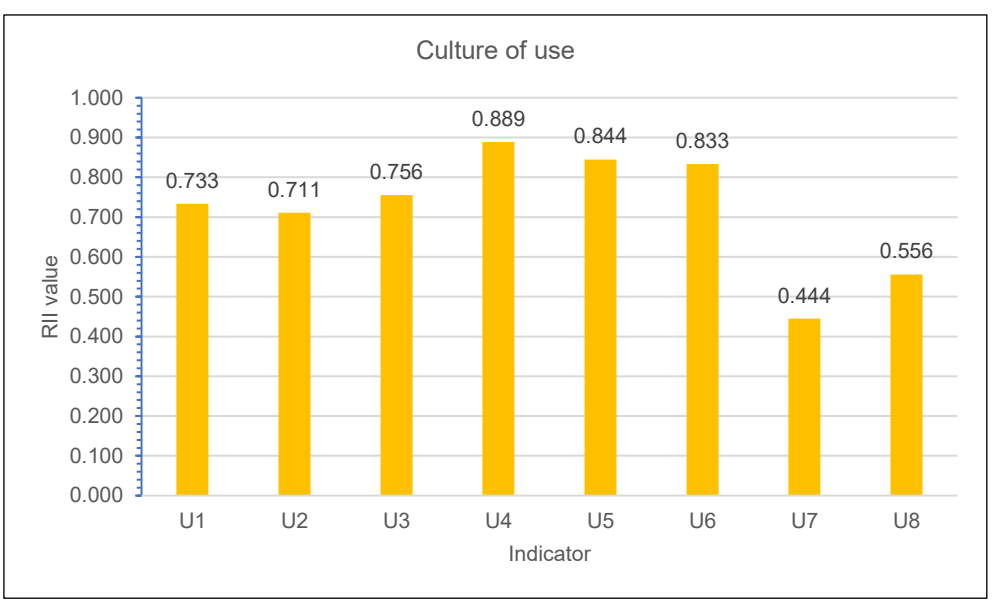


Figure 7. RII Results for The Culture of Use

The indicators U4 - internal support (0.889) and U5 – external support (0.844) from the culture of use obtained the highest two scores through RII calculation. Experts who participated in the research declared that the support within the organisation and external stakeholders for the use of digital construction tools, including BIM, BDA, CAD, and other construction technologies, arises from the demands of current project requirements. Next, U6 – data standardisation (0.833) was recorded as the third highest RII value in the culture of use.

The research found that the standardisation of naming convention, model development, information sharing, and parameter specification has been practised through the BIM JKR Standard and BIM Specification Parameter. The expert panellists in this research point out that U7 – building model exploration (0.444) has the lowest priority for building a data-driven culture in the construction industry, as assessed by the sub-attribute of "culture of use." According to the expert participants, as an example, the model exploration has limitations due to the disabilities of BIM software in integrating model designs from multiple disciplines in AutoDesk. For example, the schematic electric drawing and concrete reinforcement design, utilise 2D and have problems integrating with 3D model design in construction projects.

RII Analysis – Culture of Production

The research progresses by examining the practices of industry practitioners concerning the sub-attribute known as the culture of production, as shown in Figure 8.

Experts described their practices concerning the key indicators of a data-driven culture via a sub-attribute of production, where P6 – prevention and P7 – mitigation strategies exhibited the highest and equal RII value of 0.722. Through experts' practices, the utilisation of BIM application in prevention and mitigation strategy occurs through clash analysis and 30 per cent, 60 per cent, and 90 per cent model review at the design phase of a construction project. Next, the P8 – control strategy (0.656) indicated the third highest RII value in the culture of production.

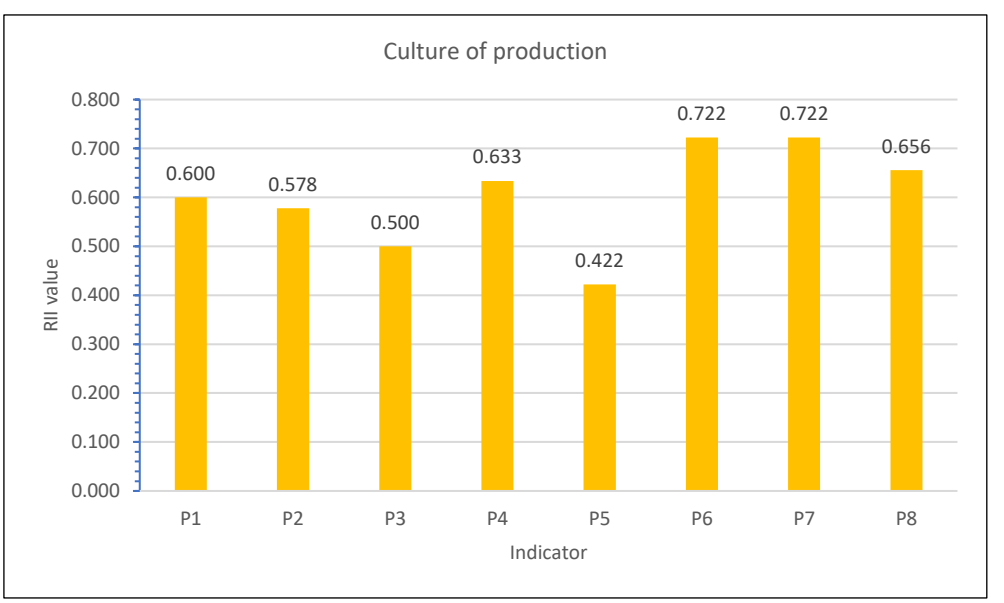


Figure 8. RII Results for The Culture of Production

CONCLUSION

The assessment of data-driven culture for digital competitiveness within the construction industry is often undervalued by construction professionals due to its non-quantifiable nature. Consequently, construction practitioners tend to pay less attention to the need to cultivate an effective data-driven culture. Thus, a quantifiable measurement of the level of

competitiveness among the construction industry workforce in practising a data-driven culture has been shown through this research. This research has integrated relevant academic literature, analysed and interpreted the results from various data collection phases to produce comprehensive findings for the development of the assessment tool, specifically identifying the 33 most critical indicators along with their corresponding weight and suitable scale level for each indicator to justify "practices" of data-driven culture in construction industry through RII analysis. To implement a data-driven culture in the construction industry, experts suggested that construction organisations focus on the highest RII values for analysed indicators through each sub-attribute: D4 – progress monitoring, ID3 – availability of funds, C2 – willingness to adopt new technology, U4 – internal support, P6 – prevention, and P7 – mitigation action. With the findings, the accomplishment of research objectives has been achieved, and a new understanding of practices on data-driven culture in the construction industry is being documented. The study significantly impacts construction industry professionals, enhancing their competitiveness and relevance by documenting their practices as practitioners, aligning with the forthcoming Malaysian Digital Construction and Industry 4.0 Roadmap 2020-2025 and the Malaysian National Construction Plan (NCP) 2030 under "Thrust 1 – Technology as Game Changer."

ACKNOWLEDGEMENTS

This research paper was entirely funded by a grant from the Fundamental Research Grant Scheme (FRGS) of the Ministry of Higher Education, Malaysia, via Universiti Teknologi MARA, Malaysia. Reference: FRGS/1/2021/TK01/UITM/02/1. Not forgetting my late father, Hashim bin Saad and my lovely mother, Rosnah binti Hashim, for full support in the education line of the author.

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OPTIMISING MATERIAL HANDLING IN CHINA HIGH-RISE BUILDINGS: KEY SUCCESS FACTORS FOR SUSTAINABLE AND EFFICIENT CONSTRUCTION

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Abstract
China's construction industry has experienced rapid growth, particularly in high-rise building development. However, material handling (MH) inefficiencies remain a major challenge, causing cost overruns, delays, and environmental impacts. Poor logistics planning, limited technology use, and weak stakeholder collaboration further hinder construction efficiency. Despite MH's significance in ensuring time efficiency, cost-effectiveness, safety, and sustainability, research on MH optimisation in China's High-Rise Buildings (CHRB) remains limited. This study identifies key success factors (SFs) for MH optimisation in CHRB through semi-structured interviews with 30 industry professionals and thematic analysis. The findings categorise SFs into four key themes: education, awareness and research, utilisation of advanced technology, and market drivers. Enhanced training programs, sustainable MH awareness, and digital automation technologies are essential for improving efficiency. Additionally, stakeholder collaboration and government policies play a crucial role in fostering an environment conducive to MH optimisation. The study aligns with China's Construction Industry Modernization Guidelines (2020–2035) and provides a framework for local governments, policymakers, and industry professionals to optimise MH practices in CHRB. By implementing these success factors, construction projects can improve cost efficiency, reduce environmental impact, and enhance sustainability. These findings contribute valuable insights for advancing efficient MH practices, ensuring the long-term resilience of China's construction industry.

Keywords: *High-Rise Buildings; Material Handling; Success Factors; Optimisation; China*

INTRODUCTION

Rapid urbanisation and economic expansion have resulted in the rapid growth of high-rise buildings in China (Cui et al., 2021). However, there are significant difficulties in constructing these large buildings, especially in the case of material handling. Effective material handling can facilitate interaction between operations, reduce costs, avoid delays, and improve construction site safety (Yazdani et al., 2021). Logistics and its complexities, such as incorrect materials assigned to a particular floor and communication gaps between different processes, pose serious challenges for high-rise material handling (MH) (Tataria et al., 2021). The vertical construction of buildings and the hazards associated with such construction have led to an increase in safety concerns in the industry, with workplace injuries due to inadequate handling and fastening procedures resulting in employee hazards and potentially prolonged construction durations (Martines et al., 2020). Optimising the MH process is a key factor to be considered in high-rise buildings under the current competitive conditions, which require a focus on project efficiency, risk mitigation, and cost savings. The improvement of MH needs to focus on several aspects, including optimising cost, efficiency, safety, and sustainability, as well as providing practical recommendations for future projects in high-rise buildings. Therefore, it provides a proper investigation of the factors contributing to the successful optimisation of MH in the CHRB industry.

Existing studies in the literature cover the complex nature of the moving parts of construction materials (Sepasgozor et al., 2023; Yi, 2020), referring to vertical transportation (Liu et al., 2022), storage, and coordination between different industries discussing the problem of material wastage and emphasising the natural and economic impacts of inefficiencies in MH (Sun et al., 2022; Umar et al., 2022; Rajeshkumar et al., 2021).

To further research the literature review, it examines concepts and theories in construction management, logistics, and safety that can assist any interested party who wants to understand material handling practices. It reviews models and methods that have been used in construction projects to optimise material flow, remove waste, and improve safety (Xu et al., 2022; Patil et al., 2022; Teng et al., 2020; Xu et al., 2020; Wu et al., 2019).

Navaratnam (2022) studied the most suitable sustainable construction methods for high-rise structures and evaluated the effectiveness of different construction methods, namely, building automation construction, aluminium stencil construction, off-site construction, and robotic construction techniques, to advocate efficiency in construction. Utilising modern technologies such as Building Information Modelling (BIM), robotic applications, and automation, efficient project implementation was facilitated by examining the intricate details of the construction process, helping to reduce material handling steps and environmentally avoid landfills (Sepasgozar et al., 2023; Shi & Wang, 2022; Xie et al., 2022; Yongqian et al., 2021; Egbu, 2006).

A revised compilation of research findings from academic institutions, industry reports, and case studies provides a global view of the current state of materials handling in high-rise office buildings and the interior of Chongqing (Mirrahimi, 2016).

Zhang et al. (2023) and Wang et al. (2020) conducted an extensive investigation on the specific carbon emissions of residential buildings in China, emphasising their significant impact on the environmental building sector, while a study on low-carbon buildings in China showed that buildings need to use green and low-carbon materials to reduce carbon emissions. Javanroodi et al. (2019) presented a multi-objective optimisation framework based on genetic algorithms-Energy Efficient Form Finder (EEF), which examines five reference structures in five different urban environments, using a new methodology called Building Modular Units (BMUs). The study examined the structural composition of five reference structures in five different urban environments using a new methodology called 'modular building units', leading to 25 different design issues. Different strategies adopted to address barriers and promote sustainable approaches, the key role of government regulations in facilitating the expansion of the Green and Innovative Building Materials (GIBMs) sector, the importance of integrated materials' management models in enhancing the procurement process, and the complexity of carbon emissions are presented as ways to reduce and mitigate carbon emissions. The transformative power of automation and robotics is also examined (Ali et al., 2022; Mohammadi et al., 2022; Rajeshkumar et al., 2021).

Ma et al. (2020), among others, examined waste management and waste utilisation practices, providing insights into sustainable public building design. The popular theories and models related to MH include lean construction theory, supply chain management (SCM), technology acceptance model (TAM) and triple bottom line (TBL) framework (Huang et al., 2018). Lean construction theory emphasises waste reduction, workflow efficiency, and value

maximisation, which directly relates to MH optimisation. Applying lean principles can enhance logistics coordination and reduce delays in high-rise projects. SCM in construction highlights material flow efficiency, supplier coordination, and real-time logistics tracking. Implementing digital supply chain strategies can improve material availability and reduce inefficiencies in MH processes. Given the emphasis on advanced technology in MH, TAM provides a useful framework for understanding stakeholder adoption of digital tools such as BIM, IoT, and automation. The study could explore barriers to technology adoption and how to improve its implementation. The TBL framework should be applied to show how MH optimisation affects economic (cost savings), environmental (carbon footprint reduction), and social (worker safety) factors.

Currently, the national policies, including the "Green Building Action Plan" (MOHURD, 2021) and "China's Construction Industry Modernisation Guidelines" (2020–2035), which mandate digitalisation, prefabrication, and sustainable logistics, have great impacts on MH regulations (Sepasgozar et al., 2023). As suggested by Xu et al. (2022), Government agencies should develop mandatory digital tracking systems for MH compliance using RFID and blockchain-based material passports. Construction firms should be incentivised to adopt efficient and eco-friendly MH solutions.

Previous scholars have mostly stayed in the theoretical study of green building materials, sustainable buildings, carbon emissions and other hot issues of worldwide concern, followed by the impact of MH on schedule, cost and safety, and then building design, construction material handling and selection, cultural factors and other aspects. However, few empirical studies were conducted on specific high-rise buildings in China as the object of study, especially on the unique problems that are different from those of conventional vertical buildings. To address these research gaps, the research question of this study is: what are the success factors (SF) for effective optimisation of MH in CHRB? To answer the research question, the research objective of this study is to identify the SF for effective optimisation of MH in CHRB.

METHODOLOGY

This study uses semi-structured interviews and thematic analysis to determine the success factors that influence the optimisation of MH in CHRB. The subject of this choice of qualitative research is to embrace data collection, analysis, and interpretation so that it avails checks and balances that enhance the reliability of research. Semi-structured interviews were chosen as the primary data collection method for the following reasons. MH in CHRB is a complex issue influenced by multiple factors, including logistics, technology, regulations, and stakeholder collaboration. Interviews allow for detailed insights from industry experts, helping to uncover nuanced challenges and success factors (SFs) that may not be captured through quantitative surveys. Semi-structured interviews provide the flexibility to explore unexpected insights that may arise during discussions. This approach enables researchers to ask follow-up questions, clarify responses, and gather richer data on best practices, barriers, and stakeholder perspectives regarding MH optimisation.

Data Collection

A standardised interview protocol was first developed to conduct the interviews. This was sent to potential interviewees via different online mediums such as Microsoft Team, Voov and Zoom, along with formal interview invitations. The medium and schedule of the interviews were further coordinated through mutual discussion among the industry stakeholders who agreed to participate.

The interviewee population was all related to China's building and construction industry. Emphasis was given to ensure that the selection of participants was diverse, including developers, suppliers, contractors, consultants, architects, engineers, site supervisors, and relevant researchers, to encompass as many of the different participant's perspectives and experiences as possible. To better understand the context and to optimise the interview questions, the first six interviews were conducted face-to-face with interviewees of varying experience. After optimising the questions, the rest of the interview sessions were conducted and recorded online, partly via audio or video conferencing. Consent was first sought from the interviewees to record the interviews, with particular emphasis on transcribing the interview content into written form with a high degree of standardisation to prevent any misrepresentation of the answers provided by participants. Interviews were conducted until data saturation was reached and gradually realised after 30 interviews had been completed.

The interviews used open-ended questions. Questions were structured to provide a clear and logical flow, ensuring participants could easily comprehend and respond to each item. To minimise the effects of bias and maintain the credibility of the study's results, several precautions were taken throughout the study. A purposive sampling approach was used to recruit participants, extensive records of the interview sessions were kept, coding was done in conformity with protocol, and the results were checked and affirmed by the participants and peer auditors.

Respondents' Demographics

At the beginning of each interview, several demographic information was collected. The descriptive statistics, shown in Table 1 and Figures 1-4, provide an overview of the participant demographics, including their age, gender, level of education, position in a construction project, and years of experience, laying the groundwork for similar evaluation and interpretation of information.

Table 1. Demographic Characteristics of The Participants

Information	N	Minimum	Maximum	Average	Std. Deviation
Age (Years)	30	24	48	34.5	8.23
Gender (1: Male, 2: Female)	30	1	2	1.2	.41
Academic Degree (1: Bachelor, 2: Master's, 3: PhD, 4: Others)	30	1	4	1.6	.77
Work Experience (Years)	30	2	25	11.6	7.55

According to Table 1 below, the mean age average is 34.5 years. This is in line with the hypothesis that mature professionals who are mostly in a stable career are more inclined to participate in this type of research. In contrast, the standard deviation of 8.23 indicates that

there is some variation in age, as the participants' ages ranged from 21-50 years, as shown in Figure 1, thus covering a wide range of ages.

In terms of education level, the average score of 1.6 indicates that the majority of participants have a bachelor-level degree. A significant proportion, one-third, of the respondents, however, has a Master's degree, as evident in Figure 2.

On average, the participants had 11.6 years of work experience, with a significant standard deviation of 7.65, which indicated a wide variation in experience. Most of the participants were engineers working in China's construction industry, as can be seen in Figure 3. There were a significant number of architects, researchers, and project leaders, as well as some site supervisors, consultants, and supervisors, who had a wide variety of career roles to facilitate a holistic comprehension of the MH perspective in CHRB.

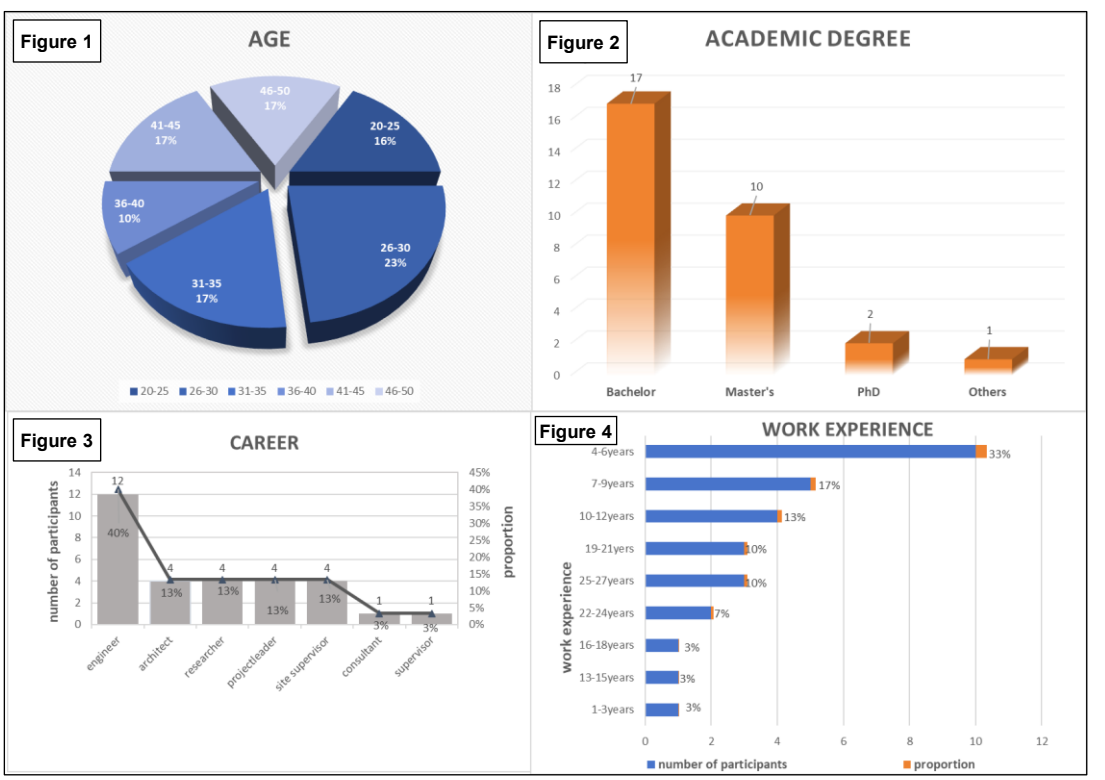

Figure 1–4. Descriptive Statistics of Demographic Characteristics

Data Analysis

Thematic analysis was the primary approach used for the analysis of the collected interview data. This is a systematic approach, adapted from Braun and Clarke (2006), to determine patterns, themes as well as categories in the collated interview transcripts. There were several steps involved in this process, as shown in Figure 5: initial exposure to the data, code generation, theme search, theme reviewing, naming of the themes, and the final step of writing the report.

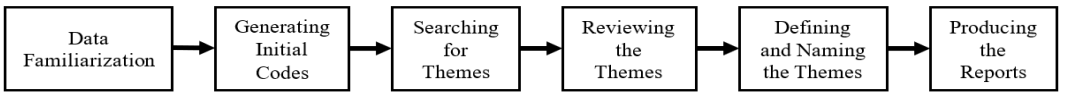

Figure 5. Thematic Analysis Process

Firstly, the interview transcripts were carefully studied to understand the interviews fully and extract the viewpoints. Initial codes were systematically generated by identifying interviewees' perceptions of any SF in the original dataset. In order to manage the dataset systematically, duplicate, similar, and related codes were combined and grouped to generate sub-themes and themes. These themes represented the key concepts and patterns in the data. Ongoing reviews critically assessed the consistency and relevance of the coded extracts and themes across the dataset.

Subsequently, the themes were refined to generate clear definitions and names that articulated the core ideas of each theme. Finally, the report was produced by analysing the selected extracted factors and relating them to the research questions. Between these stages, there were several iterations to achieve the best representation and categorisation of respondents' views. The key themes were critically analysed to identify patterns related to trends, issues, and prospects in MH within CHRB. This involved simultaneously examining the collected qualitative data alongside existing literature and theories. This concise and systematic approach ensured reliability and a comprehensive understanding of the professionals' perspectives on the dynamics of MH in the context of this particular industry.

In conclusion, the data collection and analysis approach utilised in this research offers a credible analysis of the success factors that impact MH optimisation in high-rise building projects in China.

RESULTS AND DISCUSSION

In this study, qualitative data analysis was conducted on the views captured from the participants that involved categorising recurring patterns, themes, and subthemes associated with MH optimisation in CHRB.

Through interviews with 30 industry professionals and thematic analysis of the interview results, a total of 30 SFs were identified for this study and organised into four themes, as shown in Figure 6. The themes were educational awareness and research, utilisation of advanced technology, regulation and coordination, and market drivers. These categories and the identified SFs are briefly discussed below.

Educational Awareness and Research

SFs related to education, awareness, and research are critical, and this theme includes *i) Sufficient argumentation and research on MH, ii) Practical understanding of the scope and process of MH, iii) Adoption of lean logistics concepts, iv) Industry training, including safety, skills, and ethics v) Integration of industry and education vi) Sincerity from the engineers and companies*.

Interviewees emphasised the importance of adequate discussion and research on MH. In particular, the recognition and demonstration of MH optimisation of CHRB requires social and collective consciousness in light of its safety, capital cost, and timeliness potentials, which are the core contents and ultimate goal of optimal MH in high-rise buildings. The lean logistics concept was also put forward as a potential idea to save expenses and prevent the wastage of resources by removing redundant activities if implemented effectively in the respective context. Promoting the integration and development of education, science and technology, and human resources is an inevitable requirement for the construction of Chinese-style modernisation. The concept of MH must be incorporated into university curricula, especially at the undergraduate level, requiring mutual involvement of industry and universities in curriculum development and funded research.

Employee training and skill enhancement to improve employees' MH knowledge and increase awareness of safety issues in the handling process were also brought out as other major influential factors in controlling losses and accidents. Training activities can be conducted regularly so that workers are informed of newer MH techniques and safety measures. Also, the spending on training can increase the employees' motivation and productivity in challenging some of the complicated tasks as per MH business. As addressed in a previous literature review by Rajeshkumar et al. (2021), some engineers indicated that engineers and companies could play a key role by sincerely adhering to good intentions, emphasising the role of fostering a collaborative work environment, and encouraging cross-departmental cooperation to optimise MH operations.

Utilisation of Advanced Technology

Seven SFs related to technical issues were identified from the participants' responses: *i) Application and research of sustainable green building materials ii) Advanced automation and intelligence technology iii) Stable and high-quality energy supply iv) Application of Building Information Modelling (BIM) v) Warehouse Management System (WMS) and Enterprise Resource Planning (ERP) system vi) Scientific material storage and management systems vii) Strategic planning and simulation*.

Participants emphasised that comprehensive development cannot be achieved without research and the application of sustainable green building materials, which facilitate waste reduction and cost savings and align with MH's target outlook. Some of the things highlighted by the participants include the need to maximise modern MH equipment and technology. This refers to advanced intelligent handling tools, such as robots, automated guided vehicles (AGV), and other sophisticated technologies used in material management. These technologies improve efficiency by enhancing the accuracy and precision of tasks, resulting in higher performance and minimising errors. Additionally, these technologies enable real-time tracking and monitoring of materials, proving valuable for analysing material and inventory movement. Some participants stated that a stable energy supply that provides a strong guarantee of advanced technology is essential for optimising the MH.

Participants emphasised that BIM has been widely used in the construction industry to visualise and integrate information in the physical phase of buildings, avoiding duplication of labour and greatly improving the efficiency of MH (Sepasgozr et al., 2013). They also advocated for the adoption of advanced information integration systems, including WMS and

ERP systems, to save money, reduce waste, and ensure safety. Scientific storage has also been put forward as a vital measure to prevent material damage and quality loss in contrary to conventional storage practices.

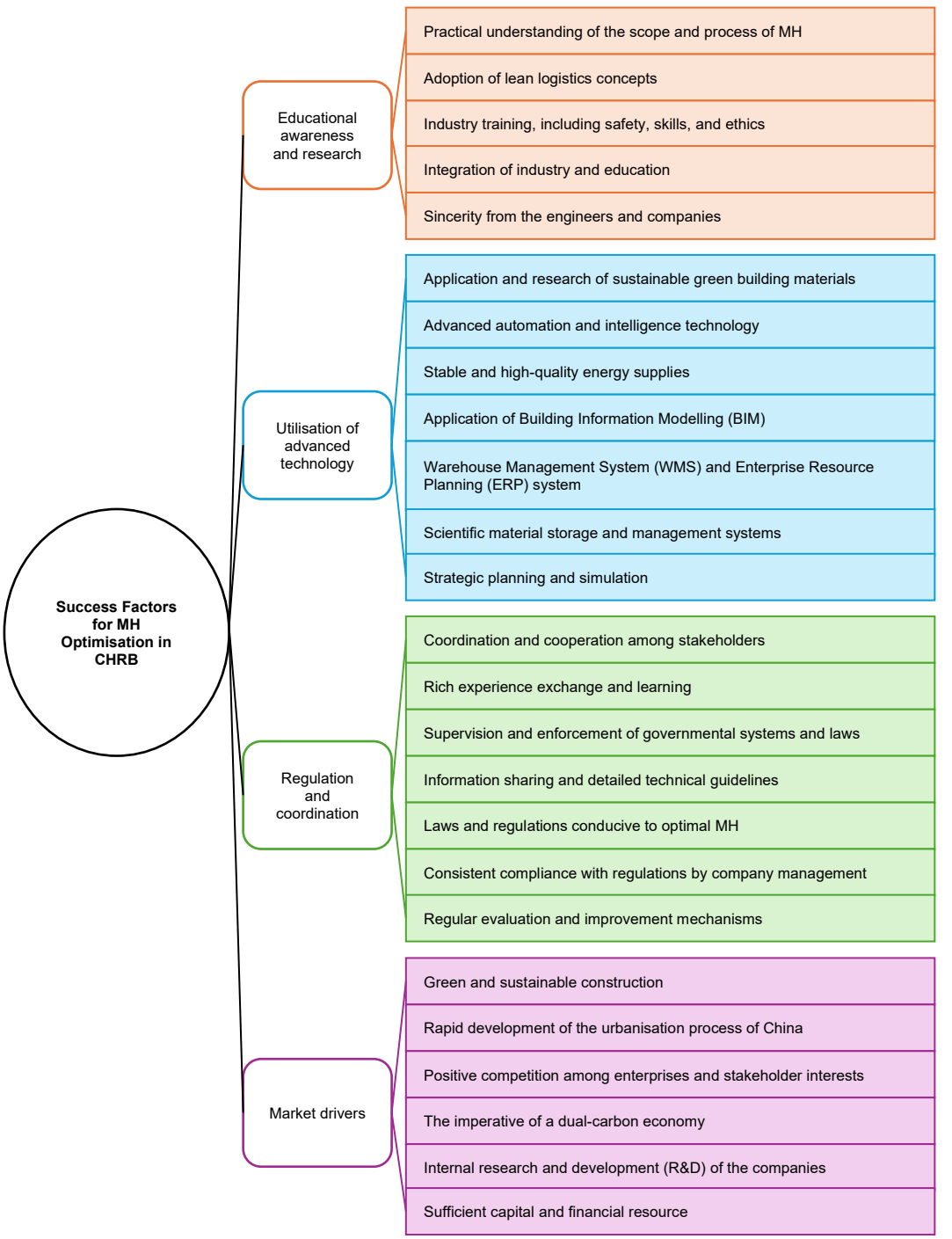

Figure 6. Success Factors for MH Adoption in CHRB

Several measures that were mentioned as good for recommending proper handling routes and, consequently, reducing transport time and distance included pre-planning and simulating material places and paths. If project managers apply simulation instruments, they can expect where problems may occur with space management and material flow; therefore, proper adjustments can be made. The above strategy also improves the overall efficiency of MH and affords better project scheduling and resource utilisation, which are factors contributing to cost control and timely delivery of projects.

Regulation and Coordination

Regulatory monitoring from different government departments and industry associations was found to be essential for effective implementation, and seven SFs were identified as relevant to this theme. These are: *i) Coordination and cooperation among stakeholders ii) Rich experience exchange and learning iii) Supervision and enforcement of governmental systems and laws iv) Information sharing and detailed technical guidelines v) Laws and regulations conducive to optimal MH vi) Consistent compliance with regulations by company management vii) Regular evaluation and improvement mechanisms*.

Participants emphasised the need for strict enforcement and accountability measures, including fines and penalties for code violations. They emphasised the need for accessible information and detailed guidelines on the incorporation of MH principles into building construction. Policies to follow were another subject acknowledged as critical in understanding the importance of the integration of MH practices with governmental policies. Governments must establish appropriate laws and regulations to ensure the effective optimisation of MH in CHRB. Some interviewees claimed that while some companies try to comply with codes and regulations, widespread compliance is required to achieve the desired optimisation of the industry. Participants also emphasised that coordination and cooperation among stakeholders, building on strengths, and a rich exchange of experiences and learning would contribute to better optimisation of MH. Regular evaluation and improvement mechanisms are needed as well to ensure proper implementation.

Market Drivers

Market drivers significantly contribute to the optimisation of MH, and six SFs related to this theme were identified: *i) Green and sustainable construction, ii) Rapid development of the urbanisation process of China, iii) Positive competition among enterprises and stakeholder interests, iv) The imperative of a dual-carbon economy v) Internal research and development (R&D) of the companies vi) Sufficient capital and financial resource*.

A number of interviewees indicated that the desire to have a better MH system than their competitors was a driving factor in companies choosing to do well. It was emphasised that the costs associated with ensuring appropriate quality and sustainability should be viewed positively by relevant stakeholders, especially owners.

At the same time, all relevant stakeholders need to envision the potential for cost and profit savings and be eager to incorporate sustainable practices. R&D within construction companies is considered essential, and this is mentioned as being dependent on the continued growth and expansion of the company. Green and sustainable construction is particularly

important due to the global economy and the national dual-carbon economy, and material handling in China's high-rise buildings needs to take into account this powerful externally-driven factor to promote the effective development of MH, thereby improving the core competitiveness of the companies themselves. Additionally, sufficient capital and financial resources were deemed essential for investing in materials and machinery related to MH.

CONCLUSION

This study utilised semi-structured interviews with 30 stakeholders and thematic analysis to identify a comprehensive set of SFs for optimising material handling (MH) in Chinese high-rise building (CHRB) construction projects. These factors include four themes: educational awareness and research, utilisation of advanced technology, regulation and coordination, and market drivers.

Education and research were found to be crucial for fostering a well-informed workforce, integrating lean logistics concepts, and enhancing industry-academia collaboration. The need for continuous technical advancement, especially through sustainable materials, automation, and digital tools like BIM, was emphasised as critical for improving MH efficiency. Strategic planning and simulation techniques contribute to optimising workflows, reducing waste, and enhancing project timelines. Furthermore, regulatory frameworks and government policies play a pivotal role in enforcing compliance, coordination, and accountability across stakeholders. Finally, market drivers, such as competition, urbanisation, and sustainability adoption, push companies to innovate and integrate environmentally conscious practices into MH processes.

This study contributes to the enrichment of the existing body of knowledge by emphasising some specific issues in the context of MH. By addressing education, technology, planning, regulation, and market influences, the construction industry can enhance efficiency, reduce costs, and improve safety and sustainability in MH. The government, policymakers, industry stakeholders, and academia can leverage these findings to formulate a comprehensive strategic framework for optimising MH, ultimately contributing to the successful execution of high-rise building projects in China. This can also serve as a valuable reference for other countries with similar socio-economic contexts.

As this study adopted a qualitative approach to explore MH across the entire scope of the high-rise building construction industry, future research could focus on specific themes for deeper and more detailed studies. This would help improve MH practices in high-rise buildings and provide precise empirical references for the industry. Additionally, implementing quantitative surveys could be beneficial in obtaining a wider sample size and prioritising the identified SFs. Lastly, the study can be extended to determine the barriers and strategies for optimising MH for high-rise buildings based on the foundation of the outcome of this study. By implementing these recommendations, China’s construction industry can significantly improve MH efficiency, reduce costs and delays, enhance worker safety, and contribute to long-term sustainability in high-rise building projects.

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BRIDGING THE GAP: ENHANCING STANDARDISATION AND EFFECTIVE IMPLEMENTATION OF BIM EXECUTION PLANS IN MALAYSIAN CONSTRUCTION PROJECTS

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Abstract
The Building Information Modelling Execution Plan (BEP) is a vital document that streamlines communication and promotes collaboration among project stakeholders. The BEP provides a clear framework that outlines roles, responsibilities, and deliverables, ensuring alignment and reducing misunderstandings throughout the project lifecycle. However, the lack of standardisation in BEP usage in projects presents challenges in defining its scope and ensuring its accuracy reflects the project's goals and requirements, often resulting in misaligned expectations among project stakeholders. Therefore, this study aims to identify the existing elements of BEP in construction projects and examine the challenges associated with its current usage in Malaysian construction projects. Additionally, the researcher has analysed fourteen (14) BEP documents using a qualitative method by means of document analysis. The findings revealed that there is no universally adopted BEP standard in BIM projects, leading to inconsistencies in the elements included in BEPs across different organisations. This lack of standardisation contributes to variability in BEP implementation and practices in different projects. Therefore, this study is expected to enhance the implementation of BEP practices for construction projects and facilitate future studies related to BEP, specifically in Malaysia, thereby improving BIM implementation and aligning with government policies for enhancing BIM enhancement in the construction industry.

Keywords: *Building Information Modelling (BIM); BIM Execution Plan (BEP); BEP Standard; BEP Implementation; Construction Projects*

INTRODUCTION

Building Information Modelling (BIM) is a key technological component of the Fourth Industrial Revolution (IR 4.0) that is rapidly advancing in the construction industry, alongside Digital Twin (DT) construction, the Internet of Things (IoT), big data, and additive manufacturing (Begić & Galić, 2021). To facilitate its implementation, several national agendas have been introduced by the government, including the Construction 4.0 Strategic Plan 2021–2025 by the Construction Industry Development Board (CIDB), the PWD Strategic Plan 2021–2025 by the Public Works Department (PWD), the Twelfth Malaysia Plan by the Economic Planning Unit (EPU), Ministry of Economy, and the National Construction Policy 2030 by the Ministry of Works (KKR). Additionally, BIM has been identified as one of the 12 emerging technologies outlined in the CIDB Construction 4.0 Strategic Plan 2021–2025. It has been designated for short-term implementation, with integration targeted within a year, as stated by CIDB in 2020 (CIDB, 2020).

Meanwhile, the Public Works Department (PWD), in its PWD Strategic Plan 2021–2025, has set a target to implement BIM in 50% of construction projects valued at RM10 million and above, with an annual increment of 10% in subsequent years until 2025 (PWD, 2020). To execute BIM, an essential guideline which is the BIM Execution Plan (BEP), is needed for planning and monitoring strategy (Bakar et al., 2020). In addition, BIM standards are needed to produce BEP key contents. The current standard used for the BEP creation is BS EN ISO 19650-1 and BS EN ISO 19650-2 by the International Organisation for Standardisation. BS EN ISO 19650-1 is for concepts and principles, while BS EN ISO 19650-2 is for the delivery phase of the assets (ISO, 2018a, 2018b). As a result, BEP from various countries around the world today are aligned with these two ISO standards, and Malaysia is among those countries (CIDB, 2019).

The purpose of a BEP is to provide a framework that ensures all stakeholders are aware of their roles and opportunities in implementing BIM for projects while also facilitating the effective integration of BIM in construction projects (Bakar et al., 2020). Nevertheless, the lack of BEP creation standardisation leads to inconsistencies that hinder collaboration and limit the full benefits of BIM (Shawky et al., 2024). This argument is reinforced by the inadequacy of the national BIM standard (Kah & Qin, 2021) which worsens the BEP implementation in Malaysian BIM construction projects. The fragmentation in process and documentation has exacerbated this issue, as BIM technology promises seamless collaboration and integration (Shawky et al., 2024). In addition, BEP itself is required to respond to the Exchange Information Requirements (EIR) of every project (CIDB, 2019). EIR is a client's requirement, which includes technical aspects, managerial aspects, and technical aspects of the project. Thus, BEP needs to be aligned with the EIR of the project as BEP shall be developed in a holistic approach according to project requirements (Bakar et al., 2020). Besides that, BEP is a live document that needs to be updated throughout the project (Ramírez-Sáenz et al., 2018) as it is the main reference for the project teams for BIM information related to the project, such as project goals, project characteristics, project stakeholders and infrastructure required (Bakar et al., 2020). Therefore, it is essential to identify the current use of BEPs in BIM construction projects. The following section will provide a detailed discussion of the definition of BEP and its aspects related to BIM.

BIM Execution Plan (BEP)

The BIM Execution Plan (BEP) functions as a reference document for contracting parties to implement BIM projects in accordance with the BS EN ISO 19650 standards or ISO 19650 (ISO, 2018a, 2018b). The BIM Execution Plan defines the processes and methodologies essential for fostering collaborative working practices in BIM projects (CIDB, 2017). In the Malaysian construction industry, the appointed party is mandated to develop the BIM Execution Plan (BEP) for projects implementing BIM. The preparation of the BEP involves two stages: pre-contract and post-contract. Additionally, the Public Works Department (PWD) has outlined key elements of the BEP in its BIM guideline, including project information, key project contacts, BIM objectives and uses, organisational roles and responsibilities, BIM workflows, model information, coordination and collaboration management, quality control measures, infrastructure requirements, model structure and file naming conventions, and project scheduling (PWD, 2021).

Furthermore, BEP is deemed essential for BIM construction projects and is tailored to meet the specific Exchange Information Requirements (EIR) of each project (CIDB, 2019). EIR encapsulates a client's technical, managerial, and commercial needs. Consequently, BEP must align with the EIR of the project, emphasising the need for different BEP for different projects and reflecting the diverse requirements of appointing parties (clients) across projects. In addition, BEPs should incorporate BIM elements that address people, processes, policies, and technology to enhance the delivery and performance of the construction process (CIDB, 2017).

Aspects of Building Information Modelling (BIM)

There are four key aspects of BIM: people, process, policy, and technology (Dawood & Vukovic, 2015; Succar et al., 2012). First, for any construction project, stakeholders must foster collaboration among all teams involved. This requires personnel to possess the technical skills and knowledge necessary to execute BIM-related activities and deliver corresponding outcomes (AECUK, 2015), including defining BIM uses and assigning organisational roles for the project. Second, in BEP, the process is crucial for creating and managing project information throughout the entire life cycle from the preliminary, design, construction, and as-built stages (NIBS, 2022). Third, technology with processes involved, including essential software and hardware, supports BIM activities such as 3D modelling, clash detection, and 4D scheduling (Kjartansdóttir et al., 2017). These tools enable comprehensive project visualisation and coordination. Finally, the Malaysian government has introduced several policies to enhance BIM adoption in the construction industry, such as the Construction 4.0 Strategic Plan 2021-2025, PWD Strategic Plan 2021-2025, the Twelfth Malaysia Plan, and the National Construction Policy 2030 (CIDB, 2020; EPU, 2021; KKR, 2021; PWD, 2021). To support these four BIM aspects, Publicly Available Specification 1192-2 (PAS 1192-2) provides a detailed framework, ensuring that information is consistently and accurately managed throughout construction projects. The next section discusses the PAS 1192-2 standards and how they align with and support BIM's aspects in practice.

Publicly Available Specification 1192 (PAS 1192-2)

PAS 1192-2 serves as a foundational framework that complements the four BIM aspects by offering specific guidance for managing BIM-related information across construction projects. This specification outlines processes to enhance collaboration among people and provide clarity in assigning BIM-related roles, directly supporting the "people" aspect (BSI, 2013). For the process aspect, PAS 1192-2 emphasises the importance of creating, managing, and sharing accurate project information at each project stage, ensuring that all stakeholders follow a unified process. Technological support is also addressed, as the specification provides guidance on using tools for accurate 3D models and managing information flows throughout the project lifecycle. Furthermore, PAS 1192-2 aligns with BIM policies by setting national standards that promote uniformity in construction practices, ensuring consistency across projects. Although PAS 1192-2 was withdrawn in 2018 to make way for ISO 19650, its principles continue to influence BIM practices and set a foundation for the newer international standards (NBS, 2018).

International Standardisation for Organisation 19650 (ISO 19650)

ISO 19650 is a standard that acts as an international benchmark for the effective management of information across the entire lifecycle of a built asset. It leverages BIM and ensures close alignment with the existing UK 1192 standards (BSI, 2019). ISO 19650 also replaces BS 1192:2007+A2:2016 and PAS 1192-2:2013, both of which are grounded in the UK's standards. ISO 19650-1 outlines the concepts and principles for business processes across the built environment sector, supporting the management and production of information throughout the lifecycle of built assets. In the context of Building Information Modelling (BIM), this process is referred to as 'information management' (ISO, 2018a). Meanwhile, ISO 19650-2 is developed to assist appointing parties in defining their information requirements during the delivery phase of assets. It also aims to create the appropriate commercial and collaborative environment in which appointed parties can efficiently and effectively produce the necessary information (ISO, 2018b).

METHODOLOGY

This study employed a qualitative approach through document analysis to examine the current use of BEPs in Malaysian BIM construction projects. A total of 10 BEP templates from research institutions, government agencies, and national standards bodies were selected due to their accessibility. Meanwhile, the remaining four (4) BEP templates from private agencies were obtained with difficulty, as BEP templates from private agencies are harder to obtain and less accessible. Table 1 outlines the list of analysed BEP templates. Document analysis was conducted using content analysis, a method particularly effective for systematically identifying and quantifying specific elements, themes, or patterns within documents.

Table 1. BIM Execution Plan (BEP) Templates

No.	Organisation Type	BEP Template	Year
1	Research Institute	Pennsylvania State University Computer Integrated Construction (PSU CIC)	2011
2	Research Institute	United Kingdom Construction Industry Council (UK CIC)	2018
3	Government Agency	Architecture, Engineering and Construction United Kingdom (AEC UK)	2015
4	Government Agency	General Services Administration United States of America (GSA USA)	2016
5	Government Agency	National Institute of Building Sciences (NIBS US)	2023
6	National Standard	Building and Construction Authority Singapore (BCA Singapore)	2013
7	National Standard	National Building Specification (NATSPEC)	2016
8	National Standard	Hong Kong Construction Industry Council (Hong Kong CIC)	2019
9	National Standard	New Zealand	2019
10	National Standard	Public Works Department Malaysia (PWD Malaysia)	2021
11	Private Consultants (PC)	PC 1	2017
12	Private Consultants	PC 2	2017
13	Private Consultants	PC 3	2018
14	Private Consultants	PC 4	2022

The data obtained was analysed through content analysis. This study aims to systematically capture the presence, frequency, and significance of key elements within each BEP. This approach enabled the identification of gaps and inconsistencies across BEPs, bringing focus to areas in need of standardisation and improvement to optimise BIM processes in Malaysia's construction projects. Furthermore, content analysis allowed for a structured comparison of BEPs, highlighting the strengths and weaknesses of current practices and providing a deeper understanding of critical elements essential for effective BEP implementation. This systematic analysis also contributes to clearer insights into areas where standardisation and refinement are needed, promoting more effective BEP adoption across the industry.

RESULTS AND DISCUSSION

Comparative Analysis of BIM Execution Plan (BEP) Elements Across Research Institutions, Government Agencies, Standards Bodies and Private Companies

This study has analysed 14 BEP documents sourced from various institutions: two from research organisations (Pennsylvania State University and United Kingdom Construction Industry Council), three from government agencies (AEC UK, the National Institute of Building Science, NIBS US, and the USA General Services Administration USA GSA), five from national standards bodies (Building Construction Authority Singapore BCA Singapore, National Building Specification Australia - NATSPEC Australia, Hong Kong CIC, New Zealand, and PWD Malaysia) and four from Malaysian private companies.

The reviewed BEP elements encompass the BEP overview, project information, key personnel contacts, project goals and BIM uses, organisational roles, BIM process design, information exchange, data requirements, collaboration strategies, quality control measures, technological infrastructure needs, model structure, project deliverables, delivery strategy, attachments or appendices, key performance indicators, and model. The study analysis revealed that most BEPs reviewed share nearly identical elements, largely because the BEP developed by Pennsylvania State University in 2009 has served as a foundational model for many others. This is in line with other researchers where the BEP developed by Pennsylvania State University in 2009 has been considered a well-documented BEP that is considered a fundamental feature in BIM (Anderson et al., 2020; Argasiński & Kuroczyński, 2023).

Next, the key elements of the 14 BEPs reviewed are organised into four main categories: people, process, technology, and policy, as shown in Table 2 below. The 'people' category includes seven elements: BEP overview, project information, key personnel, project goals and BIM uses, organisational roles, key performance indicators, and model information. The 'process' category encompasses project goals, and BIM uses, BIM process design, information exchange, data requirements, collaboration, quality control, delivery strategies, and attachments. The 'technology' category includes technological infrastructure needs, model structure, project deliverables, and model information.

Table 2. BEP Templates are Categorised According to BIM Aspects

No	BIM Aspect		Organisation Types	Research Institutions		Government Agencies			National Standard					Private Consultants			
			Publication Year	2011	2018	2015	2023	2016	2013	2016	2019	2019	2021	2017	2017	2018	2022
			BEP Template	PSU CIC	UK CIC	AEC UK	NIBS US	GSA USA	BCA Singapore	NATSPEC	Hong Kong CIC	New Zealand	PWD Malaysia	PC 1	PC 2	PC 3	PC 4
1	Policy	People	BEP Overview	✓	×	×	✓	✓	×	×	×	×	×	×	✓	✓	×
2		People	Project Information	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
3		People	Key Personnel Contacts	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
4		People/ Process	Project Goals/BIM Uses	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
5		People	Organisation Roles	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓
6		Process	BIM Process Design	✓	×	×	✓	×	✓	×	✓	×	✓	✓	✓	✓	✓
7		Process	Information Exchange	✓	✓	✓	✓	×	✓	×	✓	✓	×	×	✓	✓	✓
8		Process	Data Requirements	✓	×	×	✓	×	✓	✓	×	×	×	×	×	✓	✓
9		Process	Collaboration	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
10		Process	Quality Control	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓
11		Tech	Technological Infrastructure Needs	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓	✓	✓
12		Tech	Model Structure	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓
13		Tech	Project Deliverables	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
14		Process	Delivery Strategy	✓	✓	✓	✓	×	✓	✓	×	×	✓	×	×	×	×
15		Process	Attachment/ Appendix	✓	×	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	✓	✓
16		People	Key Performance Indicators	×	×	×	×	✓	×	×	×	×	×	×	×	×	×
17		People/ Tech	Model Information	×	×	×	×	×	×	×	×	×	✓	×	×	×	×
Total				**15**	**11**	**12**	**15**	**12**	**14**	**12**	**12**	**9**	**13**	**8**	**13**	**14**	**13**

Among the reviewed BEPs, the PSU CIC BEP is the most comprehensive, covering nearly all 17 elements. As a pioneer in BEP development, PSU CIC has a significant advantage over other BEPs, although it lacks key performance indicators and model information. In addition, the NIBS US BEP was derived from the PSU CIC BEP, leading to significant similarities in content. The UK CIC BEP, while including 11 elements, is missing the crucial component of BIM process design. Similarly, the AEC UK BEP, which includes 12 elements, also lacks BIM process design and data requirements. The GSA US BEP, with 12 elements, does not include BIM process design, information exchange, or data requirements. In contrast, the BCA Singapore BEP is comprehensive and closely comparable to the PSU CIC BEP.

In summary, among the 14 BEPs analysed, Pennsylvania State University contains the most elements, reflecting its continuous evolution since its inception in 2009, along with the NIBS US. This is followed by the BCA Singapore BEP with 14 elements and the PWD Malaysia BEP with 13 elements. The BEPs from AEC UK, GSA USA, and PC 2 each feature 12 key elements, while the UK CIC have 11. The New Zealand BEP contain 9, and PC 1 has eight elements. Across all BEPs, three elements, which are project information, key project contacts, and project goals/BIM uses, are consistently present. Additionally, collaboration is also a commonly featured element.

Issues with the Current BIM Execution Plan (BEP) Elements Across Research Institutions, Government Agencies, Standards Bodies and Private Companies

These findings correspond with the identified research issue, underscoring the lack of standardisation in the creation of BEPs (Shawky et al., 2024). This issue is exacerbated by the inadequacy of national BIM standards (Balfaqih et al., 2023; Kah & Qin, 2021), which exacerbates the implementation of BEPs in construction projects. As a result, poor communication and collaboration among construction stakeholders, especially structural and mechanical, electrical, and plumbing (MEP) designers, leads to inconsistencies and a lack of coordination in project design, affecting overall project progress due to design clashes (Yahya et al., 2022). Despite the potential of BIM technology to foster seamless collaboration and integration, the fragmentation of processes and documentation standards intensifies this issue (Shawky et al., 2024). Additionally, inconsistencies in key elements across BEPs further emphasise the absence of a standardised approach in BIM implementation. For example, CIDB's BIM Guide 4: BIM Execution Plan refers to two distinct BEPs: one for PWD and another for PC1. While the content of these BEPs is similar, their formats differ (CIDB, 2017).

Added to that, the key findings depict that the NATSPEC BEP and Hong Kong CIC BEP lack critical components where the NATSPEC BEP omits the BIM process design and information exchange, while the Hong Kong CIC BEP lacks data requirements. Since BIM process design is fundamental for establishing the stages, roles, and interactions necessary for BIM execution, its omission could lead to inconsistencies in project workflows (Andújar-Montoya et al., 2020). Similarly, information exchange protocols are vital for ensuring accurate data transfer between stakeholders (Mirhosseini et al., 2020). The Hong Kong CIC BEP also lacks data requirements, which are essential for specifying the type, frequency, and detail of information necessary to meet project needs. The absence of these elements in both BEPs points to potential inefficiencies in communication and data handling, which could hinder project execution.

The New Zealand BEP, which has only nine elements, shows substantial gaps, lacking key components such as organisation roles, BIM process design, data requirements, and technological infrastructure needs. This limitation reduces the BEP's ability to establish a clear structure for stakeholder responsibilities, outline the process flow, and identify technical resources (Jang & Collinge, 2020). Without organisation roles, the allocation of responsibilities remains ambiguous, which can lead to conflicts and inefficiencies. The absence of BIM process design and data requirements further limits the BEP's scope, leaving project teams without clear guidance on procedural steps and the specifics of information to be shared.

Meanwhile, despite containing 13 elements, the PWD Malaysia BEP lacks information exchange protocols and data requirements, which are essential for supporting structured communication and defining information needs. While relatively comprehensive in other areas, this BEP's missing elements highlight a gap in ensuring seamless information flow, especially critical for government-led projects that involve multiple stakeholders and public accountability.

Among the private company BEPs, there is a notable variance in the elements included. PC 1, with only eight elements, lacks information exchange, data requirements, and model structure as components essential for managing data flow, defining the types and frequency of data, and setting up the project model's structure. These omissions indicate potential challenges in managing data consistency and maintaining a standard model setup, which can compromise project accuracy and coordination (Kaya & Özener, 2024). Conversely, PC 3 and PC 4 are more complete, featuring elements aligned with those in Malaysia's BEP and covering all essential components. This suggests a more robust approach in these BEPs, likely leading to greater efficiency in project management and communication.

The final finding on BIM deliverables shows that the PWD BEP outlines the information and data exchange, specifying the data source, provider receiver and file format, as illustrated in Table 3. In contrast, PC 1 includes details on the Level of Development (LOD), start and end dates, and descriptions of BIM uses (Table 4). A key distinction between the two is that the PWD BEP separates BEPs for pre- and post-contract phases, whereas PC 1 consolidates them, highlighting a further lack of standardisation.

Table 3. BIM Deliverables Table in PWD BEP

No.	Information Exchange				Data Exchange	
	Information	**Data Source**	**Provider**	**Receiver**	**Original File Format**	**Latest File Format**
1	Detailed Design Civil	Detailed Design Model	Civil Designer	Project Team	.dwg (C3D)	.dwg (CAD) .nwc
2	Building Detailed Design (Architecture)	Building Detailed Design Model	Architecture Designer	Project Team	.rvt	.nwc .dwfx
3	Building Detailed Design (Electrical)	Building Detailed Design Model	Electrical Designer	Project Team	.rvt	.nwc .dwfx

Table 4. BIM Deliverables Table in PC 1

Activities	Conceptual Design	
Level of Development (LOD)	100	
Start	15 March 202x	
End	31 March 202x	
BIM Uses	Site Analysis	✓
	Site Planning	✓
	Conceptual Massing	✓

Finally, a robust policy framework is crucial for the effective implementation of BEPs in BIM projects. Consistent and stringent policy enforcement ensures that all stakeholders comply with the BEP throughout the project lifecycle, ultimately resulting in more efficient and accurate project execution. Future studies will focus on developing a detailed framework that guides construction professionals on effectively using BEP documents, enabling project teams to implement BIM successfully by following the specified BEP elements at each project stage.

CONCLUSION

This study highlights the essential role of BIM Execution Plans (BEPs) in driving the adoption of BIM within the construction industry, with a particular focus on Malaysia. Through an in-depth analysis of 14 BEPs from diverse sources, including research organisations, government bodies, standards agencies, and private companies, the study reveals significant inconsistencies in the inclusion of key BIM elements. Gaps in aspects such as information exchange, technological requirements, and data management highlight a lack of standardisation, which limits BEPs' effectiveness in fostering collaboration, efficient data handling, and process alignment, where these are the key factors for successful BIM project outcomes.

The findings are expected to have significant implications for construction professionals, as there is a need for a standardised BEP framework to guide policymakers and professionals in enhancing BEP consistency and application across projects. Such standardisation can improve workflow efficiency, support better project integration among project stakeholders, and ultimately lead to higher-quality results. Moreover, this study is also expected to benefit academicians by providing a foundation for further exploration into BEP frameworks and their role in BIM adoption, informing future curricula that equip graduates with the skills needed for effective BIM management. By bridging the gap between theory and practice, academia can help prepare a new generation of professionals ready to lead in BIM-driven project environments. Together, these contributions provide a roadmap for a cohesive approach to BEP development, fostering more collaborative, accurate, and successful BIM implementations across the industry.

ACKNOWLEDGEMENTS

The author would like to extend special gratitude to the Research Management Centre of Universiti Teknologi MARA (UiTM) and the Ministry of Higher Education for funding this research under the Fundamental Research Grant Scheme (FRGS), grant number FRGS/1/2022/TK01/UITM/02/6. Their financial support has been instrumental in facilitating this study.

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HOW CAN ARTIFICIAL INTELLIGENCE REVOLUTIONISE OCCUPATIONAL HEALTH AND SAFETY IN THE CONSTRUCTION INDUSTRY?

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Abstract
The construction industry is considered one of the most dangerous industries for workers. The manual, labour-intensive and time-consuming nature of traditional safety management methods makes them ineffective and prone to mistakes. This research addressed this gap by investigating how the application of Artificial Intelligence could be used to identify safety hazards, analyse risks and enhance communication between project teams, hence improving construction safety. The study employed an exploratory research approach that combined both qualitative and quantitative methodologies. Data was collected from a Building Information Modelling project, and safety data was processed using an HSE nation AI tool. The results from the study revealed that the AI tool identified sixteen hazards, including falls from heights, heavy machinery hazards, slips and trips, electrocution, chemical exposure, and noise hazards. The tool further categorised the initial risks using a probability and impact matrix into high, medium, and low risks using a colour-coded risk level. High-risk areas, such as falls and machinery-related hazards, were prioritised for immediate safety interventions. After implementing control measures, reassessment showed significant risk reduction, with most high-risk hazards downgraded to medium or low risk. This data is fed into the Building Information Modelling, where it produces colour-coded simulations enabling visualisation and communication of potential hazards before controls and how risks have changed post-mitigation. The study concluded that the incorporation of Artificial Intelligence into health and safety management provides a proactive approach to enhancing safety outcomes in construction projects.

Keywords: *Artificial Intelligence; Safety Hazards; Risk Assessment; Building Information Modelling; Communication*

INTRODUCTION

Eurostat's data (2022) indicates that there were 2.7 million non-fatal accidents leading to a minimum of four calendar days of work absence, alongside 3,355 fatal accidents in the same year. Construction was the sector with the highest rate of fatal accidents at work among all economic activities, and it had the third-highest rate for non-fatal accidents in 2022. These figures demonstrate how hazardous this industry is and how ineffective the present approaches are at reducing the frequency of occupational accidents. Construction accidents result in project delays and budget overruns, and in severe instances, they can lead to fatalities (Chiocha et al., 2019).

Artificial intelligence is a highly valuable development in the construction industry, as it fosters collaboration and coordination among all stakeholders (Mellado & Lou, 2020). A study by Akyildiz (2023) discovered that digital AI technologies allow a safety monitoring system which tracks employees and their activities and vehicle and equipment usage in real-time, detects risks in hazardous areas, and alerts authorised personnel, hence maximising

workplace safety and preventing work accidents. This agrees with the findings of Kong & Jie (2024), who highlighted the advantages of digital transformation in the construction industry, which include increased productivity, higher efficiency, less dependency on foreign labour, better site safety management and better cost and project management.

Data is a crucial element of artificial intelligence, according to Opoku et al. (2021). The data gathered at different phases of the building process can be compared across projects at different construction companies to provide useful learning data for AI applications. Sofiat O. Abioye (2021) discovered that some recent applications of AI in health and safety include wearable technology for construction safety monitoring, AI-based fall hazard detection and integration of sensor-based technologies with BIM to enhance construction safety. Further, Rane (2023) asserts that BIM and AI stand out as powerful technologies that, when combined, can transform construction safety management, while AI empowers machines to perform tasks requiring human-like intelligence, such as learning and problem-solving. (Pishgar, et al., 2021) established a framework named Risk Evolution, Detection, Evaluation, and Control of Accidents (REDECA) that focused on the utilisation of AI in predicting and controlling exposure to hazards within a worker's immediate surroundings.

The current approaches to safety planning are standalone, text-based, check-sheet-style tools that are accessible on paper (Vilventhan & Mohapatra, 2022). According to Mutwale and Ziba (2018), the current safety management processes rely on manual observations from previous projects, which means that accident records, whether in hardcopy or softcopy, are regularly referred to get data about potential risks and hazards. This method needs a lot of work and is likely to make mistakes because each project site is unique. According to a study by Zhang et al. (2013), a major contributing factor to workplace accidents is the failure to incorporate health and safety into the design process. Additionally, Mafuzah & Hassim (2024) came to the conclusion that poor management is predominantly the main cause of accidents, particularly when safety controls are not taken during the design stage.

Thus, this study sought to bridge the aforementioned gap by promoting the application of AI for safety enhancement and urging the early incorporation of safety measures into the planning and construction phases for both large and small projects. With the help of AI, safety in the construction industry can be monitored at ease, accurately and faster by analysing the safe and unsafe conditions and thereby reducing accidents at the construction sites to an extent.

METHODOLOGY

The study utilised an exploratory research design. This design was chosen due to its suitability in gaining insights into the integration of AI into health and safety management. The research employed a case study strategy to investigate a contemporary phenomenon within its real-life context using multiple sources of evidence. The study was conducted using the mixed approach since it involved an investigation of social phenomena through mathematical techniques. The combination of quantitative and qualitative approaches helped in leveraging the strengths of both to offer a thorough comprehension of the research problem.

The case study involved developing an architectural and structural BIM model in Autodesk Revit software, as shown in Figure 1, which served as the foundation for risk assessment. Autodesk Revit was used as the primary data collection instrument due to its unique modelling and visualisation capabilities. HSE Nation AI tool was used to automatically identify hazards and perform risk assessments. Dynamo, a visual programming tool integrated with Revit, was used to automate the application of risk levels to different building elements of the BIM.

A detailed 3D BIM model, as shown in Figure 1, was created using Autodesk Revit, including key construction activities and safety objects. The BIM model was imported into the HSE AI tool, which used inbuilt historical safety data to identify and assess potential risks for each construction activity. The AI tool then produced a comprehensive risk assessment matrix for the entire structure, providing a clear overview of the risks associated with different parts of the building. A Dynamo script was run on the BIM-AI platform to automatically apply risk levels to different parts of the model, colour-coding them as extreme, very high, medium, or low.



Figure 1. Studied BIM,3 Storey Building Generated Using Autodesk Revit 2024

Data Analysis

The AI tool was used on the BIM model to analyse and process historical safety data. It used machine learning algorithms to identify patterns and predict hazards, reducing manual data compilation time. The tool automated data extraction and generated comprehensive risk assessment reports, which are consistent with legal and regulatory frameworks.

To analyse the data from the HSE Nation tool, it identified a distinct set of hazards for each activity, and this data was downloaded and manually organised in Excel, where columns were created for each construction activity, identified hazards, and who might be harmed.

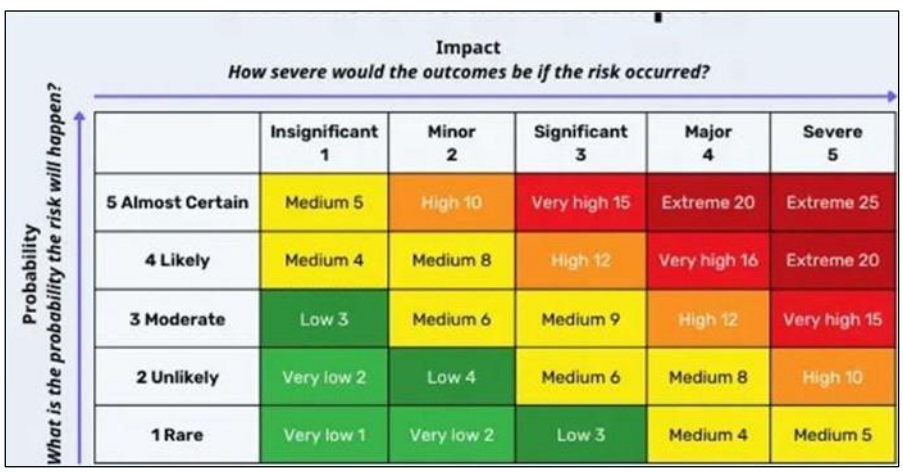
To complete information on the AI-generated risk assessment, the researcher input values for the likelihood and impact of identified risk on the Excel worksheet and a risk parameter (NRi) according to Equation 1 was created for each identified risk.

$$NRi = Pi \times Gi \quad \text{Equation 1}$$

Where NRi in Equation 1, risk rating with a colour coding corresponding with the numerical value as shown in Figure 2.

Pi represents the Probability Parameter, with values ranging from 1 to 5 for rare, unlikely, moderate, likely and certain probabilities, respectively. Gi denotes the Impact Parameter, again with values 1 to 5 indicating insignificant, minor, significant, major and severe impacts.

Based on this, the Excel sheet worksheet and the quantitative matrix of Figure 2 were uploaded to the HSE AI tool, which automatically generated a risk assessment matrix for each risk based on the risk level and colour coding prior to implementing safety measures. These hazards were classified using a colour-coded system: extreme risk in dark red, very high-risk areas in red, medium risk in yellow, and low risk in green, based on Figure 2 and Table 1.



(Source: BWC Safety, 2020)

Figure 2. Quantitative (5x5) Matrix of Risk Assessment

Table 1. Decisions to be Implemented According to The Risk Level and Colour Code Adopted in The Assessment

Risk Level	Action Required
Low Risk (T)	No specific action is required.
Medium Risk	There is no need to improve preventive action. However, more cost-effective solutions or measures with less economic implications should be considered. Routine checks are required to maintain control effectiveness.
High Risk	Effort should be committed to reducing the risk and determining specific investments. Measures to minimize risk must be implemented within the given period. Further action may be needed for extremely harmful consequences.
Very High Risk	Work should not commence until the risk has been reduced. Considerable resources may be required. For ongoing jobs, the problem must be resolved faster than with moderate risks.
Extreme Risk	Work should not start or continue until the risk is reduced. If the risk cannot be reduced, even with unlimited resources, work should be prohibited.

(Source: BWC Safety, 2020)

Control measures, including scaffolds, safety nets, procedures and standards, were included in the BIM by establishing URL features linked to previously constructed health and safety BIM objects.

To incorporate the re-evaluation stage into AI and act in accordance with the law, the risk levels must be determined through Equation 2.

$$NR_i = R_Pi \times R_Gi \quad \text{Equation 2}$$

Where NR_i represents the re-evaluated risk rating, which is accompanied by a colour code, (R_Pi) is the probability value and (R_Gi) is the re-assessed value for severity for each construction activity in the BIM and its identified risks.

The researcher manually organised the re-assessed risk assessment matrix automatically generated by the HSE AI tool. The matrices from the initial and reassessment phases were then combined into one comprehensive risk assessment (RA) document for the entire building.

The risk assessment matrix was then input into the BIM as an extension file. By using BIM parametric flexibility, planning tables were created using Dynamo scripts for parameters NRi and N_Ri were applied using colour filters, allowing for visualisation and simulation of the building's potential hazards before control and how risks have changed post-mitigation.

RESULTS AND DISCUSSIONS

Risk Identification

The HSE AI tool identified 16 primary hazards, as shown in Table 2.

Table 2. Identified Risks from The HSE Nation AI Tool

No.	Identified Risk
1	Falls
2	Heavy machinery hazards
3	Slips and trips
4	Chemical exposure
5	Electrocution hazards
6	Noise hazards
7	Weather conditions - extreme heat, cold, rains
8	Manual handling hazards leading to musculoskeletal injuries
9	Struck - by hazards
10	Working at heights
11	Dust, fumes, or other airborne particles.
12	Cave-ins
13	Ergonomic hazards.
14	Confined spaces can pose a risk of asphyxiation,
15	Exposure to hazardous gases
16	Entrapment

Finding sixteen distinct hazards demonstrated how precise and comprehensive AI can be for risk detection. With projects being so complicated and changing all the time, this skill is very important in the building industry. Analysing enormous volumes of data from several sources, including historical accident records, real-time sensor data, and workplace inspections and audits, the HSE Nation AI technology found hazards that might otherwise go unnoticed. It did this with advanced algorithms and machine learning.

These findings aligned with the research of Cortés-Pérez et al. (2020), who looked at how AI might be combined with BIM to identify and classify safety issues during the building process automatically. A study by Teizer et al. (2022) also emphasised the use of AI-driven systems to recognise potentially dangerous events as they emerge and classify them based on their possible consequences. The accuracy with which this system can identify and classify hazards helped to reduce accidents significantly on construction sites by enabling immediate interventions.

Risk Assessment

A quantitative risk assessment matrix was generated using the HSE AI tool, considering the parameters Probability (Pi) and Impact (Gi). Each risk was rated and colour-coded into extreme risk in dark red, very high risk in red, medium risk in yellow, and low risk in green. After downloading the matrix, a manual organisation in Excel provided a clear representation of risks for each construction activity, as shown in Figure 3. This enabled the identification of high-risk areas, allowing for prioritisation in resource allocation and safety planning.

RISK ASSESSMENT FOR A 3 STOREY BUILDING					
ACTIVITY	**WHAT ARE THE HAZARDS**	**WHO MIGHT BE HARMED**	**Probability(Pi)**	**Impact(Gi)**	**INITIAL RISK LEVEL**
2.0 FOUNDATION	Excavation Hazards – Risk of cave-ins, falls, and equipment accidents	Personnel/Contractors/visitors /children/General public/Vulnerable groups(people with disabilities,pregnant staff)	4	5	20
	Struck-By Hazards		4	4	16
	Electrical Hazards		3	3	9
	Slips, Trips, and Falls:		4	5	20
	Manual Handling Hazards leading to musculo-skeleton injuries		3	4	12
	Chemical Hazards		3	2	6
3. WALLING	Working at heights: There is a risk of falling from scaffolding or ladders	Personnel/Contractors/visitors /children/General public/Vulnerable groups(people with disabilities,pregnant staff)	5	4	20
	Manual Handling Hazards leading to musculo-skeleton injuries		5	4	20
	Exposure to dust and fumes:		4	4	16
	Electrical hazards:		3	2	6
	Slips, trips, and falls		4	5	20
	Chemical Hazards		2	3	6
4.RCC COMPONENTS					
4. BEAMS	Manual Handling Hazards leading to musculo-skeleton injuries	Personnel/Contractors/visitors /children/General public/Vulnerable groups(people with disabilities,pregnant staff)	5	4	20
	Chemical Hazards		4	5	20
	Slips, trips, and falls		4	5	20
	Working in confined spaces with beams may lead to asphyxiation or other confined space hazards		3	5	15
COLUMNS AND SLABS	Fall hazards	Personnel/Contractors/visitors /children/General public/Vulnerable groups(people with	5	4	20
	Struck-by hazards:		4	4	16
	Crush hazards:		3	4	12
	Musculoskeletal hazards:		3	4	12

Figure 3. An Extract of An Initial Risk Assessment for The Studied BIM as Generated from AI HSE Tool

RISK ASSESSMENT FOR A 3 STOREY BUILDING					
ACTIVITY	**WHAT ARE THE HAZARDS**	**CONTROLS (URL links for OSHA**	**Probability(Pi)**	**Impact(Gi)**	**RESIDUAL RISK**
2.0 FOUNDATION	Excavation Hazards – Risk of cave-ins, falls, and equipment accidents	https://www.hse.gov.uk/construction/s	1	2	2
	Struck-By Hazards	https://docs.google.com/document/d/1	1	2	2
	Electrical Hazards	https://www.osha.gov/electrical	1	2	2
	Slips, Trips, and Falls:	https://www.osha.gov/walking-workin	1	2	2
	Manual Handling Hazards leading to musculo-skeleton injuries	https://www.osha.gov/machine-guardi	1	2	2
	Chemical Hazards	https://www.hse.gov.uk/chemicals	1	2	2
3. WALLING	Working at heights: There is a risk of falling from scaffolding or ladders	https://www.osha.gov/fall-protection	1	2	2
	Manual Handling Hazards leading to musculo-skeleton injuries	https://www.osha.gov/ergonomics	1	2	2
	Exposure to dust and fumes:	https://www.osha.gov/respiratory-prot	2	1	2
	Electrical hazards:	https://www.osha.gov/electrical	1	1	1
	Slips, trips, and falls	https://www.osha.gov/walking-workin	1	2	2
4.RCC COMPONENTS					
4. BEAMS	Manual Handling Hazards leading to musculo-skeleton injuries	https://www.osha.gov/ergonomics	2	2	4
	Slips, trips, and falls	https://www.osha.gov/electrical	2	2	4
	Working in confined spaces with beams may lead to asphyxiation or other confined space hazards	https://www.osha.gov/confined-spaces	3	2	6
COLUMNS AND SLABS	Fall hazards	https://www.osha.gov/fall-protection	2	2	4
	Struck-by hazards:	https://www.hse.gov.uk/construction/s	2	2	4
	Crush hazards:	https://www.hse.gov.uk/work-equipme	2	2	4
	Musculoskeletal hazards:	https://www.hse.gov.uk/work-equipme	2	2	4

Figure 4. An Extract of The Re-Assessed Risk Matrix After Incorporating Control Measures URL Links as Generated from the AI HSE Tool

Based on the risk rating, risk reduction measures were incorporated, and the outcome of the reassessment process was the generation of a second risk assessment matrix, as shown in Figure 4, which reflects the newly calculated risk ratings (NR_i) derived from the reassessed probability (P_i) and severity (G_i) parameters. The second matrix, colour-coded according to the risk levels, showed the effectiveness of the implemented safety controls by reducing the previously high-risk areas to medium or low-risk categories.

The application of AI in this study showed a positive direction towards a risk assessment approach that is more objective, consistent, and data-driven. AI systems examined vast amounts of safety data, found potential hazards, and proposed control measures using natural language processing and machine learning approaches.

Consistent with this point of view,(Zhou, et al., 2020) looked at a hybrid approach combining BIM and machine learning to reduce automated safety risk. Their research showed that using AI to make decisions about risk is better because it reduces human error and makes risk assessments more accurate.

Colour coding helped to simplify complicated data related to risk assessments and made it understandable. This approach quickened the decision-making process and helped several project teams to distribute risks effectively. Research by Jin et al. (2020) and Rajendran et al. (2022) supported this strategy, which emphasised the need to merge AI-driven safety data and visual tools like BIM to enhance risk management in the building sector.

Visual Management and Communication

At this stage, assigning risk levels NR1 to each identified risk on the structural elements was done using the dynamo script; for instance, the risk of falling from heights on the selected column of Figure 5 the dynamo code was run, and it created a 3D simulation showing colour coded risk level hence displaying the work requirements regarding safety for the project.

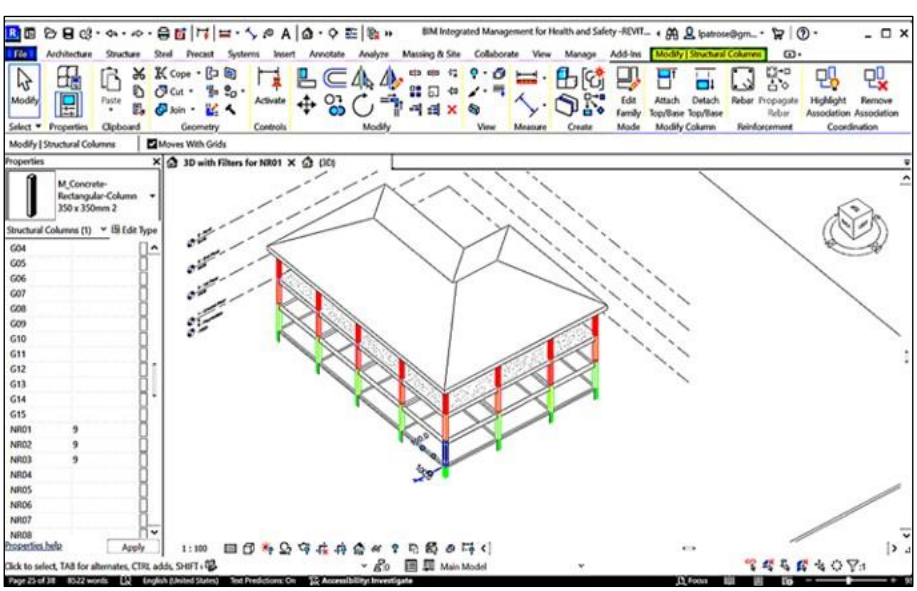


Figure 5. Risk Level of 9 for The Risk of Falling from A Different Level for The Ground Floor Column

For the purposes of this study, the risk of falling from heights for the structural columns at the ground and first floor levels was analysed. As shown in Figure 5 below, for the ground floor column, the risk level from the risk assessment matrix is 9, indicating a medium risk and the colour filter is yellow, while that of the first-floor column, the risk level of NR is 16, indicating a very high risk and has red colour as shown in Figure 6.

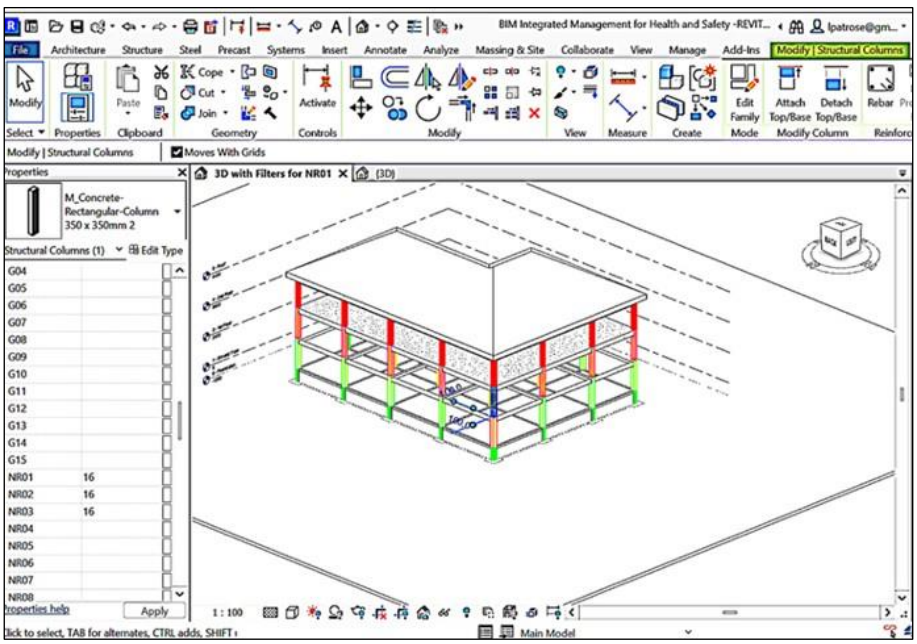


Figure 6. Risk Level of 16 For The Risk of Falling from Different Level for The First-Floor Column

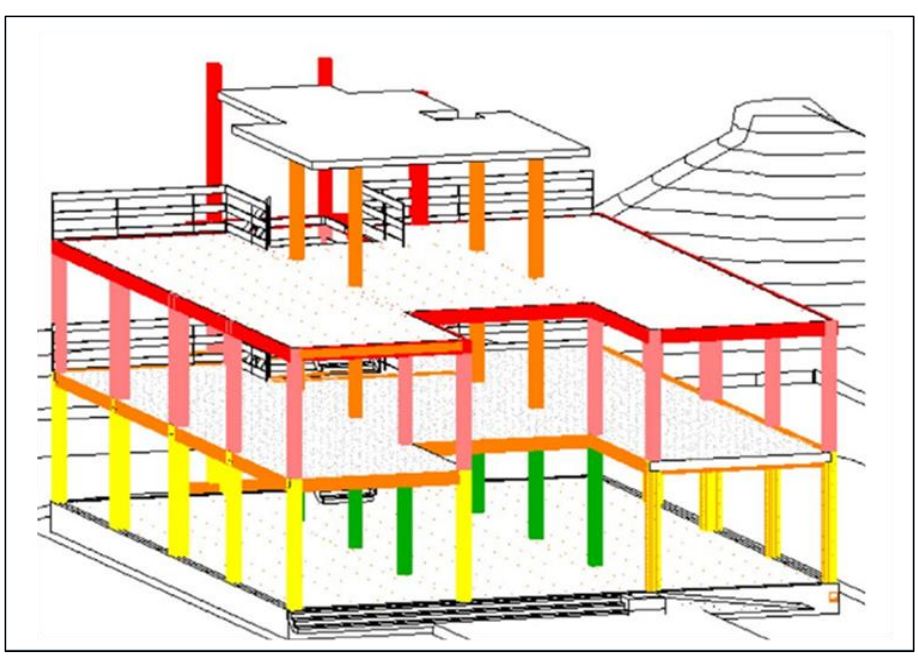


Figure 7. Three-Dimensional Visualization of The Risk of Falling from Heights for Structural Columns of The BIM

Figure 7 presents a three-dimensional representation of the building along with risk evaluation 01. The above illustration on managing H&S was generated using colour filters established by the recommended code for each risk rating in Figure 7, facilitating a visual depiction of the risk level associated with each element and its relevant components. Risk control procedures were implemented for elements identified with a risk level above NR > 9 to mitigate the risk to a more manageable level.

As an illustration of this methodology's use, specifically designed H and S BIM objects, such as scaffolds for fall prevention, were incorporated at the edges of the columns in the model for risk 01. Following a review of this risk, the NR_i value was determined to be 9, signifying that the risk level was acceptable at that time. In Figure 8, the phase of risk re-evaluation is depicted, where the researcher incorporated the control measures document stored in the cloud into the BIM.



Figure 8. 3 Dimensional Perspectives for Risk Assessment 1 “Falling from Heights” (On The Left) and Following Re-Evaluation (On The Right) for Columns Marked in Colour Coded Risk Levels

The URL attribute was used to filter information and incorporate the control measures into tables. Additionally, the URL parameter on the BIM was linked to the most recent health and safety documents available on the internet.

As the case study showed, increasing the effectiveness of safety management in the construction sector depends on using colour-coded risk categories to denote risk intensity. Red denotes high risk, yellow signifies medium risk, and green indicates low risk. The technique provided a rapid and simple means of visualising the hazards existing in the surroundings. Employees, safety officials and project managers could quickly assess the severity of any hazards and allocate their responses. Colour coding helped to simplify complicated data, which is usually connected with risk assessments and becomes more understandable. This visual approach of colour-coded risk levels promoted proactive safety management by means of continuous observation and application of safety measures as the project developed. The colour-coding scheme changed to show the current risk levels after the risks were reassessed and resolved so that every team member was aware of the most recent safety status. Research by Jin et al. (2020) and Rajendran et al. (2022) supported this strategy, which emphasised the need to merge AI-driven safety data and visual tools like BIM to enhance risk management in buildings.

The integration of AI-generated H&S data into BIM allowed for real-time sharing of safety information among designers, contractors, and safety professionals. This collaborative approach ensured that all parties were aware of potential risks and the necessary safety measures, thereby reducing the likelihood of accidents. The cloud-based storage and access to safety documents and risk assessments further facilitated this process, making it easier for teams to stay updated and compliant with safety regulations.

This agreed with the results of (Gibson, 2021), who found that AI-enhanced real-time data collection and visualisation technologies greatly increase proactive risk management and communication in construction safety, are consistent with this integration strategy. By enabling instant access to up-to-date safety information, the AI-integrated BIM model supports a more cohesive and informed project team, leading to better decision-making and enhanced safety outcomes.

CONCLUSIONS

This study concluded that the integration of Artificial Intelligence into Occupational Health Safety management offers several transformative benefits that can significantly reduce workplace accidents. AI-enhanced hazard identification improved the efficiency and accuracy of risk assessments and strengthened communication and collaboration, ultimately leading to safer and more efficient construction projects.

ACKNOWLEDGEMENT

Support for this study came from the SPREE initiative, which was financed by the African and European Unions under Project No. [614586-MOBAF 2019-1-1]. Additionally, thanks to the University of Zambia for their institutional assistance.

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INTEGRATING PLANNING AND SCHEDULING FOR CONTRACTORS: A FRAMEWORK FOR ENHANCED CONSTRUCTION PROJECT CONTROL

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Abstract
The integration of planning and scheduling is critical for developing feasible construction project schedules that enhance monitoring, control, and overall project efficiency. This study aims to develop an integrated planning and scheduling framework tailored for contractors in the construction industry. Grounded in an interpretive and inductive approach, the research explores the complexities of planning and scheduling practices through qualitative case study research. Semi-structured interviews with key personnel provide in-depth insights into organisational perspectives, while document reviews and observations offer additional contextual understanding. The research focuses on contemporary practices during the planning phase, offering valuable insights into their impact on project execution and control. By employing qualitative content analysis, the study identifies patterns and themes that inform the development of a conceptual framework reflecting real-world challenges and practices. The findings indicate that Scope, Schedule, and Cost are the primary knowledge areas influencing schedule development, with the remaining seven knowledge areas indirectly integrated within the framework. The Input, Tool and Technique, Output (ITTO) model standardises planning and scheduling tasks through eleven inputs, sixteen techniques, and twenty-three project data points, enhancing task sequencing, resource allocation, and timeline adherence. Validation through expert reviews confirmed the framework's practical applicability, ensuring its effectiveness in improving project planning and execution outcomes. By bridging theoretical concepts with industry practices, this study offers a structured approach for contractors to develop feasible schedules systematically. Integrating planning and scheduling within the framework supports proactive project monitoring and control, leading to better resource optimisation, reduced inefficiencies, and improved project outcomes.

Keywords: *Planning and Scheduling; Project Management Knowledge Areas; Construction Project Scheduling; Project Monitoring and Control; Project Planning Framework*

INTRODUCTION

The construction industry is one of the main contributors to the Gross Domestic Product (GDP) growth in developing countries. Promoting and maintaining long-term economic growth and stability is often an outgrowth of the expansion and stability of the construction industries (Kabirifar and Mojtahedi, 2019). Within Malaysia, the construction industry contributes 4% to the GDP, with projections indicating a contribution of 3.8% by 2025 (The Twelfth Malaysia Plan 2021-2025, 2021). Various national initiatives, such as the Construction Industry Transformation Programme (CITP) 2016–2020, have aimed to accelerate the industry's development to meet future economic demands, yet significant issues persist despite numerous initiatives (CIDB, 2015). Construction project delays have been widely studied to identify their underlying causes and develop effective mitigation strategies. Ballesteros-Pérez et al. (2018) and Sia & Razak (2021) identified various factors contributing to construction project delays, including poor planning and monitoring practices, site

management issues, labour and material shortages, rework, financial difficulties, design changes, and legal disputes, with poor planning and monitoring consistently highlighted as a recurrent issue in project management literature. Haron et al. (2018) emphasised the vital role of Malaysia's construction industry in economic growth while highlighting its challenges, including cost overruns, unrealistic schedules, abandoned projects, and the urgent need to address poor project management practices to prevent failures. Al Hadidi and Maher (2017) emphasised that project management is a complex process of interrelated operations, where planning and scheduling serve as the foundation for effective management, enabling project managers to monitor and control projects to prevent significant time and monetary losses. To address these ongoing challenges, it is essential to strengthen project management practices, particularly in planning and scheduling, to improve efficiency and support the sustainable growth of the construction industry.

The Gap Between Planning and Scheduling

Planning and scheduling, though integral to project management, are often treated as separate yet interdependent processes. In practice, planning and scheduling processes are carried out sequentially, starting with planning project activities without assessing resource limitations and then scheduling the project according to these pre-planned activities (Ben Issa & Tu, 2017). Planning and scheduling should be recognised as two separate processes, closely related but not performed concurrently in practice; planning should precede scheduling, and scheduling should never precede planning (Baldwin & Bordoli, 2014). Ben Issa and Tu (2017) stated that project planners prepare a complete set of activities to achieve objectives, which is then handed over to project schedulers for time and resource assignment. Planning and scheduling should be separate processes handled by different people for large projects to minimise confusion and differentiate the roles (Baldwin & Bordoli, 2014). However, Ben Issa and Tu (2017) found that not all project planning generated by the planning department is schedulable due to resource availability and other constraints, and some activities may require splitting to meet timeframes, while pre-planned activities could prevent an optimal schedule, leading to forward and backward planning, reduced resource utilisation efficiency, and poor schedule preparation. Al Nasseri and Aulin (2016) further clarified that while planning and scheduling are often synonymous, they are distinct yet interrelated processes, with planning proactively addressing schedule deviations and requiring multiple iterations to account for resource limitations and risks to create a feasible project schedule. The gap between planning and scheduling processes underscores the necessity for their integration to enhance project efficiency and effectiveness.

The Role of Project Management Software

Integrating project management software with planning methodologies is essential for improving project execution. Haron et al. (2018) emphasised that the government should reaffirm its commitment to implementing project management practices in all initiatives to reduce inefficiency while allocating funds to improve the use of project management tools among contractors, particularly in small-scale firms, where gradual adoption is recommended to avoid disruptive changes. Despite growing reliance on project management software, challenges remain in its effective application. Bellah et al. (2018) highlighted the growing expectation for project management courses to incorporate project management software, reflecting the increasing industry demand for software-driven projects. However, Bellah et al.

(2018) noted that university lecturers use Microsoft Project to teach project management. However, students often experience frustration and confusion as they struggle to manage projects effectively after applying the software. Similarly, Baldwin and Bordoli (2014) advised practitioners to avoid the temptation of using project management software to draft schedules prematurely, emphasising the importance of fully considering the main elements, their relationships, and the information to be conveyed for effective planning. These challenges underscore the need for a structured approach to integrating digital tools with planning and scheduling methodologies, ensuring that software enhances rather than complicates project execution.

Scheduling and Resource Management

Effective scheduling is heavily dependent on resource availability and proper sequencing of activities. Ben Issa and Tu (2017) explained that the Program Evaluation and Review Technique (PERT) and Critical Path Method (CPM) are two common project scheduling methods that assume unlimited resource availability with no constraints on scheduling decisions. However, Ben Issa and Tu (2017) also emphasised that resource availability is a common issue that delays activities in practice, explaining that each activity should start not only when precedence constraints are satisfied but also to consider the availability of the required resources for the time when the activities need to be started. Al Nasseri and Aulin (2016) stated that scheduling problems arise without essential knowledge of project planning, as the prerequisite for successful scheduling requires defining all activities, correctly sequencing those activities, and allocating resources and time to create the schedule. A clear understanding and definition of all inputs required in project planning and scheduling will increase the chance of successful project performance (Abdullah Al Nasseri, 2015). Al Hadidi and Maher (2017) further explained that the project management software models are specifically developed to address planning and scheduling challenges. Ngugi et al. (2015) found that construction companies recognise the need to advance their project management maturity and acknowledge that project management software significantly contributes to successful project delivery. Cicibas et al. (2010) argued that developing a framework for project management software tools would assist practitioners in categorising these tools, thereby deepening their understanding of how to apply them in project management effectively. This research, drawing from the insights of Cicibas et al. (2010), aims to develop a framework that integrates project management software tools with planning and scheduling processes, providing a structured approach for better application of these tools in project planning and execution.

Research Problem and Objectives

Inefficiencies in process integration, leveraging advanced tools, and professional skills represent significant barriers to effectively implementing planning and scheduling practices. The integration of planning and scheduling required extensive study and discussion to determine the most effective integration technique (Goh et al., 2024). To address these challenges and provide a comprehensive understanding of planning and scheduling processes during the planning phase, this study aims to review the existing planning and scheduling process models in project management. Specifically, this study addresses the following research questions:

RQ1: How do the planning and scheduling processes operate to develop the schedule model in the construction industry?

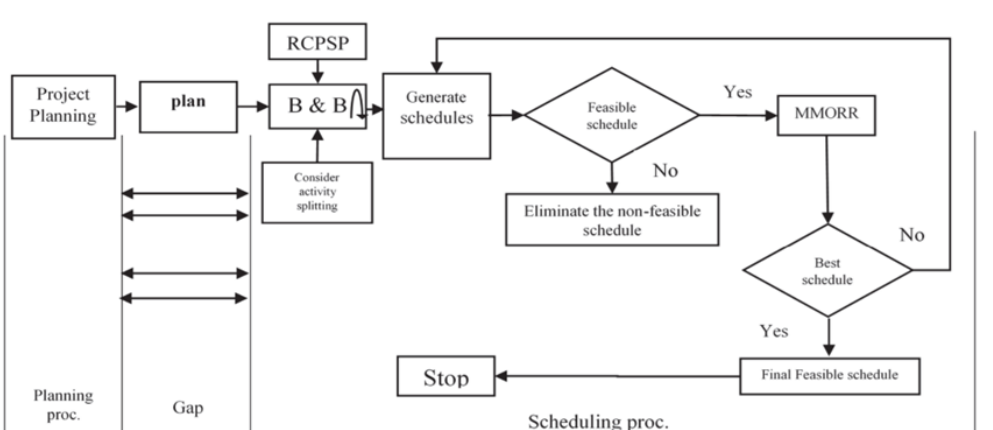
RQ2: Why does the issue of poor integration between the planning and scheduling processes arise during the development of the schedule model, leading to an unfeasible schedule model?

Research Contribution

While previous studies have extensively examined the causes of project delays and inefficiencies in construction project management (Ballesteros-Pérez et al., 2018; Haron et al., 2018; Sia & Razak, 2021), limited research has focused on the specific misalignment between planning and scheduling processes and its impact on schedule feasibility. Existing studies have predominantly treated planning and scheduling as independent functions, overlooking the necessity of their integration in achieving a realistic and executable project schedule (Ben Issa & Tu, 2017; Al Nasseri & Aulin, 2016). Furthermore, while adopting project management software has been widely discussed in the literature (Bellah et al., 2018; Ngugi et al., 2015), the challenge lies in its practical implementation. Previous research has highlighted software-related difficulties, but few studies have proposed structured frameworks that guide contractors in effectively integrating software tools into planning and scheduling workflows (Cicibas et al., 2010).

This study differentiates itself by focusing on integrating planning and scheduling processes within a structured framework tailored for contractor organisations. It provides a comprehensive approach that identifies gaps in current practices and establishes a systematic methodology using an Input, Tool and Technique, Output (ITTO) model to ensure clarity and standardisation in scheduling. By addressing these gaps, the study contributes a practical and adaptable framework that aligns theoretical project management principles with real-world industry applications, ultimately improving scheduling efficiency and project execution.

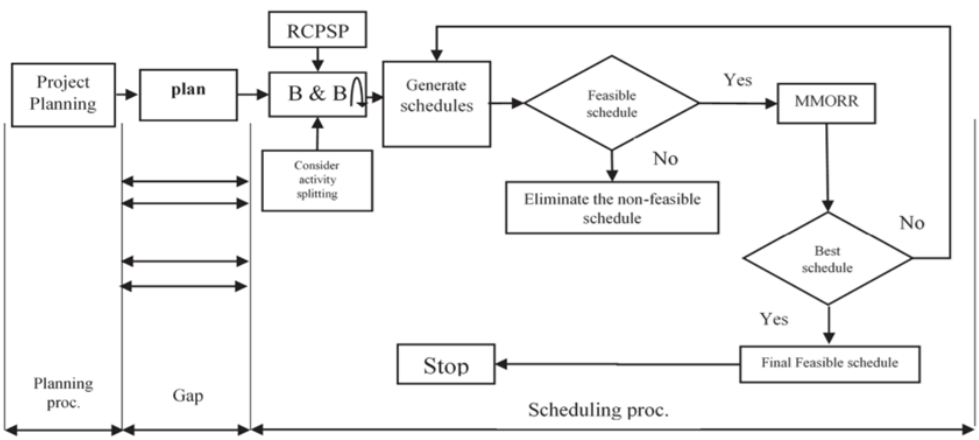
LITERATURE REVIEW



(Source: Ben Issa & Tu, 2017)

Figure 1. Gap Between Planning and Scheduling Processes

Referring to Figure 1, Resource-Constrained Project Scheduling Problems (RCPSP) have traditionally been addressed reactively during the scheduling phase after the planning phase. This reactive approach often results in inefficiencies, as resource limitations and conflicts are identified only at a later stage, necessitating schedule adjustments and resource reallocation (Ben Issa & Tu, 2017). The Integrated Process Planning and Scheduling (IPPS) model, proposed by Ben Issa & Tu (2017), addresses this issue by incorporating resource constraints into the planning process (Figure 2). This proactive approach enables project managers to anticipate and address resource limitations while developing the project plan rather than deferring these considerations to the scheduling phase. By shifting the resolution of RCPSP to the planning phase, the IPPS model enhances resource allocation, reduces project lead times, and improves overall execution efficiency (Ben Issa & Tu, 2017). This forward-thinking methodology represents a significant improvement over traditional reactive scheduling practices, fundamentally transforming how resource constraints are managed in project management.



(Source: Ben Issa & Tu, 2017)

Figure 2. Integrated Process Planning and Scheduling

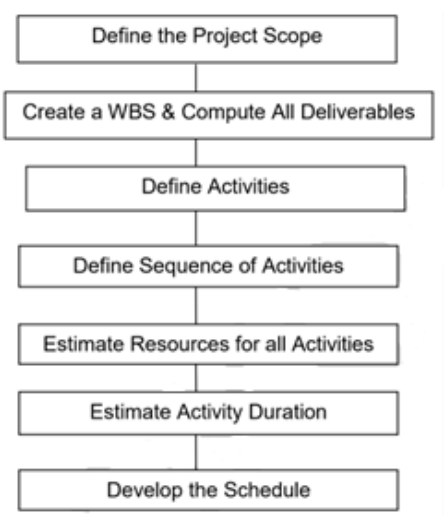
The process model allows for generating detailed schedules by breaking down activities into smaller, independent sub-activities. This capability, facilitated by the Branch and Bound (B&B) method, is designed to optimise resource utilisation from the outset (Ben Issa & Tu, 2017). The B&B method aligns closely with the "rolling wave" planning technique, where higher-level planning packages are progressively broken down into detailed work packages as more information becomes available (GAO, 2015). Construction projects are inherently complex due to physical constraints, project size, technical challenges, and contractual factors, resulting in uncertainty that creates information gaps and hinders effective decision-making (Baldwin & Bordoli, 2014). The iterative nature of the B&B method and rolling wave process requires repeated cycles of planning and scheduling, with the progressive acquisition of more detailed information until all activities can be comprehensively planned (Al Nasseri & Aulin, 2016). After generating potential schedules, the process model incorporates a crucial step to evaluate their feasibility, eliminating non-feasible schedules and forwarding only feasible options to the subsequent stage Ben Issa & Tu (2017). Ben Issa & Tu (2017) also introduced a new criterion called the Minimum Moments of Resources Required around X-Y axes (MMORR). This innovative metric measures and minimises resource idle times to enable the selection of the most optimal and feasible schedule.

Implementing these methods in real-world construction projects may present practical challenges due to the dynamic and unpredictable nature of the industry. Frequent changes, unforeseen events, and evolving project conditions add layers of complexity to applying the IPPS process model. This raises the critical question of whether the construction sector has widely adopted these proposed strategies and how effectively they are being applied. An inductive approach offers an opportunity to examine the implementation of these methods in real-world scenarios closely. Such an analysis can uncover practical challenges, highlight refinement areas, and provide valuable insights into their feasibility and impact. By gaining a deeper understanding of these strategies' application, future developments in project planning and scheduling methodologies can be better informed, promoting more effective and adaptable practices within the construction industry.

Review of Planning and Scheduling Processes

The term "construction" is widely used in the context of the built environment and the construction industry. Baldwin and Bordoli (2014) emphasised that while the term "construction" encompasses a wide range of activities from home building to heavy industrial engineering, planning and scheduling should focus on the unique characteristics of construction projects and their influence on these processes rather than on the scope of the term itself. The United States Government Accountability Office (GAO, 2015) noted that a comprehensive Integrated Master Schedule (IMS) should encompass all program activities, account for uncertainties, and adapt its level of detail based on the information available at any given time. In the Practice Standard for Scheduling, the activities are listed as 'planning packages' with less detail beyond the detailed planning wave, with cost and resource information fixed in the baseline duration and cost and further detailed added as planning progresses (Project Management Institute, 2011). The GAO (2015) further explained that in "rolling wave" planning, high-level planning packages representing several months of effort are progressively broken into detailed work packages as program elements become better defined over time, cautioning that excessive early detail could compromise schedule quality. Baldwin and Bordoli (2014) highlighted that the complexity and uncertainty of construction projects are influenced by factors such as physical constraints, project size, technical complexity, and contractual arrangements challenging information flow and decision-making. Baldwin and Bordoli (2014) also stated that planners must develop plans with limited information, leveraging their knowledge, experience, and coordination abilities to guide operations managers and forecast future events. Planning is a set of established processes to decide the tasks required to achieve project objectives within cost and time, including setting realistic schedules and budgets and ensuring resource coordination (Pierce Jr., 2013; Bjarnason, 2017). Planning is the process of selecting enterprise objectives and establishing the necessary policies, procedures, and programs to achieve them, with project requirements setting the major milestones (Kerzner, 2013; Bjarnason, 2017). Planning is an experience-based process that requires contributions from all involved parties for success, while scheduling is the science of using mathematical calculations and logic to predict the efficient and time-effective sequence of work (CIOB, 2011; Baldwin and Bordoli, 2014). In summary, effective construction planning involves leveraging experience, coordination, and decision-making processes to develop strategies that align with project objectives, manage uncertainties, and ensure successful project execution within time and cost constraints.

Planning and scheduling are continual processes throughout the project life cycle. PMI (2011) described scheduling as the process of analysing activity sequences, durations, resource requirements, and constraints to develop the project schedule. According to GAO (2015), planning and scheduling are sequential in nature, with work and strategies needing to be planned before scheduling, and emphasised that planning packages should be logically linked within the schedule to provide a comprehensive view of the program, while project schedulers must interpret, document, and update the schedule based on rolling wave planning and approved changes, including scope and resource constraints. Baldwin and Bordoli (2014) highlighted that as the project progresses and more information becomes available, the forecast must be revised, emphasising that planning and scheduling are iterative processes. Baldwin and Bordoli (2014) also stated that a good schedule clearly represents activities and milestones and provides the basis for analysis and decision-making, ensuring accurate forecasts for material, manpower, machinery, and cost requirements. In Malaysia, the Malaysian Public Work Department, or Jabatan Kerja Raya (JKR), refers to the project schedule as a "Work Program". JKR (2012) emphasised that establishing a realistic and achievable Work Program is a critical initial step in project setup, which should provide a graphical representation of tasks, milestones, dependencies, resource requirements, durations, and deadlines, detailing each Work Breakdown Structure (WBS) task, the responsible person, start and end dates, and expected durations while acknowledging that failure to meet schedule goals is often due to unrealistic deadlines, passive execution, unforeseen problems, or overlooked elements.



(Source: JKR, 2012)

Figure 3. Description of Process

The schedule incorporates vital variables such as non-working calendar periods, contingency, resource constraints, and preferred work sequences to determine durations, start dates, and finish dates of activities and key deliverables, with durations, resource assignments, and activity sequences refined over time (GAO, 2015). The Work Program serves as a practical "road map" for the project manager and team, enables them to plan, monitor, and control work execution, track project progress, manage resources efficiently, identify and manage task dependencies and constraints to prevent delays and communicate effectively with stakeholders (JKR, 2012). In conclusion, scheduling is a crucial process that provides a

structured timeline for project execution. Furthermore, planning and scheduling are iterative processes that require continuous refinement, detailed representations of project activities, and effective coordination to adapt to evolving project demands and ensure successful project management and execution.

Table 1. Theoretical Framework to Explore Planning and Scheduling

Categories			Exploration Focus
Process Group	**Knowledge Area**	**Processes**	
Initiating	Integration, Scope, Schedule, Cost, Quality, Resource, Communication, Risk, Procurement, Stakeholder.	Planning & Scheduling	Understand the interaction between processes and their interaction during project initiation.
Planning		Planning	How planning efforts are established.
		Scheduling	Evaluate scheduling tool: justification for selection and implementation.
Execution		Planning	Adapting planning efforts in response to obstacles during schedule development (e.g., resource reallocation).
		Scheduling	How scheduling efforts are implemented using project management software.
Monitoring & Control		Planning & Scheduling	The formation to ensure the planning and scheduling efforts are aligned with project goals.
Closing		Planning & Scheduling	Documentation & presentation of the final schedule model, including lessons learned and recommendations for improving future scheduling efforts.

In the modern era, many organisations are in a position that requires implementing project management standards. The construction industry, characterised by its high-risk and resource-intensive nature, particularly benefits from adopting efficient and effective project management practices. Haron et al. (2018) noted that widely used standards, methods, tools, and techniques have driven contractors to improve their planning and adopt more efficient management approaches. Abdullah et al. (2021) highlighted that major organisations such as PMI, IPMA, ANSI, and ISO have significantly contributed to developing project management theory and practice by establishing standards, guidelines, and methodologies that promote common practices for achieving project success. Grau (2013) emphasised that project management standards are implemented for various reasons, including client requirements or an organisation's desire to improve work quality through standard-driven processes, with their importance being particularly evident when multiple organisations or departments are involved, necessitating coordination of activities using consistent standards across all participants. After critically reviewing the literature, it was found that the definition and application of project management processes play a crucial role in bridging and ensuring effective planning and scheduling. Project Management Institute (2017) supports this view, emphasising that project management processes facilitate the seamless progression of a project throughout its lifecycle. According to the PMBOK Guide (6th ed.), project management is the application of knowledge, skills, tools, and techniques to project activities to meet project requirements. The Guide further highlights that applying knowledge requires effective management of the project management processes, ensuring that all project activities are properly aligned and coordinated. These processes incorporate the tools, techniques, and skills outlined in the Knowledge Areas, essential for effectively integrating planning and scheduling efforts. By applying these processes, project managers can ensure that planning and scheduling are structured and effective, ultimately leading to the development of a comprehensive and executable project schedule.

To support this integration, the proposed planning and scheduling framework organises the relevant Knowledge Areas within the Project Management Process Groups, which are instrumental in guiding the planning process. These Process Groups provide the foundation for aligning the Knowledge Areas with the Create Schedule process, resulting in a comprehensive schedule model. This framework bridges theoretical principles and practical applications, enabling more effective project scheduling. The theoretical framework for this research was developed by referencing and summarising project management processes from five different standards, including:

1) A Guide to the Project Management Body of Knowledge (Sixth Edition) (PMI, 2017),
2) BS 6079:2019+C1:2019 Project Management - Principles and Guidelines for the Management of Projects (BSI, 2019),
3) ISO 21500:2012 Guidance on Project Management (ISO, 2012),
4) APM Body of Knowledge (Sixth Edition) (APM, 2012), and
5) Individual Competence Baseline for Project, Programme, and Portfolio Management (IPMA, 2015).

This research, however, did not aim to develop a theoretical planning and scheduling framework for validation through a case study. Instead, the proposed assessment categories were used to guide the research inquiry. Knowledge areas and processes were identified based on exploratory data obtained from the case study, allowing flexibility to adapt the framework to the insights gained during interviews. This adaptive approach ensures the framework is grounded in practical findings while remaining aligned with theoretical principles. Consequently, the proposed framework provides a structured yet flexible foundation for effectively integrating project management processes into planning and scheduling, bridging theory and practice.

METHODOLOGY

Before initiating the research operation, it is essential to establish a well-structured research design to ensure the process proceeds smoothly. The research design serves as a framework that governs the research process and enhances the reliability of the outcomes. The qualitative case study approach was adopted, supported by a well-reasoned justification for the chosen strategy.

Research Design

This study adopts an inductive research approach aligned with the researcher's interpretive philosophical standpoint. The research intentionally refrains from seeking to find or falsify any particular factors within the existing planning and scheduling process models, instead positioning itself firmly within the qualitative research paradigm. Interpretivism is not focused on falsifying or identifying specific variables but rather on elaborating the perceived meanings communicated by participants, recognising that multiple realities may exist since truth is considered relative and dependent on individual beliefs (O'Neil & Koekemoer (2016). The interpretive approach proved valuable by recognising that each organisation had different procedures for planning and scheduling construction projects. These procedures were expected not to be standardised across all organisations; instead, they were formed by the organisation's operational practices, project-specific demands, and the perspectives of

individual stakeholders. Consequently, the data collected was highly context-dependent, reflecting the unique contributions of each organisation. This interpretive framework enabled an in-depth exploration of how diverse approaches to planning and scheduling evolve within different organisational contexts, highlighting the complex and multifaceted nature of the processes.

Justification for The Qualitative Approach

While a quantitative or mixed-method approach could provide measurable insights, they were not selected due to the research's emphasis on contextual understanding rather than numerical generalisation. A quantitative approach typically focuses on statistical analysis and large-scale surveys, which may overlook the depth and complexity of individual organisational practices in planning and scheduling. A mixed-method approach combines qualitative and quantitative elements but often requires extensive resources and time to balance both methodologies effectively. A pure qualitative approach was chosen because:

1. It allows a deep exploration of planning and scheduling practices unique to each organisation.
2. It captures the subjective experiences and perspectives of key personnel, which are crucial in understanding process integration.
3. It aligns with the interpretivist philosophy, ensuring the study remains focused on real-world insights rather than predetermined variables.

By employing qualitative research, this study ensures that planning and scheduling challenges are explored to reflect industry realities, making the findings more applicable for practical improvements.

Data Collection

The data collection process for this study was carefully planned and executed to ensure the relevance, depth, and consistency of the information gathered. Semi-structured interviews were the primary data collection method, with open-ended questions facilitating comprehensive responses. The case study interviews are typically open-ended, enabling researchers to ask respondents about facts and opinions and, in some cases, encourage them to share their perspectives, which can serve as a foundation for further inquiry and potentially shift their role from a respondent to an informant (Yin, 2003).

Site visits were a crucial aspect of the data collection process. A detailed plan was developed, including the locations visited, key contact persons, and the duration of each visit. All necessary materials, such as equipment and stationery, were prepared beforehand. Before each site visit, relevant documents were reviewed, and a list of questions was emailed to participants to foster mutual preparation. This strategy enhanced the quality of the interactions and helped extract detailed insights into the planning and scheduling practices used in construction projects. Confidentiality measures were prioritised throughout the research to protect participant privacy. This included anonymising sensitive information and securely storing collected data.

Interview Protocol

The interviews followed a semi-structured format, allowing flexibility while ensuring key themes were covered. The protocol included:

1. Number of Interviews: A total of 5 interviews were conducted.
2. Interview Duration: Each session lasted between 45 to 60 minutes.
3. Question Structure: Questions were categorised into three main areas: project planning, scheduling processes, and integration challenges.
4. Interview Medium: Interviews were conducted face-to-face and supplemented with virtual sessions where necessary.

The selection criteria for the case studies were designed to ensure that the research focused on participants with relevant expertise and practices in project planning and scheduling. By defining specific criteria, the study aimed to identify organisations and individuals who could provide meaningful insights into the research topic. This approach not only ensured the relevance of the data but also enhanced the quality and credibility of the findings.

Table 2. Selection Criteria for Case Study

Criterion	Description
Organisation Type	Contractors registered with the Malaysia Construction Industry Development Board (CIDB) registration scheme.
Key Personnel	Presence of a full-time planning engineer, project planner, or project scheduler collaborating with the project management team.
Project Management Software	Utilisation of project management software tools for developing project schedules or work programmes.
Good Project Completion Track Record	Completion of at least one project in the last ten years, adhering to contractual timelines.
Willingness to Participate	Demonstration of willingness to cooperate and provide access for data collection.

Interview Panel

The selection criteria for the interview panel ensured that participants had direct experience in planning and scheduling. By incorporating insights from multiple perspectives, the study ensured a comprehensive understanding of planning and scheduling integration. The extensive experience of the panel members contributed to rich, in-depth information and knowledge sharing, strengthening the research findings. The list of interviewees is provided in Table 3.

Table 3. List of Interviewees

Interviewee	Company	Position	Years of Experience
Project Manager 1	Company A	Project Manager	18 years
Project Manager 2	Joint Ventures (Company B & C)	Project Manager	22 years
Senior Project Planner	Company A	Senior Project Planner	15 years
Senior Planning Engineer	Company B	Senior Planning Engineer	12 years
Project Scheduler	Company C	Project Scheduler	9 years

Table 4. The Following Organisations Were Included in The Case Study, Each Contributing Valuable Insights into The Research

Company	General Profile
Company A	A multinational construction firm based in Malaysia with expertise in infrastructure, transportation, and marine engineering. The company is actively involved in EPCC projects and utilises industry-standard software such as Microsoft Project, Primavera, and Microsoft Excel for project scheduling and management. Company A employs dedicated planning teams implementing advanced scheduling techniques for large-scale infrastructure projects.
Company B	A leading local engineering firm in Malaysia specialises in construction, property development, manufacturing, quarrying, and infrastructure concessions. Company B has a strong presence in large-scale infrastructure projects, including transportation and marine works. In a joint venture with Company C, the company successfully delivered two marine infrastructure project packages on time in 2017 and 2019. The planning and scheduling tasks were managed by dedicated planners, who worked closely with the project managers to ensure timely delivery.
Company C	A multinational engineering and construction firm specialising in marine and offshore projects. With its global resources and technical expertise, Company C played a key role in the joint venture with Company B and successfully delivered a marine infrastructure project. The company supported marine construction, port facilities, and coastal engineering. The planning and scheduling tasks were handled by skilled planners who worked alongside Company B's team to ensure the project was completed on time and according to the project schedule.

The project manager from the case study was selected as the key informant, given their central role in planning, executing, monitoring, controlling, and closing projects. According to the Project Management Body of Knowledge (PMBOK, 2017), the role of the project manager is visible throughout the project. It involves initiation through closing, providing essential leadership to the project team and ensuring the achievement of project objectives. The project manager's expertise was leveraged to validate the framework and make sense of the findings, providing the results were relevant and grounded in practical experience.

Data Analysis

Following the completion of data collection through interviews, the analysis process was designed to extract meaningful insights for developing the scheduling model. The qualitative content analysis aimed to identify response patterns across participants, guided by the predetermined categories from the theoretical framework. This process began with an intra-case analysis for each case, which was analysed in depth before moving on to a cross-case analysis that compared findings across all organisations involved.

Table 5. Cross-Case Analysis between The Case Study Organisations

Company	Project Scope	Planning & Scheduling Approach	Software Used
Company A	Large-scale infrastructure and marine projects	Dedicated planning teams using structured methodologies	Microsoft Project, Primavera, Excel
Company B	Infrastructure and property development	Collaborative planning and scheduling with project managers	Microsoft Project, Excel
Company C	Utilisation of project management software tools for developing project schedules or work programmes.	Integrated scheduling with multinational expertise	Primavera, Microsoft Project

A cross-case analysis was then conducted to compare and contrast the findings across all case studies. This stage focused on identifying similarities and differences between the cases, allowing the researcher to uncover patterns that were not immediately visible within individual cases. The comparative analysis helped form generalised conclusions that extended beyond the individual cases and provided broader insights into planning and scheduling practices in construction projects. After completing the cross-case analysis, the insights

derived from the findings were synthesised into a conceptual framework that captured the core elements of planning and scheduling processes. The project manager, who served as the key informant, brought the framework to the forefront to validate its relevance and ensure alignment with practical project management experiences. The project manager's feedback was instrumental in refining the framework, offering critical insights that helped clarify and strengthen its components. Following this iterative validation and refinement process, the final framework was developed, providing a comprehensive model that integrates theoretical perspectives and practical applications in construction planning and scheduling.

RESULTS AND DISCUSSION

The Project Planning and Scheduling Framework is designed to integrate planning and scheduling processes systematically, ensuring a structured and practical approach to schedule development. It consists of three key knowledge areas—Scope, Schedule, and Cost—which are divided into eight elements defining project requirements, activity sequencing, resource allocation, and cost estimation. The framework follows the Input, Tools & Techniques, and Output (ITTO) methodology, a structured approach that facilitates a seamless transition from planning to scheduling. The planning process transforms raw project data into structured scheduling inputs, while the scheduling process translates these inputs into a detailed project schedule. The framework comprises eleven inputs, sixteen tools & techniques, and twenty-three scheduling outputs, ensuring a comprehensive process for creating a feasible schedule model.

The framework is structured into three main sections, as illustrated in Figure 4. The Planning Process (left section – orange background) is the initial phase that gathers project requirements and prepares essential inputs needed for scheduling. This includes defining scope, developing the work breakdown structure (WBS), sequencing activities, identifying resource needs, and estimating costs. Various tools and techniques, such as scope decomposition, expert judgment, and three-point estimation, are applied to refine these inputs. The outputs of this phase then serve as the foundational inputs for scheduling. The middle section (green background), labelled Planning (Output) / Create Schedule, represents the transition between planning and scheduling, where planning outputs become scheduling inputs. Key scheduling data, including work programme narrative, project milestones, activity lists, and resource/cost details, are prepared to ensure a smooth progression from planning to execution.

The Scheduling Process (right section – flowchart) outlines the step-by-step methodology for creating a project schedule. This process starts with setting up project information, such as defining the project start and finish dates, establishing the working calendar, and identifying schedule constraints. The work breakdown structure (WBS) is then developed to organise activities based on defined deliverables. Once the WBS is established, activities are sequenced by identifying dependencies, lags, and constraints to create logical workflows. Next, resources and costs are assigned to each activity, ensuring alignment with project requirements. Various techniques, such as parametric estimation, historical data analysis, and float management, are applied to estimate activity durations and optimise scheduling efficiency. The flowchart in the right section of the figure further illustrates key decision-making steps, including reviewing activity dependencies, checking resource requirements, and determining whether schedule adjustments are needed. If necessary, resource levelling is

conducted before finalising the work programme. The final output is a baseline schedule, the official reference for project execution and monitoring.

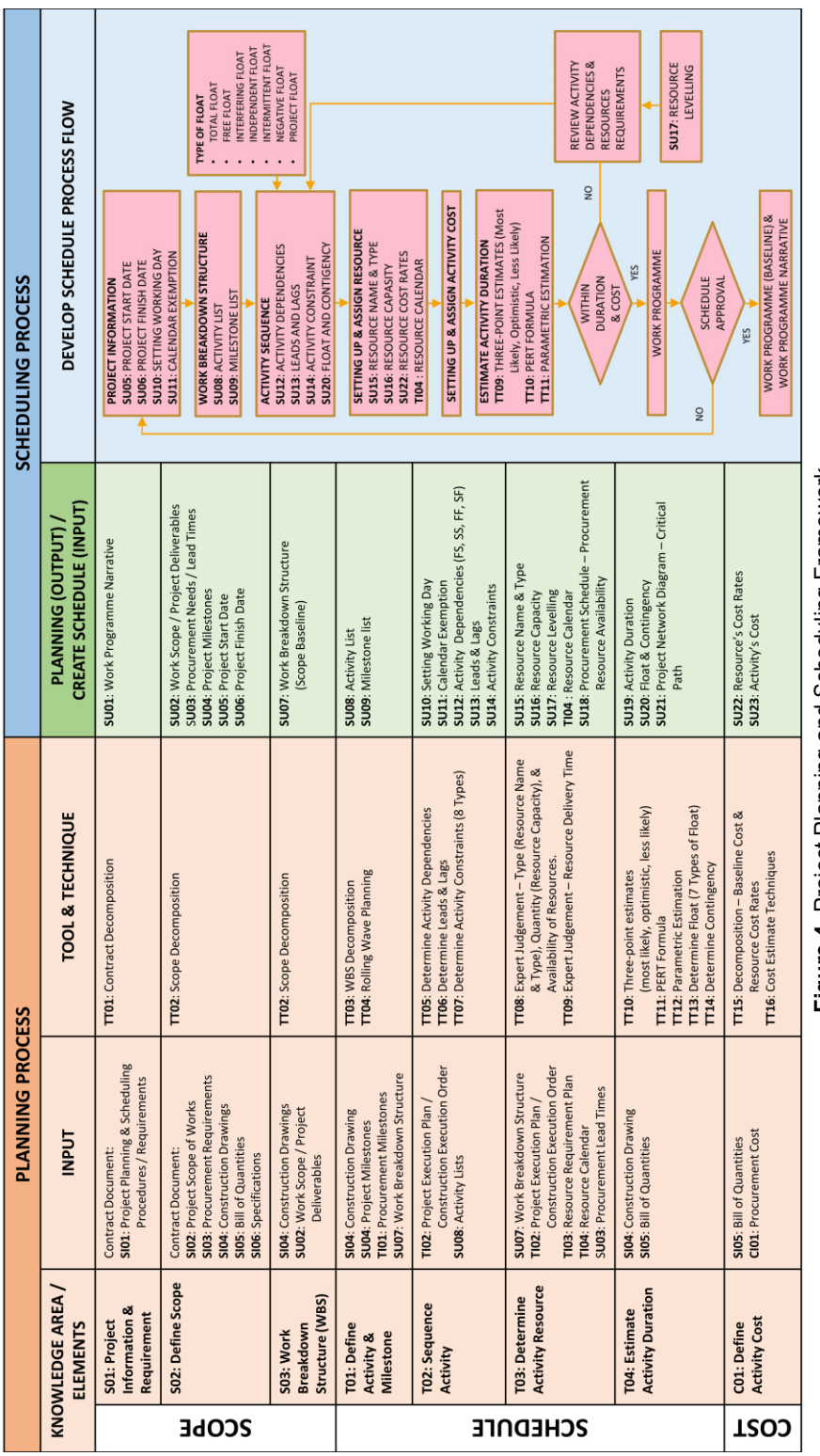


Figure 4. Project Planning and Scheduling Framework

CONCLUSION

The study findings confirmed that scope, schedule, and cost management were the most prominent knowledge areas across all companies in the case study. These three areas form the foundation of the proposed planning and scheduling framework. They are the most critical for developing the schedule model, which is the central objective of this study. The study findings revealed that aligning these knowledge areas with the triple constraint principle, balancing scope, schedule, and cost, is essential for achieving project objectives. This study further identified that while other knowledge areas, such as resource, procurement, and risk management, play supporting roles, they are indirectly embedded within the framework, ensuring a comprehensive yet practical approach to project planning and scheduling. By structuring planning and scheduling processes around these key elements, the proposed framework provides a systematic, adaptable, and industry-relevant approach to improving schedule feasibility in construction projects.

Practical Recommendations for Contractors

To effectively implement the framework, contractors should consider the following steps:

1. Define Scope Early – Clearly outline project deliverables and constraints to prevent scope creep.
2. Develop a Feasible Schedule – Utilise project management software (e.g., Primavera, Microsoft Project) to align resources and sequencing with realistic timelines.
3. Integrate Procurement into Scheduling – Ensure procurement lead times are accounted for to mitigate material delays.
4. Incorporate Risk Management – Use contingency planning and three-point estimation techniques to address scheduling uncertainties.
5. Enhance Communication – Regularly update and share schedule progress with stakeholders to ensure alignment with project goals.

By following these structured steps, contractors can enhance their planning and scheduling practices, improving project efficiency and reducing delays.

Study Implication

The study findings suggest that integrating scope, schedule, and cost within the planning and scheduling processes enhances project feasibility and execution efficiency. This study provides a structured approach that helps contractors systematically develop schedules while addressing procurement constraints within scope and schedule management. The framework offers practical implications by serving as a guideline for contractors to improve planning practices, optimise scheduling techniques, and enhance project monitoring and control. By leveraging the proposed framework, organisations can achieve better project success rates, reduce inefficiencies, and ensure more effective resource allocation in the construction industry.

Limitations and Future Research

During the course of this study, several limitations were encountered. The number of selected case studies was limited to three companies, primarily due to challenges in finding companies that met the strict criteria outlined for selection. The availability of companies that fulfilled these criteria and time constraints led to a reduced sample size. A larger dataset covering multiple project types, including commercial, infrastructure, and residential projects, could provide more comprehensive validation. Future research should expand the sample size and include quantitative analysis to measure the framework's impact on project performance metrics, such as schedule adherence and cost efficiency.

During the interview sessions, several challenges arose, including fluctuations in the time allocated for discussions and instances of off-topic conversations. Time and financial constraints further limited the ability to expand the sample size. Despite these limitations, the research provided valuable insights into planning and scheduling processes, with these challenges mitigated through a focused and adaptable approach.

This study has developed a planning and scheduling framework tailored explicitly for contractors in the construction industry. As the construction industry involves various stakeholders, future research should explore extending the framework's applicability to other key stakeholders, such as project owners and project management consultants. Expanding the framework's scope to include these stakeholders can provide a more holistic approach to integrated planning and scheduling, ensuring better alignment across all project stakeholders. The framework, which consists of generic integrated planning and scheduling processes, could be used as the baseline for future research, providing a foundation for further refinement and validation in different construction contexts.

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eISSN 2590-4140

