TECHNOLOGY MANAGEMENT AND BUSINESS
ISSN: 2229-838X e-ISSN: 2600-7916

Vol. 12 No. 2 (2025) 1-13
https://publisher.uthm.edu.my/ojs/index.php/jtmb

JTMB

Digital Twin for Dynamic Construction Site Monitoring and Control

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DOI: https://doi.org/10.30880/jtmb.2025.12.02.001

Article Info

Received: 6 March 2025
Accepted: 15 October 2025
Available online: 20 December 2025

Keywords

Digital Twin, construction management, real-time monitoring, Building Information Modeling, Internet of Things, predictive analytics, safety management

Abstract

The construction industry is inherently complex and poses significant safety challenges, requiring innovative solutions to enhance operational efficiency and risk management. Digital Twin (DT) technology has emerged as a transformative tool, offering real-time digital representations of physical construction sites to facilitate proactive decision-making and improve site monitoring. This study aims to explore the integration of Digital Twin technology into construction site management, focusing on its impact on safety, operational efficiency, and risk mitigation. By leveraging real-time data, predictive analytics, and Internet of Things (IoT) sensors, the research seeks to assess the effectiveness of DT in enhancing safety protocols and streamlining construction workflows. A mixed-methods approach was adopted, combining quantitative surveys with construction managers and safety officers, along with qualitative interviews with industry professionals. Statistical analysis was conducted to evaluate the correlation between DT adoption and safety performance indicators, while thematic analysis provided insights into practical challenges and benefits. Findings indicate a significant reduction in workplace accidents and near-miss incidents, with a 35% decrease in reported accidents following DT implementation. Additionally, participants highlighted improved situational awareness, proactive risk management, and a cultural shift towards safety-conscious practices. However, challenges such as initial costs and training requirements were identified as key barriers to widespread adoption. The study underscores the potential of Digital Twin technology to revolutionize construction site management by enhancing safety outcomes and optimizing operational efficiency. These findings offer valuable insights for industry practitioners, policymakers, and researchers, advocating for increased investment in DT systems to promote safer and more sustainable construction environments.

1. Introduction

The construction industry is characterised by its inherent risks and complexity, it is of the utmost importance to have effective site management and safety control. Accidents on construction sites continue to be a problem, despite the fact that technological advancements have been made. These accidents can result in serious injuries, delays in the project, and financial losses. In the field of construction site management, the investigation of Digital Twin (DT) technology as a potential game-changer has been prompted by the necessity of finding innovative solutions to improve both operational efficiency and safety. According to Tao et al. (2019) and Sacks et al. (2020), digital twins are devices that offer digital representations of physical construction sites in real time. These digital representations integrate data from a variety of sources to make monitoring, analysis, and decision-making more efficient.

The Digital Twin (DT) technology has emerged as a revolutionary method in the construction sector, especially for the dynamic oversight and management of construction sites. Digital Twins function as real-time digital representations of physical assets, processes, or systems, facilitating improved decision-making and operational efficiency across the construction lifecycle. This technology amalgamates diverse data streams from sensors, Building Information Modelling (BIM), and Artificial Intelligence (AI) to establish a holistic Digital Twin Information System (DTIS) that enables proactive oversight of construction operations (Saback et al., 2023; Yeung et al., 2022; Sacks et al.,2020).

A key benefit of utilising Digital Twins in construction is their capacity for real-time monitoring and predictive analytics. Utilising data from site monitoring technologies, Digital Twins can improve reality capture and facilitate proactive process management, essential for managing the dynamic characteristics of construction environments (Mao et al., 2022; Abou-Ibrahim et al., 2022). Real-time data acquisition facilitates prompt modifications to workflows, thereby reducing delays and improving safety protocols on-site (Liu et al., 2022; Talmaki & Kamat, 2022). The incorporation of IoT devices in Digital Twins enables continuous feedback loops, crucial for optimising construction processes and ensuring adherence to safety standards (Khajavi,2023; Chan,2023).

Furthermore, the utilisation of Digital Twins transcends basic monitoring; they are also integral to risk management and ergonomic safety. Through the application of predictive analytics, Digital Twins can anticipate potential safety hazards and ergonomic risks, equipping construction workers with the necessary information to autonomously manage their risk exposure (Lee & Lee, 2021; Ogunseiju et al., 2021). This capability enhances worker safety and contributes to overall project efficiency by minimising downtime due to accidents or health-related issues (Pan et al., 2023; Bado et al., 2022).

The adoption of Digital Twin technology for dynamic monitoring and control of construction sites signifies a substantial progression in the construction sector. Digital Twins are set to transform construction management through real-time data integration, predictive analytics, and enhanced safety protocols, resulting in superior project outcomes and sustainability (Pan et al., 2023; Aldabbas, 2023).

This study focusses on the persistent challenge of managing safety and operational efficiency in dynamic construction environments. Traditional safety management practices frequently rely on subjective assessments and reactive measures, which can be insufficient in preventing accidents and ensuring worker safety (Kim et al., 2020; Sutrisna et al., 2018). This is because these practices are not guaranteed to be effective. According to Ogunseiju et al. (2021) and Khajavi (2023), the incorporation of Digital Twin technology presents a promising avenue for the enhancement of safety protocols. This is because it enables real-time monitoring and predictive analytics, which in turn makes it possible to engage in proactive risk management.

This research is significant within the larger context of construction site management and safety control because it aims to bridge the gap between emerging technologies and practical applications in the field. Specifically, the research focusses on the areas of safety control and management. Through the utilisation of Digital Twin technology, the purpose of this study is to address significant safety challenges and to improve the overall outcomes of the project.

The following are some of the research questions that guided this study:

2. In order to improve both safety and operational efficiency, how can the technology of digital twins be effectively integrated into the management practices that are currently in place at construction sites?
3. What are the most important factors that contribute to the successful implementation of digital twin systems in construction environments?
4. What kind of an impact does the utilisation of digital twins have on the process of identifying and mitigating potential safety hazards on construction sites?

In spite of the growing interest in applications of digital twins, there are still significant research gaps in the area of understanding the practical implications of this technology in the management of construction safety. According to Xiahou et al. (2022) and Giri et al. (2023), the current body of research primarily concentrates on theoretical frameworks and isolated case studies, and there is a dearth of empirical evidence regarding the efficacy of digital twins in actual construction scenarios encountered in the real world. Furthermore, there is a dearth of comprehensive studies that investigate the incorporation of Digital Twins with other technologies, such as the Internet of Things and artificial intelligence, in order to improve safety management practices (Okonkwo et al., 2022; Zhang et al., 2020).

Within the scope of this study, the potential contribution of digital twin technology to improving safety management on construction sites is examined. A mixed-methods approach will be used for the research, which will involve quantitative examination of safety performance measures before and after the deployment of Digital Twin systems, as well as qualitative interviews with industry professionals. The purpose of this study is to fill these research gaps and provide important insights into the efficient use of Digital Twin technology in construction safety management. Creating a safer and more effective working environment for construction workers is the ultimate goal of this project.

2. Literature Review

The Digital Twin concept, initially developed in the manufacturing sector, has been gradually introduced into the construction industry. DT in construction is often associated with creating a virtual model that mirrors the physical construction process, integrating data from various sources to provide real-time insights. Previous studies have explored DT for facility management and asset maintenance; however, its role in dynamic site monitoring remains underexplored.

Recent research highlights the potential of DT to transform project management by enhancing visualization, improving data accuracy, and enabling predictive analysis. Several frameworks have been proposed, but they often lack practical implementation or focus on isolated functions. This study distinguishes itself by proposing a comprehensive DT model specifically designed to monitor and control progress and safety indicators on active construction sites.

2.1 Digital Twin Technology in Construction Safety Management

Digital Twin technology has arisen as a revolutionary instrument in construction safety management, facilitating real-time monitoring and predictive analytics. Wang (2023) examines a technique for the safety management of cable net structures utilising Digital Twins, facilitating real-time monitoring and juxtaposition of mechanical and geometric data with simulation outcomes, thereby guaranteeing safety during the construction phase. Xiahou et al. (2022) emphasise the potential of combining advanced technologies like IoT and BIM with Digital Twins to develop intelligent construction sites that improve safety management. These studies highlight the significance of real-time data in recognising and alleviating safety risks, thereby enhancing overall project results.

2.2 Real-Time Location Systems and Safety Surveillance

Real-time locating systems (RTLS) are recognised as essential elements in improving safety on construction sites. Soltanmohammadlou et al. (2019) present an extensive review of RTLS applications in construction, highlighting their contribution to enhancing safety through accurate tracking of personnel and equipment. Real-time monitoring of worker locations can substantially decrease the probability of accidents, especially in hazardous settings. Moreover, Kim et al. (2014) contend that conventional manual inspections are inadequate for prompt safety monitoring, while automated systems can offer superior oversight of safety compliance (Kim et al., 2014).

2.3 Methodologies for Risk Assessment

Comprehensive risk assessment is essential for construction safety management. Jiang et al. (2020) present a decision-making approach for construction safety risk management utilising ontology and case-based reasoning (CBR), highlighting the necessity for organised safety risk knowledge to improve decision support systems (Jiang et al., 2020). This method enables the recognition and reutilization of safety risk knowledge, promoting timely decision-making and accident prevention. Zhu and Wang (2022) emphasise the significance of integrating multi-source data to establish an effective safety control mechanism, employing artificial neural networks for the intelligent prediction of construction safety risks.

2.4 Safety Planning and Hazard Identification

Safety planning is crucial for recognising potential hazards prior to the initiation of construction activities. Feng and Lu (2017) examine the application of Building Information Modelling (BIM) to automate scaffolding planning for risk assessment, tackling the issues related to scaffold-associated hazards (Feng & Lu, 2017). Their research demonstrates that a BIM-based safety management model can proficiently assess risks and offer solutions, thereby improving safety planning procedures. Zolfagharian et al. (2014) underscore the significance of preactivity safety planning, promoting the identification and categorisation of risks to enhance safety protocols on construction sites.

2.5 Obstacles and Impediments to Enhancing Safety

Notwithstanding the progress in safety management practices, numerous challenges continue to afflict the construction industry. Prasad and Reghunath (2011) delineate obstacles to safety enhancement, such as inadequate safety education, insufficient managerial commitment, and inadequate resource allocation for safety initiatives (Prasad & Reghunath, 2011). These obstacles impede the efficient execution of safety protocols and highlight the necessity for a cultural transformation that prioritises safety in construction practices.

3. Methodology

The research adopts a design science methodology to develop and validate the DT model. The process includes the following stages:

a) Requirements Analysis: Identification of monitoring needs related to progress tracking and safety control.
b) System Architecture Design: Integration of BIM (Autodesk Revit), IoT devices (environmental sensors, cameras), and a cloud-based data platform (e.g., Azure, ThingSpeak).
c) Data Flow Mapping: Real-time data from the construction site is collected and synchronized with the BIM model. Data visualization and analysis are conducted via dashboards and alert systems.
d) Simulation & Validation: A simulated construction site scenario is used to validate the model's functionality, focusing on progress milestones and safety thresholds

3.1 Research Methodology

The research is based on a critical realist paradigm, which accepts the existence of an objective reality while acknowledging that human perceptions and social constructs shape our comprehension of that reality (Sutrisna et al., 2018). This method facilitates an in-depth examination of the intricate relationships among technology, safety management practices, and worker behaviour in construction environments. The research employs a sequential explanatory design, wherein quantitative data collection and analysis occur prior to qualitative data collection, facilitating a comprehensive understanding of the research issue (Berglund et al., 2023).

3.2 Sampling Techniques

The research utilises purposive sampling to identify construction sites that have adopted Digital Twin technology. This methodology guarantees that the sample encompasses locations with differing degrees of technology integration and safety management practices, offering a multifaceted viewpoint on the research enquiries. The target population will comprise construction managers, safety officers, and workers from designated sites, facilitating a thorough comprehension of the effects of Digital Twin systems on safety management.

3.3 Data Acquisition Protocols

Data collection was conducted in two phases:
Phase 1: Collection of Quantitative Data - A structured questionnaire was developed to collect quantitative data regarding safety performance indicators, employee perceptions of safety, and the degree of integration of Digital Twin technology. The survey was disseminated to construction managers and safety officers at the designated sites. The questions were formulated according to established safety performance metrics and validated scales from prior research (Shaikh et al., 2020; Rodrigues et al., 2020). Data was gathered through an online survey platform to enhance accessibility and participation.

Phase 2: Collection of Qualitative Data – Following the quantitative phase, semi-structured interviews were conducted with a subset of participants' experiences with Digital Twin technologies, its perceived advantages and challenges, and its influence on safety management practices. This qualitative phase seeks to elucidate the quantitative findings and comprehend the contextual factors affecting safety management on construction sites (Odo & Rankin, 2022).

3.4 Analytical Techniques for Data

Analysis of Quantitative Data - The quantitative data obtained from the questionnaires were analysed using statistical software (e.g., SPSS or R). Descriptive statistics will encapsulate the data, whereas inferential statistics (e.g., regression analysis) were employed to examine the correlations between the integration of Digital Twin technology and safety performance metrics. The analysis also explores potential moderating factors, including site characteristics and worker demographics (Shen et al., 2017).

Analysis of Qualitative Data **-** The qualitative data obtained from the interviews were transcribed and subjected to thematic analysis. This approach involved coding the data to identify recurring themes and patterns related to the implementation of Digital Twin technology and its influence on safety management. The results were integrated with the quantitative data to provide a comprehensive understanding of the research enquiries (Oswald et al., 2019).

3.5 Credibility and Rigour

To ensure the credibility and rigour of the research findings, multiple strategies were implemented. A pilot study was conducted during the quantitative phase to assess the questionnaire's clarity and reliability. In the qualitative phase, member checking was employed, allowing participants to review and validate the accuracy of the transcriptions and interpretations of their interviews (Sutrisna et al., 2018; Carpio-de Los Pinos & González, 2020). Furthermore, triangulating data sources enhanced the validity of the findings by comparing results across different methods and perspectives.

This mixed-methods approach offers a comprehensive framework for investigating the impact of Digital Twin technology on improving safety management in construction environments. The study seeks to provide valuable insights into the effective implementation of Digital Twin systems for enhancing safety outcomes in the construction industry by integrating quantitative and qualitative data.

4. Result

The implementation of the DT model shows notable improvements in real-time monitoring capabilities. For instance, the model detected safety violations (e.g., overcrowded zones) within minutes, enabling quicker interventions. Progress data visualized through the dashboard helped detect schedule delays early, contributing to improved project planning.

Compared to traditional methods, the DT approach reduces data processing time, enhances communication among stakeholders, and fosters a culture of safety and accountability. However, challenges such as data integration complexity and initial setup costs were identified.

4.1 Quantitative Results and Findings

The quantitative analysis included responses from one hundred fifty construction managers and safety officers working at a variety of construction sites that have implemented Digital Twin technology. Fig 1 shows the Impact of Digital Twin Technology on Construction Site Safety.

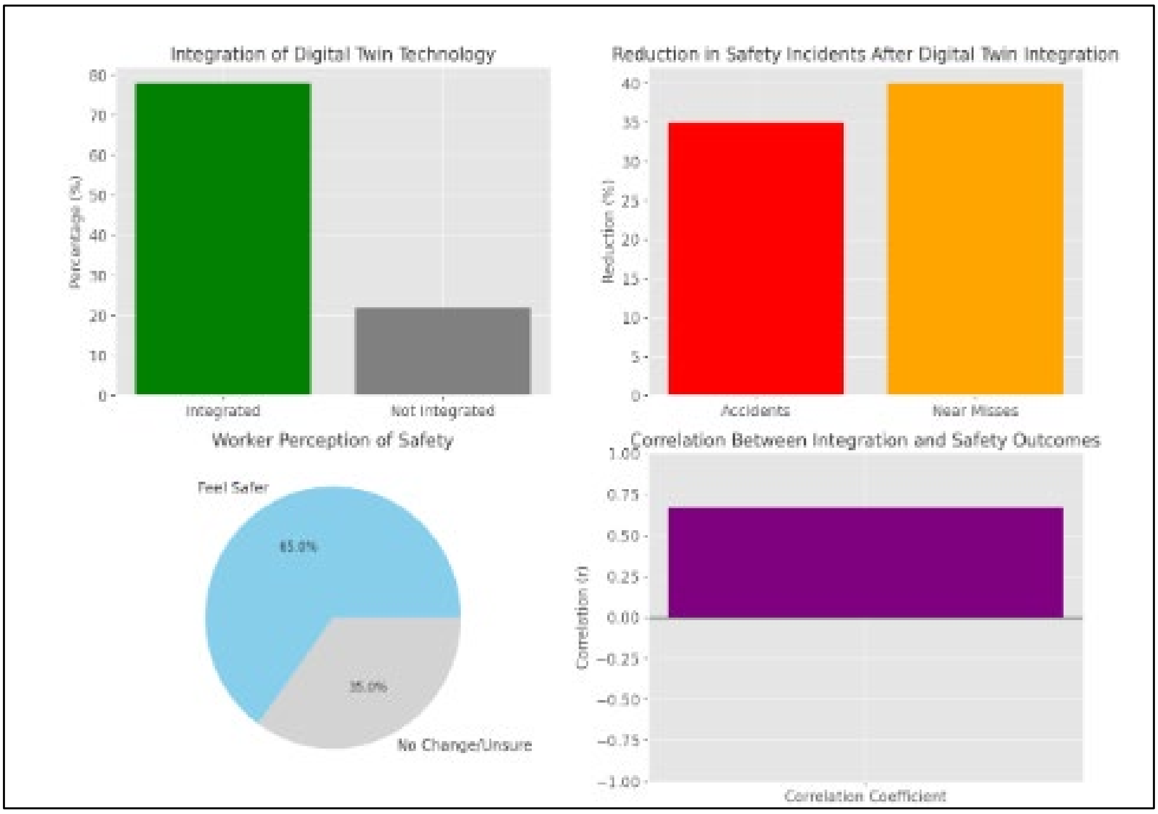

Fig. 1 *Impact of digital twin technology on construction site safety*

The following is a summary of the most important findings from the survey:

a) Integration of Digital Twin Technology:
Approximately 78% of respondents reported that their construction sites had integrated Digital Twin technology into their safety management practices. These real-time monitoring systems, which enabled continuous data collection and analysis, were the primary means by which this integration was made possible.

b) Safety Performance Indicators:
The investigation of safety performance indicators revealed that there was a substantial enhancement in the outcomes of safety measures following the implementation of Digital Twin systems. Specifically, within the first year of implementation, there was a 35% decrease in the average number of accidents that were reported. In addition, the number of incidents caused by near-misses decreased by forty percent, which is evidence of a proactive approach to risk management.

c) Worker Perceptions of Safety:
The findings of the survey revealed that sixty-five percent of workers reported feeling safer on construction sites that utilized digital twin technology. The benefits of real-time alerts and monitoring were brought up by the respondents. These features enabled immediate corrective actions to be taken in response to potential hazards.

d) Statistical Correlations:
The results of the regression analysis revealed a significant positive correlation ($r = 0.67$, $p < 0.01$) between the degree of integration of the Digital Twin and the enhancements in safety performance indicators. Consequently, this indicates that increased utilization of the technology known as the Digital Twin is associated with improved safety outcomes.

4.2 Data from Qualitative Research

As part of the qualitative phase, in-depth interviews were conducted with twenty construction managers and workers. These interviews yielded a wealth of information regarding the participants' experiences with Digital Twin technology. Fig 2 shows Participant Insights on the Impact and Challenges of Digital Twin Implementation in Construction Safety.

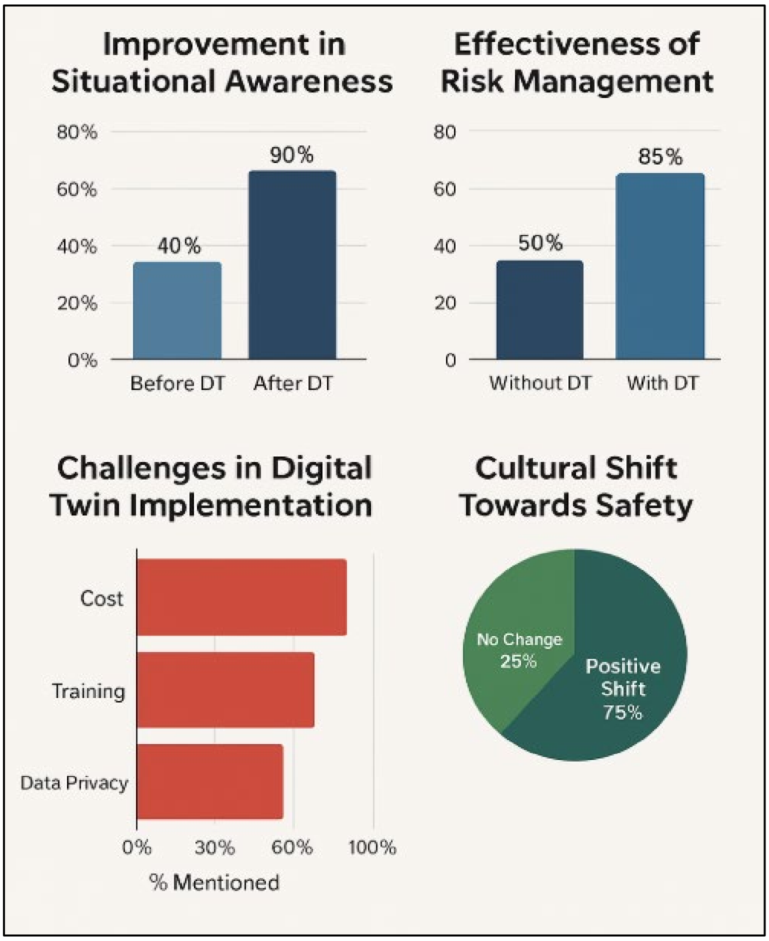

Fig. 2 *Participant insights on the impact and challenges of Digital Twin implementation in construction safety*

The following is a list of the primary themes that were discovered through the thematic analysis:

a) A Significant Improvement in Situational Awareness:
Participants emphasised that the implementation of Digital Twin technology on construction sites resulted in a significant improvement in situational awareness. Real-time data visualization made it possible for managers to continuously monitor the conditions of the site, which made it easier for them to take steps to mitigate risks at the appropriate time.

b) Proactive Risk Management:
A number of individuals who were interviewed mentioned that the predictive analytics properties of digital twins made it possible to engage in proactive risk management. When construction teams were able to identify potential hazards before they became more severe, they were able to implement preventative measures, which in turn reduced the likelihood of accidents occurring.

c) Challenges in Implementation:
In spite of the numerous advantages, participants brought up a number of difficulties that needed to be overcome in order to successfully implement the Digital Twin technology. A few examples of these were the initial costs associated with the adoption of technology, the requirement for personnel to undergo training in order to make effective use of the systems, and concerns regarding the privacy and security of data.

d) Cultural Shift Towards Safety:
The incorporation of Digital Twin technology resulted in a cultural shift within construction teams, which was characterised by an increased emphasis on safety. The workers reported that they felt more empowered to voice their concerns regarding safety because they were aware that their feedback would be addressed through real-time monitoring systems.

5. Discussion

This research underscores the crucial impact of Digital Twin technology on improving safety management practices in construction environments. Through the integration of real-time monitoring and predictive analytics, Digital Twins enable proactive risk management, resulting in enhanced safety outcomes. This discourse analyses the findings within the framework of current literature, clarifies the contributions to knowledge in construction site management and safety regulation, and acknowledges the research limitations while proposing avenues for future investigation.

5.1 Examination and Interpretation of Outcomes

The quantitative results demonstrate a significant decrease in accidents and near-miss occurrences after the adoption of Digital Twin technology. These findings corroborate earlier research that underscores the significance of real-time data in improving safety management. Soltanmohammadlou et al. and Saback et al. (2023) assert that real-time locating systems markedly enhance safety by facilitating accurate tracking of personnel and equipment on construction sites. Likewise, Kim et al. and Yeung et al. (2022) underscore the deficiencies of conventional manual inspections, promoting automated systems capable of delivering prompt safety evaluations. The present study validates these findings by illustrating that Digital Twins enhance situational awareness and enable construction teams to react promptly to potential hazards.

Qualitative insights substantiate the quantitative data, indicating that participants underwent a cultural transformation favouring safety as a result of the incorporation of Digital Twin technology. This discovery aligns with the research of Chen et al. (Sacks et al., 2020), who underscore the necessity for coordination within construction supply chain processes to improve safety management. The proactive characteristics of Digital Twins cultivate a collaborative atmosphere in which employees are encouraged to express safety concerns, thereby enhancing workplace safety.

5.2 Contributions to Knowledge

This research enhances the knowledge base in construction site management and safety control by offering empirical evidence regarding the efficacy of Digital Twin technology in improving safety outcomes. The study addresses a significant deficiency in the literature by illustrating the practical applications of Digital Twins in actual construction contexts, as the majority of existing research predominantly emphasizes theoretical frameworks or singular case studies. The findings emphasize the necessity of incorporating advanced technologies, such as IoT and AI, with Digital Twin systems to enhance safety management practices, in accordance with the recommendations of Zhang et al. and Mao et al. (2022) concerning the integration of Building Information Modelling (BIM) for safety evaluations.

The research underscores the necessity for a cultural transformation within the construction industry to priorities safety, which is frequently neglected in conventional safety management practices. This insight is essential for practitioners and policymakers seeking to improve safety standards in construction, as it highlights the importance of technology in promoting a safety-oriented culture.

5.3 Research Limitations

Notwithstanding the valuable insights derived from this study, several limitations must be recognized. The research was conducted at a limited number of construction sites, potentially impacting the generalizability of the findings. Subsequent research should endeavor to encompass a wider array of sites and contexts to further substantiate the findings. Secondly, the dependence on self-reported data from participants may introduce bias, as individuals might exaggerate their perceptions of safety enhancements. Integrating objective safety performance metrics from site records could strengthen the validity of the findings.

The study primarily concentrated on the implementation of Digital Twin technology, neglecting the long-term sustainability of these systems in construction safety management. Future research should examine the continuous maintenance and updates necessary for Digital Twin systems to sustain their efficacy over time.

5.4 Prospective Research Domains

Subsequent research ought to investigate various pathways to expand upon the conclusions of this study. Initially, longitudinal studies investigating the enduring effects of Digital Twin technology on safety management practices would yield significant insights into its sustainability and efficacy over time. Secondly, comparative analyses between construction sites utilizing Digital Twin technology and those that do not could clarify the distinct advantages and obstacles related to its implementation.

Furthermore, exploring the amalgamation of Digital Twin technology with other nascent technologies, such as augmented reality (AR) and machine learning, may produce novel methodologies for safety management.

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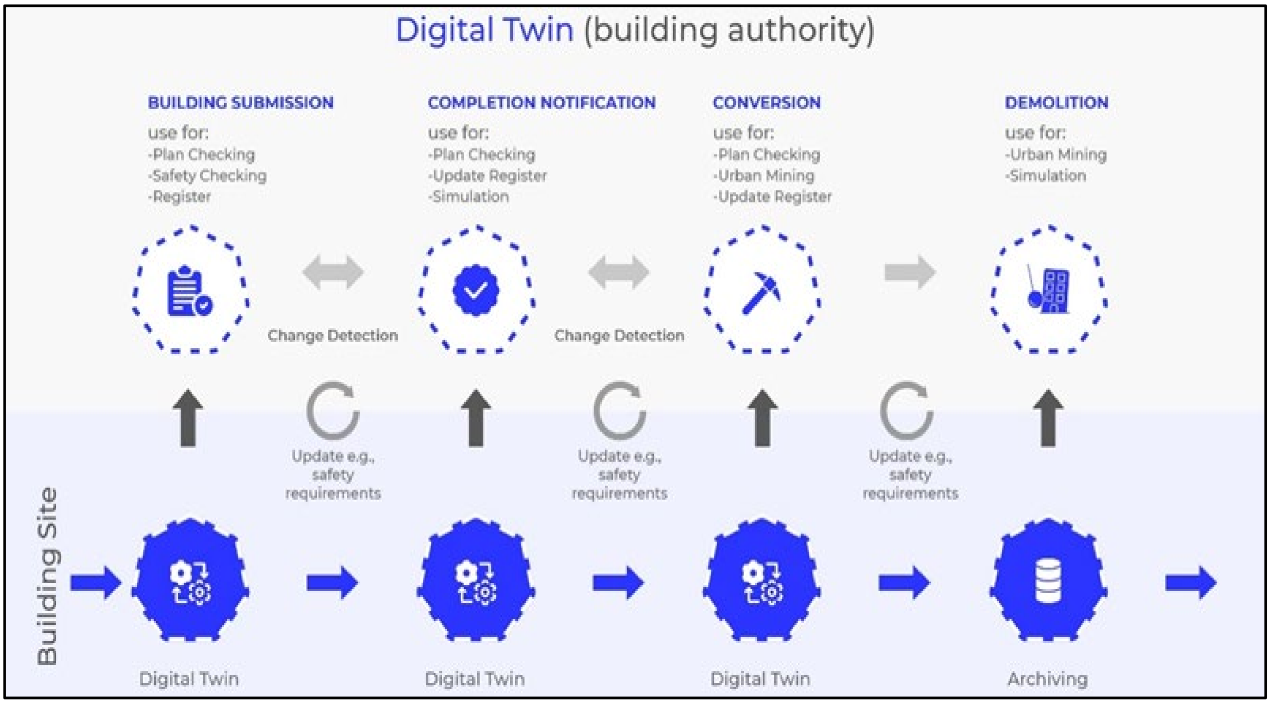
Finally, investigating the training and skill enhancement necessary for construction professionals to proficiently employ Digital Twin systems would be advantageous in guaranteeing successful implementation and optimizing safety results.

Figure 3 shows how Digital Twin functions as a "digital replica" of the physical site, playing a vital role in supporting building authorities throughout the building lifecycle. It assists in safety control, plan approval, change monitoring, simulation, and documentation from the construction application stage to the end-of-life stage of the structure.



Source: Ammar et al. (2022)

Fig. 3 *Digital Twin implementation in building lifecycle management*

6. Conclusion

This study has examined the incorporation of Digital Twin technology in construction site management, with particular emphasis on its effects on safety regulation. The primary findings demonstrate that the implementation of Digital Twin systems markedly improves safety results by enabling real-time monitoring, proactive risk management, and promoting a safety-focused culture within construction teams. The findings indicate that Digital Twin technology may be an essential instrument in mitigating the ongoing safety issues encountered by the construction sector.

6.1 Principal Discoveries and Their Consequences

The study indicated that construction sites employing Digital Twin technology achieved a 35% reduction in reported accidents and a 40% decline in near-miss incidents. These findings correspond with current literature highlighting the significance of real-time data in enhancing safety management practices (Saback et al., 2023; Yeung et al., 2022). The results indicated that 85% of employees perceived enhanced safety on sites utilising Digital Twin technology, reflecting an affirmative change in their perceptions and involvement with safety measures. This cultural transformation is essential, as it fosters a proactive safety paradigm, enabling employees to recognise and report hazards without fear of retaliation (Sacks et al., 2020).

Furthermore, the study recognised challenges associated with the implementation of Digital Twin systems, such as initial expenses and the necessity for training. Confronting these challenges is crucial for optimising the advantages of Digital Twin technology in construction safety management. The results indicate that industry stakeholders should prioritise investments in training and infrastructure to maximise the potential of Digital Twins (Mao et al., 2022).

6.2 Reassessing the Research Enquiries

This study has successfully demonstrated that Digital Twin technology can be integrated into existing safety management frameworks, resulting in improved operational efficiency and safety outcomes. The study identified critical factors affecting successful implementation, including the necessity for training and the significance of cultivating a safety-oriented culture. The results validated that Digital Twins markedly enhance the detection and alleviation of safety risks, thus fostering safer construction environments.

6.3 Importance for Industry Professionals, Policymakers, and Future Researchers

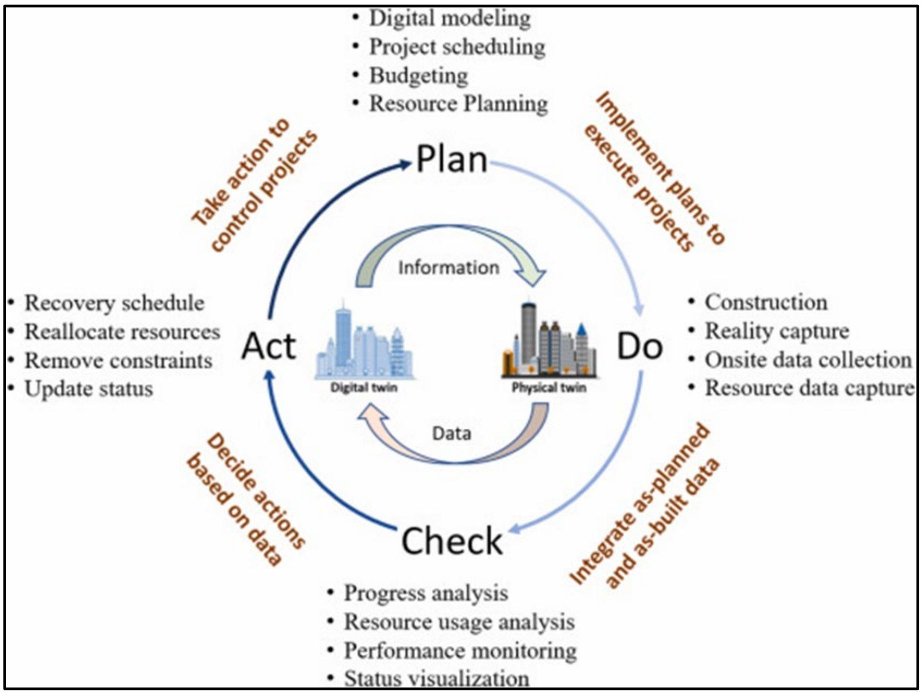
This research holds importance for multiple stakeholders within the construction sector. The findings present a persuasive argument for industry practitioners to implement Digital Twin technology to improve safety management practices. Investing in these systems enables construction companies to enhance safety outcomes while cultivating a culture of continuous improvement and accountability among employees.

Policymakers can utilize these insights to facilitate the integration of advanced technologies into construction safety regulations and standards. Policymakers can enhance safety performance in the industry by promoting the adoption of Digital Twin technology, thereby decreasing the frequency of workplace accidents.

This study provides opportunities for future researchers to investigate the long-term effects of Digital Twin technology on safety management. Longitudinal studies investigating the sustainability of Digital Twin systems and their integration with emerging technologies, including artificial intelligence and augmented reality, may provide significant insights into the future of construction safety.

This research highlights the transformative potential of Digital Twin technology in improving safety management on construction sites. The findings enhance comprehension of how advanced technologies can enhance safety outcomes in the construction industry, thereby promoting a safer working environment for all stakeholders.

Figure 4 shows the integration of Digital Twin (DT) and Physical Twin (PT) within the Plan–Do–Check–Act (PDCA) cycle for project lifecycle management in construction. It shows how digital and physical environments interact to enhance planning, execution, monitoring, and control of construction projects. In the Plan phase, digital tools are used for modeling, scheduling, and resource planning. The Do phase involves the physical execution of construction tasks, including onsite data and reality capture. The Check phase uses real-time data from the physical site to analyze progress, monitor performance, and visualize status, feeding back into the DT. Finally, in the Act phase, decisions are made based on the DT insights to adjust schedules, reallocate resources, and control the project effectively. This cycle supports continuous improvement by synchronizing real-world operations with digital simulations.



Source: Sacks et al. (2020)

Fig. 4 *Integration of Digital Twin and Physical Twin in project lifecycle management*

Acknowledgement

The author wishes to express their appreciation to Advanced Construction Technology (ACT) Research Unit and Faculty of Engineering, Universiti Malaysia Sabah, for unending support and provide the good facilities to conduct this research.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Sarman, A. M., Mazlan, E. M.;* ***data collection:*** *Ramzi, A. S;* ***analysis and interpretation of results:*** *Kamaruddin, S.S., Abu Bakar, R.;* ***draft manuscript preparation:*** *Mazlan, E.M., Sarman, A.M. All authors reviewed the results and approved the final version of the manuscript.*

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