(REVIEW ARTICLE)

Digital twins in construction: A review of applications and gaps

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Abstract

DT (Digital twin) technology is currently disrupting the construction industry as it allows integration of data for decision making and simulations in real time throughout the life of the construction asset. This article systematically maps the applications, advantages, and digital twin construction technology gaps in the construction industry. Construction professionals were surveyed using structured questionnaires to measure their awareness, application, perceived benefits, and barriers to digital twin technology in construction, and data was analyzed quantitatively. Digital twin technology awareness is indeed high among professionals; however, its practical application is very low owing to high costs, technical challenges, and low digital skills of the workforce. The most common applications are performance monitoring, predictive maintenance, and visualization. However, other applications, including sustainability forecasting and safety planning, are underutilized. This study offers a set of prescriptions to fill the gaps identified in the construction industry. Focusing on building capacity, digital construction unification, construction workforce financial motivation, and construction industry strengthening of cybersecurity frameworks are essential for successfully assimilating digital twins into the practices of the construction industry. The main goal of the digital twin construction technology is to provide smart infrastructure to a user.

Keywords: Digital Twins; Technology; Construction; Real time; Project

1. Introduction

The merging of new technologies into the construction industry is beginning to shift the industry away from its historical tendency of dealing with disorganized workflows and treating project management as an afterthought. One of the more promising technologies to emerge is the Digital Twin (DT) concept, which is receiving attention as a real-time analytics and predictive modeling tool for built asset lifecycle management. The digital twin concept stems from aerospace and manufacturing industries (Grieves, 2003) and is now penetrating the construction industry, providing a virtual construction that continuously updates with real-time information from the constructed asset (Sacks et al., 2020). This real-time updating improves the quality of the decisions taken on the projects and enables more predictive maintenance as well as energy and sustainability improvements during the project lifecycle.

Digital twins create a feedback loop in construction that blends the digital and physical worlds together. Real-time data exchange streamlines coordination in project execution, minimizing rework and cutting lifecycle costs (Boje et al., 2020). DTs have proven useful for monitoring structural health, estimating equipment utilization, and construction workflow simulations in various conditions (GhaffarianHoseini et al., 2022). Also, the fusion of BIM with IoT, machine learning, and AI technologies greatly increases the ability of DTs to shift the paradigm of conventional construction methods (Lu et al., 2020). This synergy is groundbreaking for predictive analysis, automated asset management, and virtual commissioning, especially for complex infrastructure projects.

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Regardless of the rising publications discussing the use of digital twins in construction, there are still many critical gaps. One of the issues is the absence of uniformity in the data standards, files, integration software, and physical sensors and digital platforms (Bolton et al., 2018). This poorly managed interoperability commonly results in inefficient interface integration across various software tools. This furthermore them makes it difficult to fully take advantage of all functionalities within the DT. In addition, while the use of digital twins is growing in acceptance in developed regions, particularly with large scale commercial or government funded initiatives, small and medium enterprises (SMEs) in developing regions continue to face a multitude of barriers such as high initial investment, inadequate levels of digital skills, and lack of regulatory frameworks (Sepasgozar et al., 2021).

Another fundamental challenge is the lack of focus on practical applications of digital twins after construction is completed. The focus has entirely been on the design and construction phases, while operations and facility management remains mostly untapped. As Tang et al. (2022) argue, this skew not only limits the functionality of digital twins, but also their potential impact towards sustainability and health monitoring of building occupants over the building's life cycle. Furthermore, ethical concerns such as privacy, surveillance, and digital sovereignty are more pronounced as DTs collect more detailed granular data from built structures and their users and interactions (Zhao et al., 2021).

Based on the above, this research aims to analyze the applications of digital twins in construction project to determine the research and practical gaps, as well as the users' awareness, challenges, and the readiness to implement these technologies through a questionnaire survey. The study intends to measure, only through the use of frequency and percentage analysis, the patterns of adoption, usefulness perceptions, barriers to entry, and integration suggestions. This method will furnish evidence-based insights for policymakers, industry stakeholders, and researchers to aid in the construction preparedness and digital twin technology integration strategies.

Given the smart construction needs of the 21st century, digital twins are set to serve as major assets. Unlocking their potential, however, requires identifying carefully strategized opportunities and understanding their current limitations. This study seeks to meaningfully contribute to the development of digital construction by addressing a gap in the literature.

2. Literature Review

DTs have their roots in aerospace engineering, where they were first introduced in the early 2000s (Grieves, 2003) and are now successfully integrated in the construction industry. A digital twin is, by definition, a virtual copy of a certain physical asset. It is updated in real time with data and can predict scenarios. (Sacks et al. 2020). In construction, DTs are utilized to create virtual models of buildings, infrastructure, and even entire cities, which aid the stakeholders in designing, constructing, and optimizing operations.

2.1. Evolution of Digital Twins in Construction

According to Boje et al. (2020), Digital Twin (DT) is an extension of Building Information Modeling (BIM) with real-time data and analytics capabilities. BIM captures the static information of the asset whereas digital twins enable the continuous monitoring of the built asset's performance for proactive decision making. As noted by GhaffarianHoseini et al. (2022), digital twins in construction provide dynamic feedback loops between the physical asset and the virtual one, which facilitates operational intelligence and predictive maintenance.

Lu et al. (2020) traced the development of digital twins from static building model replication to fully integrated systems that leverage data from IoT sensors, drones, and real-time monitoring tools for intelligent asset management. The shift from design-centric to lifecycle-centric applications reflects the versatility of digital twins in complex project environments.

2.2. Applications of Digital Twins in Construction

As mentioned earlier, the use of DTs spans various construction domains. As Alizadehsalehi et al. (2020) point out, digital twins assist in the monitoring of construction progress in real-time, which improves accuracy in schedule prediction, forecasting, and resource allocation. Their application in health and safety functions, especially in large-scale projects, is noted by Tang et al. (2022) where real-time anomaly and hazard alerts can be issued.

In addition, DTs are being used in the development of smart cities and infrastructure to model energy efficiency, optimize HVAC systems, and incorporate renewable energy as well as in traffic simulation, pollution monitoring, and

infrastructure expansion planning as urban DTs, as discussed by Zhao et al. (2021). These functions greatly assist in the achievement of sustainable urban development which is why smart cities are designed with the help of DTs.

2.3. Integration with Other Technologies

Like all new emerging technologies, DTs are often complemented with other technologies that increase their significance. For example, Borrmann et al. (2020) showcase the integration of DTs with AI and ML and the enhanced predictive capabilities that result, provided by these systems and historical data learning to forecast potential failures or optimize building operations.

In much the same way, the Internet of Things (IoT) is essential for providing live data to Digital Twins (DTs). GhaffarianHoseini et al. (2022) emphasized IoT data's granularity, describing its quality and frequency, and how it affects accuracy of simulations within a DT model. This coupling has advantages, but peripheral concerns such as volume, governance, data management, privacy and security, as well as the integration of disparate systems work interoperability all need to be tackled to maximize value.

2.4. Identified Gaps in Research and Practice

Looking ahead, the construction industry still faces hurdles in the practical use of DTs. A notable gap pointed out by Sepasgozar et al. (2021) was the absence of a standardized framework for DTs. There is no single rule for data exchange between physical and virtual models, which detracts from scalability.

Bolton et al. (2018) pointed out the significant capital investment needed alongside high implementation costs and steep learning curve associated with DT technologies, especially for small and medium enterprises (SMEs). These limitations dampen widespread adoption and worsen the digital divide in the construction industry. In addition, the available literature appears to focus on the design and construction phases, and leave the post-occupancy and operational use angles unexplored (Tang et al., 2022).

Another socially overlooked area concerning DT deployment is its use for surveillance, privacy, and ownership of digital information. Construction-relayed research has, for some reason, bypassed scrutinizing these considerations.

2.5. Further Developments and Developments to Future Investigations

There is emerging research on digital twin maturity models that assist organizations in staged adoption, which is a welcome development (Boje et al., 2020). Additionally, some researchers, such as Alizadehsalehi et al. (2020), are promoting DT platforms with a less restrictive digital barrier to entrance and greater cross-platform compatibility.

Integrating blockchain for secure information sharing, as well as edge computing for real-time processing of data from the construction site, is also gaining traction (Lu et al., 2020). Research in the future are now more likely to investigate the integration of these technologies within DT ecosystems to address current logistical and technical limitations.

3. Methodology

This study employs a quantitative method to investigate the use and gaps in the use of Digital Twins in construction projects with the help of a structured survey. A quantitative approach was preferred because it provides measurable and analyzable data to identify trends, usage, and limitations of digital twin technologies in construction settings.

3.1. Population and Sampling

The study's focus was construction professionals, including engineers, architects, project managers, and BIM experts, employed at firms with digital twin technologies or knowledge of them. A purposive sampling method was used in this study so that only participants who had relevant knowledge or exposure to the use of digital twins would take part in the study.

3.2. Instrument for Data Collection

For the purposes of the study, a structured questionnaire was developed to serve as a sole instrument for data collection. The questionnaire contains closed ended questions and is divided into three parts:

- Educational background and demographic information
- Current applications of Digital Twins in construction

- Identification of gaps, challenges, and opportunities for further development

The responses were captured using a binary (Yes/No) and Likert scale coupled with frequency metrics, to allow for delimitation using frequency and percentage tables.

3.3. Procedure for Data Collection

The questionnaire was sent out through email and online surveys (e.g. Google Forms) for a duration of four weeks. Respondents were guaranteed confidentiality and provided informed consent prior to participation.

3.4. Analysis of Data

The data was processed and analyzed using descriptive statistics, particularly frequency and percentage calculations. This approach will be useful for determining the prevailing views, awareness, and the most reported gaps in the use of digital twins among the surveyed participants.

4. Findings
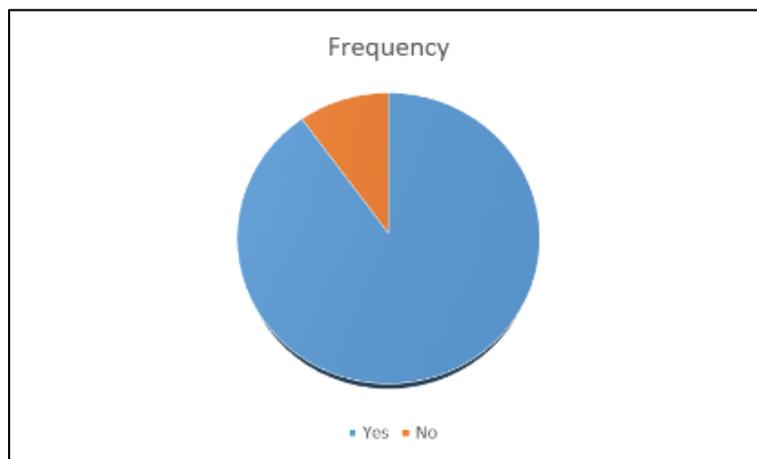
Figure 1 Awareness of Digital Twin Technology

The data in figure 1 reveals that 90% (45 respondents) are aware of digital twin technology in the construction sector. This indicates a high level of awareness among professionals, suggesting that the concept of digital twins is well-recognized. However, the 10% (5 respondents) who are not aware suggest there is still a minor knowledge gap that should be addressed through targeted training and awareness campaigns, especially among mid-level and field professionals.
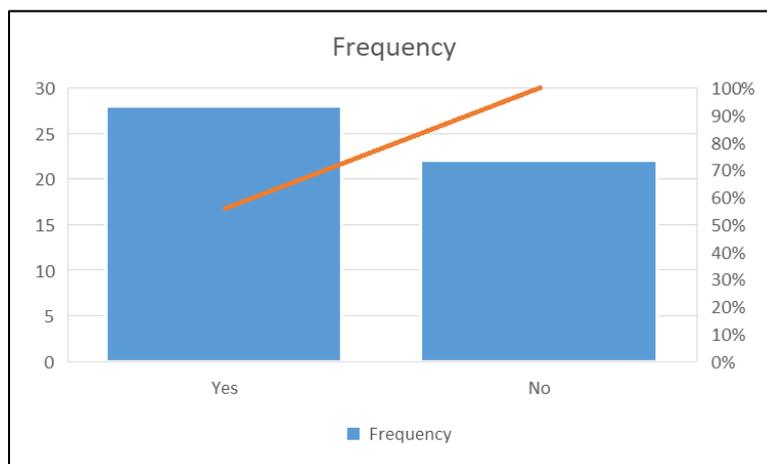
Figure 2 Current Use of Digital Twin in Construction Projects

From the results in Figure 2, 56% (28 respondents) have been involved in projects where digital twin technologies were applied. This shows that more than half of the sampled professionals have first-hand experience using digital twins, reflecting a growing trend in adoption. Conversely, 44% (22 respondents) have not used the technology directly, suggesting that although awareness is high, actual implementation still lags. This may be due to cost, lack of technical expertise, or the complexity of integration with existing systems.

Table 1 Key Areas of Digital Twin Application

| Area of Application	Frequency	Percentage (%)
Project Monitoring	20	40%
Predictive Maintenance	12	24%
Design Optimization	10	20%
Safety and Risk Analysis	8	16%
Total	50	100%

4.1.1. Interpretation

Table 1 indicates that the most common use of digital twins is in project monitoring (40%), followed by predictive maintenance (24%), design optimization (20%), and safety/risk analysis (16%). These results reflect a trend where digital twins are primarily leveraged for real-time tracking of project status and performance. Less emphasis on safety and risk analysis suggests a potential area for future development and training to broaden the scope of digital twin applications.

Table 2 Perceived Benefits of Using Digital Twins

Benefit	Frequency	Percentage (%)
Improved Decision-Making	22	44%
Enhanced Visualization	15	30%
Reduced Rework	8	16%
Cost Savings	5	10%
Total	50	100%

4.1.2. Interpretation

According to Table 2, improved decision-making (44%) and enhanced visualization (30%) are the leading perceived benefits of using digital twins in construction. These features are crucial for facilitating coordination, reducing delays, and optimizing performance. Interestingly, only 10% of respondents identified cost savings, suggesting that while digital twins may help indirectly reduce costs, this benefit may not yet be tangible or well-quantified in current use cases.
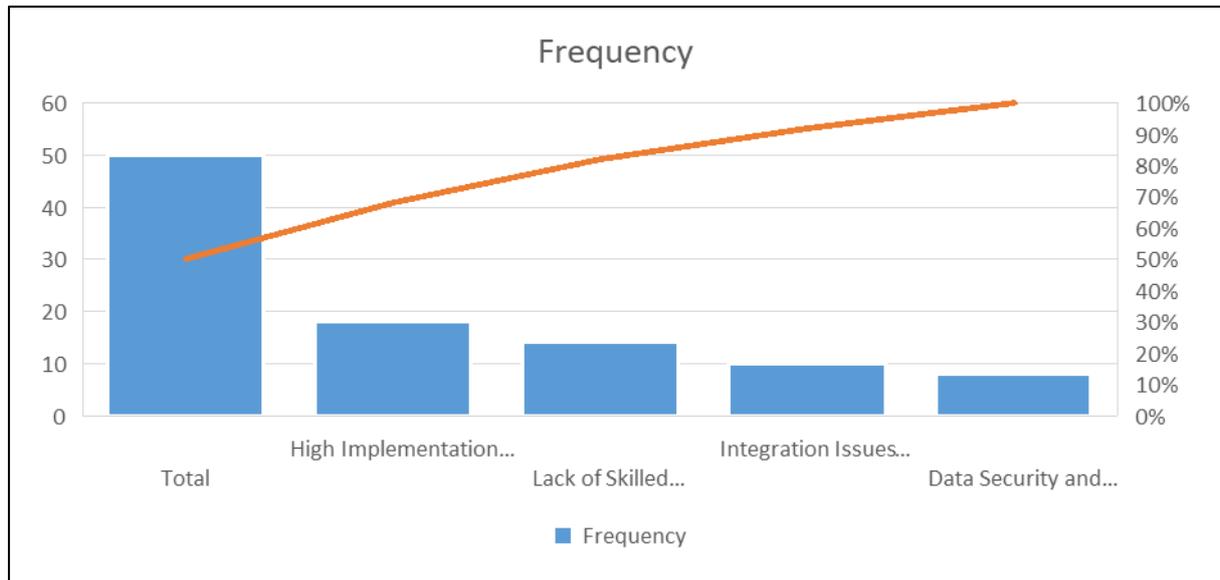
Figure 3 Challenges Limiting the Adoption of Digital Twins

F 5 highlights that cost (36%) remains the most significant barrier to the widespread adoption of digital twins, followed by a lack of skilled workforce (28%), and integration issues (20%). These results underscore the need for more cost-effective tools, training programs, and improved interoperability between digital twin platforms and other construction technologies such as BIM. Data security (16%), although lower, is also a notable concern in the context of cloud-based infrastructures.

5. Conclusion

This research examined the understanding, use, advantages, and obstacles of adopting digital twin technology in construction. Based on the results of a structured questionnaire, awareness of digital twins stood at 90% while actual adoption was at a moderate 56%. Project tracking, predictive maintenance, and decision-making were the primary focus areas cited. Enhanced visualization as a digitally-assisted benefit was also highly valued.

As noted, there is a generally positive perception about decision-making and visualization assists. However, several critical barriers to adoption challenge the perception. These include the high cost of implementation, lack of trained personnel, issues relating to integration with existing Building Information Modelling (BIM) structures, and gaps in foreseen predictive assurances. Many firms face a digital twin paradox whereby cost-saving and operational-efficacy advantages are not immediately visible, slowing adoption rates. Addressong ressing the gaps in skill gaps, infrastructural issues, and cost efficiency while fostering the strategic growing importance the research indicates will help digital twin technologies drive faster adoption and digital transformation within construction.

Recommendations

- Enhancing Technical Skills Investments by government agencies, construction companies, and other related organizations should focus on relevant technical and certification training pertaining to digital twin systems. This will bridge the skillset gap and increase the successful assimilation of the technologies into these systems.
- Financial Grants and Incentives Due to the large initial expenditure, incentives such as tax rebates or grants should be put into place to help firms willing to invest into digital twin technologies. This will provide access to SMEs and will greatly increase the number of adopters.
- Improved Interoperability: Digit layout is of significant concern as its relation to other legacy systems, notably BIM systems, and twin systems which require advanced frameworks for automation as a full automation is termed legacy systems.
- Safety and Health Risk: While the monitoring of a project as well as the decisions pertaining to the project was the core of the digital twin concept, there is room to leverage a digital twin for forward-looking risk management and health and safety assurance and welfare. This is the finding that was least utilized.
- Public Promotion: Digital twins need to be demonstrated through public pilot projects to be put on display to the public. Public pilot projects will help to articulate the focusing outcomes that these systems will work on

and exhibit the real-world outcomes where the systems significantly improve the efficiency, safety or cost outcomes to increase public interest..

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Al-Sehrawy, R. and Kumar, B. (2022). Digital twins in construction: a review of developments, opportunities and challenges. Journal of Building Engineering, 52, 104391. https://doi.org/10.1016/j.jobe.2022.104391

[2] Boje, C., Guerriero, A., Kubicki, S., and Rezgui, Y. (2020). Towards a semantic Construction Digital Twin: Directions for future research. Automation in Construction, 114, 103179. https://doi.org/10.1016/j.autcon.2020.103179

[3] Opoku, D., Perera, S., and Aziz, Z. (2021). Barriers and Drivers to the Implementation of Digital Twins in the Construction Industry. Built Environment Project and Asset Management, 11(4), 608–623. https://doi.org/10.1108/BEPAM-02-2020-0048

[4] Sepasgozar, S. M. E. (2021). Digital twin and cyber-physical systems for facilities management: A review. Built Environment Project and Asset Management, 11(1), 91–105. https://doi.org/10.1108/BEPAM-03-2020-0039

[5] Meža, S., Turk, Ž., and Dolenc, M. (2015). Component based engineering of a mobile BIM-based augmented reality system. Automation in Construction, 57, 129–141. https://doi.org/10.1016/j.autcon.2015.05.005

[6] Ghosh, A., Bhattacharya, S., and Chattopadhyay, A. (2022). Digital Twins for Smart Infrastructure: A systematic literature review. IEEE Access, 10, 51978–51994. https://doi.org/10.1109/ACCESS.2022.3173316

[7] Sacks, R., Brilakis, I., Pikas, E., and Xie, H. (2020). Construction with digital twin information. Automation in Construction, 114, 103117. https://doi.org/10.1016/j.autcon.2020.103117

[8] Abanda, F. H., Vidalakis, C., and Oti, A. H. (2020). Digital twins in the built environment: research trends and future directions. Journal of Information Technology in Construction, 25, 281–293. https://doi.org/10.36680/j.itcon.2020.019