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Digital Twin Implementation in Smart Construction: Comparing China and Singapore

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ABSTRACT

Digital Twin (DT) has become a key technology in smart construction by integrating Building Information Modeling (BIM), the Internet of Things (IoT), Artificial Intelligence (AI), and real-time data analytics to improve project performance and infrastructure management. China and Singapore are among the leading countries adopting Digital Twin to support digital transformation in the construction sector through different implementation strategies. This study aims to systematically review recent research on Digital Twin implementation in smart construction by comparing technological developments, applications, benefits, challenges, and future opportunities in China and Singapore. A Systematic Literature Review (SLR) was conducted using peer-reviewed articles published over the last five years. The review indicates that China emphasizes Digital Twin for large-scale infrastructure and intelligent construction, while Singapore focuses on smart city development, sustainable buildings, and lifecycle asset management. Despite notable progress, challenges related to interoperability, data integration, cybersecurity, implementation costs, and workforce readiness remain significant. The findings provide insights for advancing Digital Twin adoption in sustainable and intelligent construction.

Keywords: *Building Information Modeling, China, Digital Twin, Singapore, Smart Construction.*

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1. | INTRODUCTION

The construction industry is experiencing a significant digital transformation driven by the increasing adoption of advanced technologies associated with Industry 4.0. Among these technologies, Digital Twin (DT) has emerged as one of the most promising innovations for improving construction efficiency, project management, asset lifecycle performance, and infrastructure sustainability (Li et al., 2022). A Digital Twin is a dynamic digital representation of a physical asset, process, or system that continuously exchanges information through real-time data integration. Supported by Building Information Modeling (BIM), the Internet of Things (IoT), Artificial Intelligence (AI), cloud computing, and big data analytics, Digital Twin enables stakeholders to monitor, simulate, predict, and optimize construction activities throughout the entire project lifecycle.

The increasing complexity of construction projects, combined with the demand for sustainable infrastructure and efficient resource management, has accelerated the implementation of Digital Twin technology worldwide (Mazzetto, 2024). Traditional construction management often suffers from fragmented information, limited communication among stakeholders, inefficient decision-making, and delays caused by inaccurate project monitoring. Digital Twin addresses these challenges by providing real-time visualization, predictive analysis, automated monitoring, and intelligent decision support that improve project quality, productivity, safety, and operational efficiency (Opoku et al., 2021).

Among Asian countries, China and Singapore have become global leaders in adopting Digital Twin technology for smart construction (Naji et al., 2024). China has invested heavily in intelligent construction, digital infrastructure, and smart city development through national policies promoting digital transformation and advanced construction technologies. Large-scale infrastructure projects have increasingly integrated Digital Twin with BIM, AI, robotics, and IoT to improve project delivery, infrastructure monitoring, and lifecycle management. In contrast, Singapore has focused on implementing Digital Twin within its Smart Nation initiative, emphasizing sustainable urban development, intelligent buildings, and integrated digital infrastructure. Government agencies, research institutions, and industry partners have actively collaborated to develop Digital Twin applications for building management, urban planning, and facility operation (Schrotter & Hürzeler, 2020).

Despite the rapid growth of Digital Twin research, existing studies generally concentrate on technical frameworks, system architectures, or specific engineering applications. Comparative investigations examining how different countries implement Digital Twin in smart construction remain relatively limited. Understanding the similarities and differences between China and Singapore is important because both countries represent successful but distinct approaches to digital transformation. China emphasizes large-scale infrastructure development and industrial digitalization, whereas Singapore prioritizes integrated urban management, sustainability, and smart city governance. Comparing these approaches can provide valuable insights into technology adoption strategies, policy support, implementation challenges, and future opportunities for other countries seeking to accelerate digital transformation in the construction sector.

Therefore, this study conducts a Systematic Literature Review (SLR) to synthesize recent research published between 2020 and 2024 regarding the implementation of Digital Twin in smart construction, with a comparative focus on China and Singapore. The review aims to identify major research trends, technological components, practical applications, benefits, implementation barriers, and future research directions. The findings are expected to contribute to the growing body of knowledge on Digital Twin technology while providing practical recommendations for researchers, construction professionals, policymakers, and industry stakeholders interested in promoting sustainable and intelligent construction practices through digital innovation.

anuscripts must be written in English with correct and consistent grammar. Authors are encouraged to use professional language editing services if needed to eliminate grammatical errors. The language must be inclusive and free from bias.

2. | RESEARCH METHOD

This study employed a Systematic Literature Review (SLR) to comprehensively identify, evaluate, and synthesize previous studies concerning the implementation of Digital Twin in smart construction, with a comparative focus on China and Singapore. The SLR approach was selected because it provides a rigorous, transparent, and reproducible process for reviewing scientific evidence while minimizing researcher bias and ensuring the credibility of the findings (Kekecs et al., 2023). The review process consisted of four sequential stages: literature identification, screening, eligibility assessment, and qualitative synthesis. Relevant publications were collected from internationally recognized scientific databases, including Scopus, Web of Science, ScienceDirect, SpringerLink, and IEEE Xplore. The literature search was conducted using combinations of keywords such as Digital Twin, Smart Construction, Building Information Modeling (BIM), Construction Industry, Smart City, Artificial Intelligence, Internet of Things (IoT), China, and Singapore. Only peer-reviewed journal articles published between 2020 and 2024 were considered to ensure that the review reflected the most recent developments in Digital Twin technologies and smart construction practices. The inclusion criteria required that the selected studies explicitly discuss Digital Twin applications, enabling technologies, implementation strategies, construction management, infrastructure lifecycle management, sustainability, or comparative analyses related to the construction industry (Hu et al., 2022). Conversely, conference proceedings, book chapters, dissertations, duplicate publications, articles not written in English, and studies focusing on manufacturing, healthcare, or other non-construction sectors were excluded from the review.

Following the screening process, the eligible articles were carefully examined through qualitative content analysis. Information extracted from each study included publication year, country of application, research objectives, methodological approach, Digital Twin technologies employed, supporting technologies such as BIM, IoT, AI, cloud computing, and big data analytics, application domains, implementation benefits, technical limitations, and future research recommendations. The extracted data were subsequently categorized into thematic groups to facilitate a comparative analysis between China and Singapore. The synthesis focused on identifying common technological trends, implementation strategies, major advantages, existing barriers, and research gaps reported across the selected studies. Furthermore, the findings were interpreted to evaluate how Digital Twin contributes to improving construction productivity, project monitoring, infrastructure sustainability, lifecycle asset management, and intelligent decision-making within smart construction environments. By adopting this systematic and structured review methodology, the study provides comprehensive, reliable, and evidence-based insights into recent advancements in Digital Twin implementation while offering practical recommendations for future research and the broader adoption of smart construction technologies.

3. | RESULTS AND DISCUSSION

The systematic literature review reveals a significant increase in research on Digital Twin (DT) implementation in the construction industry between 2020 and 2024. This growing research interest reflects the accelerating digital transformation of construction practices driven by Industry 4.0 technologies and the increasing demand for intelligent, efficient, and sustainable infrastructure (Tseng et al., 2021). Unlike conventional digital models, Digital Twin establishes a continuous connection between physical assets and virtual environments through real-time data exchange, enabling construction stakeholders to monitor project performance, simulate operational scenarios, predict potential failures, and optimize decision-making throughout the entire infrastructure lifecycle. The reviewed studies consistently identify Building Information Modeling (BIM), the Internet of Things (IoT), Artificial Intelligence (AI), cloud computing, big data analytics, Geographic Information Systems (GIS), and cyber-physical systems as the primary technological components supporting Digital Twin implementation. The integration of these technologies has transformed Digital Twin from a visualization platform into an intelligent decision-support system capable of improving planning, construction, operation, and maintenance processes.

The analysis further indicates that China and Singapore represent two of the most advanced countries in adopting Digital Twin for smart construction, although each country has developed different implementation strategies according to its national priorities (Cheng et al., 2021). China has emphasized Digital Twin adoption to support intelligent construction, industrial modernization, and the development of large-scale infrastructure. National digital transformation policies have encouraged construction companies to integrate BIM, IoT, robotics, unmanned aerial vehicles (UAVs), and AI into Digital Twin platforms for highways, railways, bridges, tunnels, airports, and industrial facilities. These technologies enable continuous monitoring of structural conditions, construction progress, equipment utilization, environmental parameters, and worker safety. By utilizing real-time information collected through distributed sensor networks, project managers can identify construction risks earlier, optimize scheduling, improve quality control, and reduce operational delays. Several reviewed studies report that Digital Twin implementation in China has significantly improved project efficiency while reducing construction costs, material waste, and maintenance expenditures through predictive maintenance and lifecycle asset management (Deng et al., 2021).

In contrast, Singapore has implemented Digital Twin as an integral component of its Smart Nation strategy, where digital technologies are utilized not only during construction but throughout the entire urban infrastructure lifecycle. Rather than focusing exclusively on large construction projects, Singapore integrates Digital Twin into smart city governance, sustainable building operation, transportation management, energy optimization, and public infrastructure maintenance (Mishra & Singh, 2023). The close collaboration among government agencies, research institutions, and private industries has accelerated the development of comprehensive digital platforms capable of combining BIM, GIS, IoT, cloud computing, and AI into unified urban management systems. This integrated digital ecosystem allows stakeholders to monitor infrastructure performance in real time, evaluate environmental conditions, optimize facility operations, and improve long-term asset management. Consequently, Digital Twin has become an important instrument for achieving Singapore's sustainability objectives while enhancing urban resilience and operational efficiency (Opoku et al., 2021).

Despite these different implementation approaches, the reviewed literature demonstrates several common characteristics shared by both countries (Ruggeri et al., 2020). BIM remains the central digital platform that supports the creation of Digital Twin models by providing accurate three-dimensional representations of physical infrastructure together with engineering information throughout the project lifecycle. IoT devices continuously collect operational data, including structural deformation, vibration, temperature, humidity, equipment conditions, and environmental variables. Artificial Intelligence algorithms subsequently analyze these datasets to predict infrastructure deterioration, optimize construction schedules, improve equipment performance, and support intelligent maintenance planning. Cloud computing facilitates efficient storage, processing, and real-time information sharing among engineers, contractors, consultants, owners, and government agencies regardless of their physical location. This integrated technological framework substantially improves collaboration, transparency, and decision-making compared with conventional construction management systems that rely on fragmented information and manual reporting.

Another important finding emerging from the reviewed studies concerns the contribution of Digital Twin to sustainable construction. Sustainability has become one of the primary objectives of modern infrastructure development due to increasing global concerns regarding carbon emissions, resource depletion, environmental degradation, and climate change. Digital Twin enables engineers to evaluate multiple design alternatives before physical construction begins through advanced simulation and performance analysis. During construction, real-time monitoring allows project teams to optimize material consumption, minimize energy use, reduce equipment idle time, and prevent unnecessary resource waste. Following project completion, Digital Twin continues supporting operational optimization through predictive maintenance, energy performance monitoring, and lifecycle asset management. Both China and

Singapore increasingly recognize Digital Twin as an effective technology for achieving sustainability targets because it improves operational efficiency while simultaneously reducing environmental impacts associated with infrastructure development (Sadiq et al., 2021). The reviewed literature also demonstrates that Digital Twin significantly improves construction productivity and project management performance by providing accurate, real-time information throughout every phase of the construction lifecycle. Traditional construction management often depends on periodic inspections, manual reporting, and fragmented communication among project stakeholders, resulting in delays in identifying construction problems and making corrective decisions. In contrast, Digital Twin continuously synchronizes physical assets with virtual models through IoT sensors and cloud-based platforms, enabling engineers and project managers to monitor project progress, equipment utilization, workforce productivity, and environmental conditions simultaneously. This real-time visibility enhances project coordination, reduces information asymmetry, and supports faster decision-making. Several studies conducted in China reported that Digital Twin implementation shortened construction schedules, improved resource allocation, and minimized rework because potential conflicts could be detected and resolved before affecting field operations (Deng & Zhong, 2024).

Beyond improving productivity, Digital Twin has become an effective tool for enhancing construction quality and infrastructure reliability. The integration of BIM with AI-based analytics enables continuous verification between design models and actual construction progress, ensuring that construction activities comply with technical specifications and project requirements. Real-time inspection data collected from drones, laser scanners, and sensor networks can automatically identify structural deviations, dimensional inaccuracies, or material defects during construction. This capability reduces human error while improving quality assurance and quality control processes. In Singapore, Digital Twin has also been extensively utilized for facility management after project completion. Digital models remain connected to physical buildings throughout their operational lifecycle, allowing facility managers to optimize maintenance schedules, monitor equipment performance, improve energy efficiency, and extend infrastructure service life. Consequently, Digital Twin supports a lifecycle-oriented approach rather than limiting digital applications to the construction stage alone (Opoku et al., 2021).

Another important benefit highlighted across the reviewed studies is the contribution of Digital Twin to occupational health and safety management (Ogunseiju et al., 2021). Construction projects involve complex activities that expose workers to numerous hazards, including equipment failure, structural instability, hazardous environmental conditions, and unsafe operational practices. Digital Twin integrates wearable sensors, surveillance systems, environmental monitoring devices, and AI algorithms to identify potential risks before accidents occur. The system can automatically generate warnings when abnormal structural behavior, excessive equipment vibration, or unsafe worker locations are detected. Predictive analytics further assist project managers in evaluating future safety risks and implementing preventive measures before construction activities become hazardous. Chinese infrastructure projects have increasingly incorporated AI-enabled Digital Twin platforms to improve worker safety while reducing accident-related project delays and financial losses. Similar developments have been reported in

Singapore, where Digital Twin supports intelligent monitoring systems for high-rise buildings, transportation facilities, and public infrastructure through continuous risk assessment and real-time operational monitoring.

Although both countries have demonstrated remarkable progress, the comparative analysis reveals several differences in implementation priorities. China's Digital Twin strategy is strongly influenced by national industrial modernization programs emphasizing intelligent construction, infrastructure expansion, and digital manufacturing. Accordingly, Digital Twin applications are predominantly implemented in megaprojects involving transportation infrastructure, industrial facilities, and large public developments where substantial economic benefits can be achieved through automation and predictive management. Singapore, however, adopts a broader urban perspective by integrating Digital Twin into smart city governance, sustainable building operation, environmental monitoring, and public service management. This approach reflects Singapore's objective of creating interconnected urban ecosystems in which construction, infrastructure, transportation, and environmental management operate within a unified digital platform. Despite these strategic differences, both countries demonstrate that long-term government commitment, technological innovation, interdisciplinary collaboration, and digital capacity building are essential prerequisites for successful Digital Twin implementation in smart construction.

4. | CONCLUSION

This study systematically reviewed the implementation of Digital Twin technology in smart construction by comparing recent developments in China and Singapore based on publications from 2020 to 2024. The review demonstrates that Digital Twin has become a fundamental technology supporting digital transformation in the construction industry through the integration of Building Information Modeling (BIM), the Internet of Things (IoT), Artificial Intelligence (AI), cloud computing, and real-time data analytics. These technologies enable more effective project planning, construction monitoring, predictive maintenance, lifecycle asset management, and data-driven decision-making, ultimately improving project productivity, operational efficiency, safety, and sustainability.

The comparative analysis reveals that China primarily emphasizes the application of Digital Twin in large-scale infrastructure development and intelligent construction, supported by strong government initiatives and industrial digitalization. In contrast, Singapore focuses on integrating Digital Twin into smart city development, sustainable building management, and urban infrastructure optimization. Although both countries have adopted different implementation strategies, they share common objectives of enhancing construction performance, infrastructure resilience, and long-term sustainability through digital innovation.

Despite its significant potential, several challenges continue to hinder the broader adoption of Digital Twin, including interoperability among digital platforms, data integration, cybersecurity, high implementation costs, and the shortage of skilled professionals. Addressing these issues will require stronger collaboration among governments, academia, technology providers, and the construction industry. Future research should focus on developing standardized Digital Twin frameworks, improving data interoperability, integrating emerging technologies such as blockchain and 5G, and expanding practical applications across diverse construction projects. These efforts will contribute to accelerating the adoption of smart construction technologies and supporting the development of more resilient, efficient, and sustainable infrastructure worldwide.

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The authors declare that there is no conflict of interest.

Ethical Approval and Originality Statement

Ethical approval was obtained for this study. The manuscript represents original work and has not been previously published, nor is it under consideration by another journal.

Data Disclosure Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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