Indunil, H.T.T.A., Bandara, R.P.H.S. and Buddhini, P.H.Y., 2025. Barriers and solutions to adopting digital twin in Sri Lankan construction. In: Waidyasekara, K.G.A.S., Jayasena, H.S., Wimalaratne, P.L.I. and Tennakoon, G.A. (eds). *Proceedings of the 13th World Construction Symposium*, 15-16 August 2025, Sri Lanka. pp. 230-242. DOI: https://doi.org/10.31705/WCS.2025.18. Available from: https://ciobwcs.com/papers/

BARRIERS AND SOLUTIONS TO ADOPTING DIGITAL TWIN IN SRI LANKAN CONSTRUCTION

H.T.T.A. Indunil[1], R.P.H.S Bandara[2] and P.H.Y. Buddhini[3]

ABSTRACT

In the Industry 4.0 era, Digital Twin (DT) technology has emerged as a key innovation, integrating physical assets with their digital counterparts to enhance coordination, safety, and cost management in construction. Despite its potential, DT adoption in construction remains limited, particularly in developing countries like Sri Lanka, due to high costs, technological barriers, and a lack of standardized integration methods. While DT has significantly improved efficiency in other sectors, the construction industry still lacks practical large-scale applications and a unified framework for implementation. This research aims to explore the applicability of DT in Sri Lankan construction projects. Moreover, semi-structured expert interviews were conducted with 7 experts to gather data. Accordingly, the literature review and insights gathered from interviews highlighted its current usage, benefits, and barriers, and proposed 8 practical solutions to facilitate broader adoption of DT in the Sri Lankan construction industry. The findings of this research are anticipated to contribute significantly to the effective integration of DT technology within the Sri Lankan construction sector. The results underscore the promising role that DT can fulfil in addressing a variety of barriers confronting the construction industry. This study not only emphasizes the critical importance of adopting Digital Twin technology but also seeks to raise awareness of its potential, thereby encouraging its utilization and ushering in a new era of innovation in the Sri Lankan construction industry.

Keywords: *Barriers; Construction Technology; Digital Twin; Sri Lanka.*

1. INTRODUCTION

In the Industry 4.0 era with the advent of digitization, Digital Twin (DT) technology is gradually becoming one of the core technologies (Li et al., 2025). DT technology, which integrates physical assets with their digital counterparts, offers high potential to address critical construction challenges by improving coordination, safety, and lifecycle cost management (Madubuike et al., 2022). The challenges faced by the construction include issues with planning, coordination, and communication, as well as safety hazards, high maintenance costs, and inefficiencies in construction processes (Shahzad et al., 2022;

[1] Graduate Civil Engineer, School of Engineering, Swinburne University of Technology, Australia, tashiniayodya99@gmail.com

[2] Senior Lecturer, Department of Civil Engineering, Sri Lanka Institute of Information Technology, Sri Lanka, hemantha.b@sliit.lk

[3] Graduate Quantity Surveyor, Department of Quantity Surveying, Sri Lanka Institute of Information Technology, Sri Lanka, phyashodhabuddhini@gmail.com

Ullah et al., 2019). Recent studies suggest that these persistent issues could be mitigated through the application of DT technologies, which have shown promise in enhancing project efficiency and real-time decision-making (Gunatilaka et al., 2021; Shahzad et al., 2022).

DT technology is an evolving concept that integrates the physical world with the digital world (Madubuike et al., 2022). A DT is an emerging technology that is seen as crucial for an organization's digital transformation. (Qamsane et al., 2021). This method allows for the creation of a virtual model of a physical asset or process that can be monitored and analysed in real-time (Madubuike et al., 2022) . Michael Grieves, formerly of the University of Michigan, is often credited with coining the term "Digital Twin" during his 2002 presentation on Product Lifecycle Management (PLM) (Qamsane et al., 2021).

'Cost' is identified as a major barrier when it comes to developing countries to the applicability of DT (Amirthavarshan et al., 2023; Geekiyanage et al., 2025). DT application in the construction industry is low compared to other industries, despite the rise of smart buildings with automated systems (Jiao et al., 2025; Madubuike et al., 2022). According to the Amirthavarshan et al., (2023) in other sectors, DT technology has been responsible for saving product development time and costs by up to 50%. Liu et al., (2024) stated the market value of DT is expected to increase from $6.9 billion in 2022 to $73.5 billion in 2027, with an average annual growth rate of over 60%. This indicates a strong growth potential for DT in the construction industry (Liu et al., 2024).

The use of DTs in the construction industry is still in its early stages, primarily involving small-scale experiments and lacking mature practical applications (Amirthavarshan et al., 2023; Tuhaise, 2023). It should be noted that the industry lacks a clear understanding of the barriers posed by technology (Amirthavarshan et al., 2023). Furthermore, there is currently no consensus among researchers and industry practitioners on standardized approaches for integrating DT processes and data-centric technologies within building and civil infrastructure projects (Sacks et al., 2020). As such, a clear research gap exists in understanding how DT technologies can be effectively adopted and adapted to the specific needs and conditions of the Sri Lankan construction sector (Gunatilaka et al., 2021). Moreover, aligning system design with stakeholder preferences ensures that proposed DT frameworks are not only technologically feasible but also aligned with operational workflows and user capacities. This aligns with global perspectives, which emphasize stakeholder-driven DT development to ensure relevance and efficiency (Revolti et al., 2024). Bandara et al., (2024) stated future research should continue exploring these areas to provide further insights and recommendations for enhancing digital adoption in the construction sector.

Therefore, this research aims to explore the applicability of implementing DT technology in construction projects in Sri Lanka, and the study's aim has been achieved by accomplishing three objectives. Accordingly, the study will investigate the current state of DT technology implementation in Sri Lanka. Then study will identify potential benefits, and barriers to DT in construction in Sri Lanka. Ultimately, the research will suggest practical steps that can be taken to overcome common barriers associated with implementing DT technology in Sri Lankan construction projects.

2. LITERATURE REVIEW

2.1 OVERVIEW OF DT

DT technology is underpinned by advanced data processing and artificial intelligence (AI) applications such as machine learning, optimisation techniques, and search algorithms to assess project performance in real time, whether the project is under construction or in operation (Akomah et al., 2020; Radzi et al., 2024). A DT consists of three integral components: the physical system, its virtual counterpart, and the communication link that synchronises the two. This linkage is enabled by technologies including cyber-physical systems, sensors, communication networks, and mobile devices (Akomah et al., 2020; Amirthavarshan et al., 2023; Madubuike et al., 2022). DT operates as dynamic simulations, leveraging digital technologies such as Geographic Information Systems (GIS), Building Information Modelling (BIM), and Internet of Things (IoT) devices to create comprehensive, real-time representations of physical assets (Amirthavarshan et al., 2023; Omrany et al., 2025). Cloud-based platforms are used for data storage and real-time data exchange, enabling system integration.(Tuhaise, 2023). According to Madubuike et al. (2022), implementing DT technology involves a six-step process: imagining opportunities, identifying a suitable process, piloting the DT, industrializing the process, scaling the twin, and monitoring and measuring.

2.2 CURRENT STATE OF DT

The use of DT technology in the construction and real estate industries has the potential to revolutionize the management of assets and projects (Attaran & Celik, 2023). The De Soysa building on Slave Island and the Rangiri Dambulla Caves are prime examples where DTs can play a crucial role. For the De Soysa building, a DT can aid in preserving its legacy amid urban development. For the Rangiri Dambulla Caves, a DT focusing on microclimatic conditions can enhance preservation efforts by predicting and mitigating environmental impacts (Kudasinghe & Jeewananda, 2024). Another one such example is the creation of the Rankoth Vehera DT. This not only illustrates how DT applications are currently used in Sri Lanka, but it also shows how transformative DT technology can be, even in developing nations, where it can move major advancements and growth, and innovation in sectors with little experience with digital technology (Buddika et al., 2022). Despite its potential, in Sri Lanka, the adoption of DTs in the construction industry lags behind more technologically advanced countries (Kudasinghe & Jeewananda, 2024).

2.3 ADVANTAGES OF DT

Amirthavarshan et al., (2023) research indicates that DT has a high potential to solve the numerous challenges in construction site progress monitoring, rather than other current technologies in use. The benefits of integrating DT into construction processes are significant (Omrany et al., 2025). According to the literature review findings, the advantages of the DT to the Sri Lankan construction industry are given in Table 1.

Table 1: Advantages of DT

Advantage	References
Enhance the design and planning	Hämäläinen (2021); Wang et al. (2025); Acampa & Pino, (2023); Melesse et al. (2021); Singh et al. (2021)
Improve industrial production efficiency	Jiao et al. (2025); Wang et al. (2025); Tuhaise (2023); Bandara et al. (2024)
Improving management efficiency	Jiao et al. (2025); Amirthavarshan et al. (2023)
Ensuring sustainable development	Jiao et al. (2025); Wang et al. (2025); Madubuike et al. (2022)
Risk management	Wang et al. (2025); Amirthavarshan et al. (2023); Acampa & Pino (2023); Melesse et al. (2021); Singh et al. (2021)
Enhanced safety	Wang et al. (2025); Amirthavarshan et al. (2023); Bandara et al. (2024); Haron & Zafir, (2025); Madubuike et al. (2022)
Cost reduction	Wang et al. (2025); Madubuike et al. (2022); Acampa & Pino (2023); Melesse et al. (2021); Singh et al. (2021)
Improve the quality of decision-making	Wang et al. (2025); Amirthavarshan et al. (2023); Nagalingam et al. (2013); Haron & Zafir (2025); Madubuike et al. (2022)
Improve performance	Tuhaise (2023)
Monitor energy consumption	Amirthavarshan et al. (2023); Madubuike et al. (2022)
Remote monitoring	Amirthavarshan et al. (2023); Madubuike et al. (2022); Attaran & Celik (2023); Acampa & Pino (2023); Melesse et al. (2021); Singh et al., (2021)
Quality assurance	Madubuike et al. (2022)

2.4 IMPACT OF DT ON KEY CONSTRUCTION INDUSTRY ISSUES

The construction industry is under growing pressure to adopt digital technologies but continues to face challenges such as system instability, technology integration difficulties, and data security concerns (Tuhaise, 2023). A major barrier to digital transformation is the disconnect between stakeholders' expectations and the perceived impact on project outcomes, with many decision-makers failing to recognize the benefits of digital tools on performance (Jiao et al., 2025). Despite these challenges, DT technology is increasingly valued not only for its technical capabilities but also for its contributions to project efficiency, predictive maintenance, cost-effectiveness, and sustainability (Geekiyanage et al., 2025)

2.4.1 Lack of Reliable and Real-Time Data

This issue can arise from outdated reporting systems, manual data collection, and insufficient technology, leading to delays in decision-making, poor communication among stakeholders, and challenges in identifying potential problems early (Nagalingam et al., 2013). The DT has emerged as a solution that can update a BIM model with real-time data to achieve cyber-physical integration (Tuhaise, 2023). With the help of this technology, real-time monitoring and analysis can help mitigate these problems by providing accurate and timely details for informed decision-making and improved coordination (Jiao et al., 2025; Nagalingam et al., 2013; Tuhaise, 2023)

2.4.2 Inefficient Building Systems and Poor Design

It can result in high energy consumption and maintenance costs, which can be particularly challenging for low-income households and small businesses (Emmanuel, 2004). One potential solution is DT technology, which can facilitate early simulation and testing of design options, as well as enhance collaboration and communication among project stakeholders (Hämäläinen, 2021; Parvin, 2021). This contributes significantly to national sustainability goals and fosters a greener construction industry (Hämäläinen, 2021; Jiao et al., 2025)

2.4.3 Safety

Safety is an ongoing concern in Sri Lanka's construction industry, with accidents and injuries being all too common. The lack of proper safety measures and training for workers can put them at risk of injury or even death (Priyadarshani et al., 2013). DT technology enhances safety on construction sites by offering real-time hazard analysis and suggesting preventive measures (Attaran & Celik, 2023b; Wang et al., 2025). This not only improves worker safety but also boosts productivity and reduces costs linked to work-related injuries (Priyadarshani et al., 2013). Chathuranga et al., (2025) findings stated key technologies like BIM, virtual reality, augmented reality, geographic information systems, and serious games provide various construction safety applications. Combining AI with video cameras, mobile devices, and sensors, DT creates a robust safety net for the construction industry by enabling virtual site reconstruction to monitor progress and detect safety hazards or deviations from the plan (Attaran & Celik, 2023).

2.4.4 Cost

The cost of construction projects is crucial to manage across the project life cycle, as cost overruns, differences between actual and estimated costs, are a key indicator of project success (Wijekoon & Attanayake, 2012). Geekiyanage et al. (2025) findings show that DT is commonly used in the design and planning phase in Sri Lanka's construction industry, but has minimal usage in construction, operations, and none in the end-of-life phase. By adopting Whole Life Cycle Costing (WLCC) and Life Cycle Costing (LCC) approaches, DT allows professionals to simulate entire building lifecycles, from design to demolition (Boussabaine & Kirkham, 2004). This facilitates more accurate forecasting of construction and maintenance costs, helping to make more informed decisions that balance short-term budgets and long-term value (Boussabaine & Kirkham, 2004).

2.5 BARRIERS FOR DT

According to the research studies, identified four main categories of barriers have been which are Stakeholder-Oriented (Li et al., 2025; Opoku et al., 2023), Industry-Related (Bandara et al., 2023; Opoku et al., 2023), Construction-Enterprise-Related (Opoku et al., 2023), and Technology-Related Barriers (Bandara et al., 2023; Li et al., 2025; Opoku et al., 2023). According to the literature review findings, the barriers to the DT in the Sri Lankan construction industry are given in Table 2.

Table 2 : Barriers for DT

Barriers		References
Main Category	**Sub Category**	
Stakeholder-Oriented Barriers	Level of maturity and experience	Aragón et al. (2025); Amirthavarshan et al. (2023); Sacks et al. (2020); Bandara et al. (2023); Geekiyanage et al. (2025)
	Limited understanding of potential benefits	Bandara et al. (2023); Geekiyanage et al. (2025)
	Lack of organizational support	Amirthavarshan et al. (2023); Melesse et al. (2021); Bandara et al. (2023); Madubuike et al. (2022); Haron & Zafir (2025)
Industry-Related Barriers	Fragmented nature	Amirthavarshan et al. (2023); Bandara et al. (2023); Madubuike et al. (2022); Geekiyanageet al. (2025)
	Lack of standards	Wang et al. (2025); Aragón et al. (2025); Madubuike et al. (2022); Melesse et al., (2021)
	Variability of projects	Aragón et al. (2025)
Construction-Enterprise-Related Barriers	Financial barriers	Aragón et al. (2025); Amirthavarshan et al. (2023); Madubuike et al. (2022); Melesse et al. (2021); Bandara et al. (2023)
	Time constraints	Amirthavarshan et al. (2023)
	Limited infrastructure and organisational culture	Bandara et al. (2023)
	Organisational resistance to change	Geekiyanage et al. (2025)
Technology-Related Barriers	Data challenges	Wang et al. (2025); Tuhaise (2023); Madubuike et al. (2022); Aragón et al. (2025); Melesse et al. (2021)
	Model maintenance challenges	Wang et al. (2025)
	Privacy and security risks	Wang et al. (2025); Tuhaise (2023); Madubuike et al. (2022)
	Visualization limitations	Tuhaise (2023)
	Technological compatibility	Aragón et al. (2025); Bandara et al. (2023); Sacks et al. (2020)

2.5.1 Stakeholder-Oriented Barriers

Stakeholder-oriented barriers refer to challenges faced by individuals and groups in the construction industry, including a lack of knowledge and acceptance of DT, misconceptions, and differing opinions on its value and potential for projects (Sacks et al., 2020).

2.5.2 Industry-Related Barriers

Industry-related barriers are specific to the characteristics of the construction industry itself. These challenges include the complexity of construction projects, difficulties in integrating various trades and components, the static nature of building data, and challenges related to managing data and technology in a fragmented industry (Lu et al., 2020).

2.5.3 Construction-Enterprise-Related Barriers

Construction-related barriers include challenges such as funding issues, lack of government support, legal and ethical concerns, and difficulties in coordinating infrastructure spending for digital technology use (West & Blackburn, 2017). Implementing DT technology involves significant financial investment in hardware, software, and training, which can be a barrier, especially for smaller firms or projects with limited budgets (Aragón et al., 2025; Geekiyanage et al., 2025).

2.5.4 Technology-Related Barriers

Technology-related barriers in digital transformation involve challenges like systems integration, data security and scalability issues, hardware and software limitations, concerns about data quality and reliability, and the necessity for constant internet connectivity.(Marocco & Garofolo, 2021).

3. METHODOLOGY

This study adopts a qualitative research method to identify and explore the barriers and potential solutions for implementing DT in the construction industry. Data collection integrates a systematic literature review and semi-structured interviews. Seven industry professionals were interviewed, and the interviews were semi-structured and open-ended to allow participants to provide detailed perspectives and insights. Thematic analysis was used to analyse the qualitative data.

3.1 QUALITATIVE DATA ANALYSIS

Qualitative research is a method that explores human experiences and social phenomena in depth using non-numerical data like interviews and texts, and it focuses on understanding meanings and context, providing detailed insights rather than numerical analysis (Christou, 2022). Thematic analysis is a flexible and accessible method that helps researchers identify, explore, and interpret patterns or themes within rich qualitative data, providing deep insights into participants' perspectives and social phenomena (Christou, 2022; Clarke & Braun, 2017).

3.2 EXPERTISE CORE DATA ANALYSIS

Table 3 represents the demographic data analysis of the interview.

Table 3 : Expertise core data analysis

Organization firm	Profession	No. of Interviewers	Years of experience
Construction Contracting firm	Project manager (R1, R2)	2	10-15 years
	Senior Engineer (R3)	1	10-15 years

Organization firm	Profession	No. of Interviewers	Years of experience
Construction Consultant firm	Architect (R4)	1	15-20 years
	Quantity Surveyor (R5)	1	15-20 years
	Engineer (R6, R7)	2	15-20 years

4. RESULTS AND DISCUSSION

4.1 CURRENT APPLICABILITY OF DT TECHNOLOGY AMONG THE SRI LANKAN CONSTRUCTION INDUSTRY PROFESSIONALS

Despite advancements, out of 7 interviewees, 4 experts mentioned that construction projects still rely on manual methods, primarily due to limited software experience and resistance to change stemming from traditional practices, while 3 experts indicated that projects utilized automated tools. Table 4 illustrates the current applicability of different digital technologies among Sri Lankan construction industry professionals, according to the interviewers' responses.

Table 4: Current applicability of digital technologies

Digital technologies	Awareness	Practical implementation
Digital Twin	1	1
Photogrammetry	2	1
BIM	2	3
LiDAR	2	1

Among the technologies, BIM showed the highest level of practical implementation, with 3 out of 7 participants confirming its use, while 2 participants indicated awareness of it. Photogrammetry and LiDAR were each mentioned by 2 participants in terms of awareness, but only 1 participant acknowledged actual implementation in practice for each. Digital Twin technology had the lowest overall recognition, with only 1 participant mentioning awareness and 1 noting practical use, indicating it is still relatively new or unfamiliar in the Sri Lankan context.

4.2 ADVANTAGES AND BARRIERS OF DT

Tables 5 and 6 represent a detailed overview of the barriers and advantages associated with the implementation of DT technology in the construction industry, incorporating insights from both the literature review and the interview findings

Table 5: Advantages of DT

	Advantages	Literature Review	Interviewers						
			R1	R2	R3	R4	R5	R6	R7
1	Enhance the design and planning	✓	✓	✓	✓	✓	✓		
2	Improve industrial production efficiency	✓			✓		✓	✓	✓
3	Improving management efficiency	✓	✓	✓			✓		

	Advantages	Literature Review	Interviewers						
			R1	R2	R3	R4	R5	R6	R7
4	Ensuring sustainable development	✓		✓					
5	Enhanced safety	✓						✓	
6	Cost reduction	✓			✓		✓	✓	✓
7	Improve the quality of decision-making	✓			✓		✓		
8	Improve performance	✓	✓	✓	✓			✓	✓
9	Monitor energy consumption	✓						✓	✓
10	Remote monitoring	✓	✓	✓		✓	✓	✓	✓

The analysis identified twelve advantages of DT implementation. Enhancing design and planning was widely supported, while improving performance and remote monitoring received unanimous backing from all seven interviewees. Other commonly cited benefits included improved management efficiency, cost reduction, and better decision-making quality, highlighting DT's practical value in project execution. Some advantages, like enhanced industrial production efficiency and energy monitoring, were recognized by the literature and certain respondents.

Table 6:Barriers for DT technology

	Barriers	Literature Review	Interviewers						
			R1	R2	R3	R4	R5	R6	R7
1	Limited Awareness & Understanding	✓	✓	✓	✓				✓
2	Lack of Skilled Workforce	✓	✓	✓	✓	✓	✓		✓
3	Low Adoption in Small Projects	✓		✓	✓				✓
4	Technical Complexity	✓						✓	✓
5	Lack of Tools for Maintenance Phase	✓	✓	✓	✓				✓
6	Financial barriers	✓			✓		✓	✓	

A total of 15 barriers were identified through the literature review. Notably, 6 of these barriers, as shown in Table 6, were also highlighted by experts during the data collection process, indicating alignment between the literature and professional insights. The most significant barrier is limited awareness, noted by four interviewees. Nearly all sources acknowledged a lack of skilled workforce, indicating a skills gap. Low adoption in small-scale projects was mentioned by three interviewees, suggesting resource constraints for smaller firms. Technical complexity was discussed by only two interviewees. Additionally, four noted the need for better tools for the maintenance phase, while three highlighted financial barriers and cost concerns related to advanced technologies.

4.3 PRACTICAL STEPS TO FACILITATE THE IMPLEMENTATION OF DT TECHNOLOGY IN SRI LANKAN CONSTRUCTION INDUSTRY

The Table 7 outlines the proposed practical steps to overcome the barriers of digital technology, according to the interviewees.

Table 7: Proposed practical steps

	Proposed Practical Steps	Interviewers						
		R1	R2	R3	R4	R5	R6	R7
1	Awareness Campaigns	✓		✓	✓	✓		
2	Standardized Framework		✓			✓		
3	Training Programs			✓	✓	✓		
4	Pilot Projects						✓	✓
5	Regulatory Support		✓			✓		
6	Collaboration			✓				✓
7	Education and Curriculum Development				✓	✓		
8	User-Friendly Platforms	✓					✓	✓

The key recommendations included awareness campaigns to improve understanding of DT, as supported by four interviewees. Training programs and curriculum development for capacity building were emphasized by three others. R6 and R7 suggested pilot projects, while R2 and R5 called for standardized frameworks and regulatory support. R3 and R7 highlighted the importance of collaboration among stakeholders, and R1, R6, and R7 stressed the need for user-friendly platforms to enhance adoption.

Figure 1 illustrates the suggested practical steps that can be taken to overcome common barriers associated with implementing DT technology in Sri Lankan construction projects.

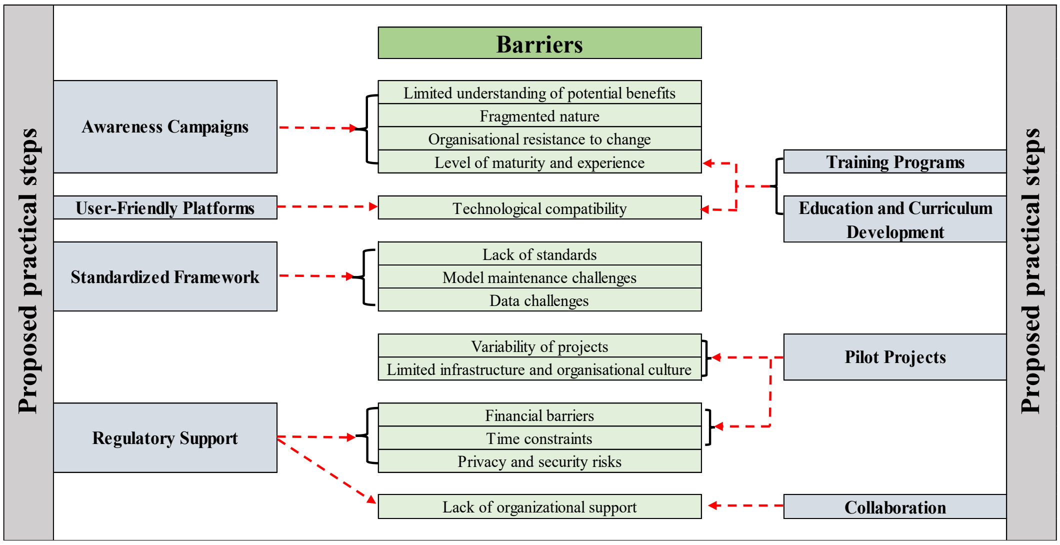

Figure 1 - Proposed practical applications to overcome the barriers of DT technology

Incorporating DT technologies into academic curricula equips future professionals with essential skills. This strategy promotes a culture that supports digital initiatives. A standardized framework enhances data sharing, model development, and integration, reducing fragmentation and improving interoperability, which is vital for effective DT applications. Creating user-friendly platforms encourages adoption, ensuring stakeholders engage with systems for smoother implementation and better data management. Pilot projects serve as test environments for DT solutions, helping identify issues, validate benefits, and build stakeholder confidence. Successful pilots demonstrate viability and encourage broader investment. Government regulations can establish industry standards, provide financial incentives, and enforce security measures, lowering risks and costs while supporting digital innovation. Collaboration across government, academia, and industry fosters knowledge sharing, drives innovation, and establishes essential support systems for successful DT implementation.

5. CONCLUSIONS

This study assessed the applicability of DT technology in Sri Lankan construction projects by examining its current usage, potential benefits, and implementation barriers. It's important to recognize limitations in the research, as technology's dynamic nature may affect the generalizability of the findings. The research findings confirm that while DT remains an emerging concept in Sri Lanka, it holds considerable promise in addressing industry specific barriers, such as improving design accuracy, monitoring performance, enhancing safety, and managing LCC. Despite growing interest, the uptake of DT is hindered by limited stakeholder awareness, insufficient technical expertise, cost constraints, and lack of regulatory support. Addressing these barriers requires a multi-pronged approach, including targeted awareness programs, integration of DT concepts into academic and professional training, pilot implementations to demonstrate value, and the development of supportive policies and standardized frameworks. With proper strategic direction, Sri Lanka's construction industry can harness DT technology not only to modernize its practices but also to contribute to a more sustainable and digitally integrated future. Therefore, future research should incorporate stakeholder input to define the scope and functionalities of DT systems that best serve the practical needs of the industry.

6. REFERENCES

Acampa, G., & Pino, A. (2023). A simplified facility management tool for condition assessment through economic evaluation and data centralization: Branch to core. *Sustainability*, *15*(8), 6418. https://doi.org/10.3390/su15086418

Akomah, B. B., Ahinaquah, L. K., & Mustapha, Z. (2020). Skilled labour shortage in the building construction industry within the Central Region. *Baltic Journal of Real Estate Economics and Construction Management, 8*, 83–92. https://doi.org/10.2478/bjreecm-2020-0006

Amirthavarshan, K., Gallage, S. D., Costa, M. D. D., & Eranga, B. A. I. (2023). Potential use of digital twin for construction progress monitoring. In K. A. T. O. Ranadewa, R. Rameezdeen, & R. Dissanayake (Eds.), *Proceedings of the 11th World Construction Symposium: Sustainable construction in the era of disruptions* (pp. 873–884). Ceylon Institute of Builders. https://doi.org/10.31705/WCS.2023.70

Aragón, A., Arquier, M., Tokdemir, O. B., Enfedaque, A., Alberti, M. G., Lieval, F., Loscos, E., Pavón, R. M., Novischi, D. M., Legazpi, P. V., & Yagüe, Á. (2025). Seeking a definition of digital twins for construction and infrastructure management. *Applied Sciences, 15*(3), 1557. https://doi.org/10.3390/app15031557

Attaran, M., & Celik, B. G. (2023). Digital twin: Benefits, use cases, challenges, and opportunities. *Decision Analytics Journal, 6*, 100165. https://doi.org/10.1016/j.dajour.2023.100165

Bandara, D. M. U. S., Jayasinghe, J. A. S. K., & Coomasaru, P. (2024). Advancing digital technology adaptation in Sri Lankan construction firms. In K. A. T. O. Ranadewa, R. Rameezdeen, & R. Dissanayake (Eds.), *Proceedings of the 12th World Construction Symposium: Towards a smart, sustainable and resilient built environment* (pp. 120–131). Ceylon Institute of Builders. https://doi.org/10.31705/WCS.2024.10

Bandara, D. W. J. W., Ranadewa, K. A. T. O., Parameswaran, A., Eranga, B. A. I., & Nawarathna, A. (2023). Lean iceberg model to minimise barriers for digital twin implementation: Sri Lankan construction industry perspective. In K. A. T. O. Ranadewa, R. Rameezdeen, & R. Dissanayake (Eds.), *Proceedings of the 11th World Construction Symposium: sustainable construction in the era of disruptions* (pp. 671–685). Ceylon Institute of Builders. https://doi.org/10.31705/WCS.2023.55

Boussabaine, H. A., & Kirkham, R. J. (2004). *Whole life-cycle costing: Risk and risk responses* (1st ed.). John Wiley & Sons. https://doi.org/10.1002/9780470759172

Buddika, H. A. D. S., Harischandra, N., & Mahmoodian, M. (2022). Conservation and management of ancient stupa using digital twins: A case study of UAV based 3D photogrammetric digitization of Rankoth Wehera stupa. In Dr. M. Thayaparan, Prof. Y. Sandanayake, Dr. W. Gamage & Dr. P. Singhapathiran (Eds.), *Proceedings of the 10th FARU International Research Symposium 2022* (pp. 493–598). University of Moratuwa. https://www.researchgate.net/publication/365743763

Chathuranga, N., Thajdeen, F., & Siriwardana, C. (2025). A conceptual framework for enhancing construction safety in Sri Lanka through digital technology implementation. *Buildings, 15*(8), 1223. https://doi.org/10.3390/buildings15081223

Christou, P. A. (2022). How to use thematic analysis in qualitative research. *Journal of Qualitative Research in Tourism, 3*(2), 79–95. https://doi.org/10.4337/jqrt.2023.0006

Clarke, V., & Braun, V. (2017). Thematic analysis. *The Journal of Positive Psychology, 12*(3), 297–298. https://doi.org/10.1080/17439760.2016.1262613

Emmanuel, R. (2004). Estimating the environmental suitability of wall materials: Preliminary results from Sri Lanka. *Building and Environment, 39*(10), 1253–1261. https://doi.org/10.1016/j.buildenv.2004.02.012

Geekiyanage, C. L., Prabodhani, L. H. K. N., Wijerathna, R. M. K. K., Lekamge, L. S., & Erandi, J. D. T. (2025). Usage of digital twin technology for sustainable development in Sri Lanka's construction sector. *International Journal of Research Publication and Reviews*, *6*(4), 2755–2767. https://doi.org/10.55248/gengpi.6.0425.1410

Gunatilaka, R. N., Abdeen, F. N., & Sepasgozar, S. M. E. (2021). Developing a scoring system to evaluate the level of smartness in commercial buildings: A case of Sri Lanka. *Buildings, 11*(12), 644. https://doi.org/10.3390/buildings11120644

Hämäläinen, M. (2021). Urban development with dynamic digital twins in Helsinki city. *IET Smart Cities, 3*(4), 201–210. https://doi.org/10.1049/smc2.12015

Haron, R. C., & Zafir, N. B. M. (2025). Digital Twin application in construction cost management. *Planning Malaysia*, 23(1) ,81-96. https://doi.org/10.21837/pm.v23i35.1665

Jiao, W., Jing, K. T., & Esa, M. (2025). The impact of digital technology applications on construction industry project performance. *Journal of Advanced Research in Applied Sciences and Engineering Technology, 53*(1), 311–322. https://doi.org/10.37934/araset.53.1.311322

Kudasinghe, K., & Jeewananda, W. (2024). Utilizing digital twin technology in conserving cultural heritage within the built environment of Sri Lanka. In Dr. M. Thayaparan, Prof. Y. Sandanayake, Dr. W. Gamage & Dr. P. Singhapathiran (Eds.) *Proceedings of the 12th FARU International Research Symposium 2024*, (pp. 87–96). University of Moratuwa.

Li, L., You, J., & Xu, T. (2025). Risk analysis of digital twin project operation based on improved FMEA method. *Systems, 13*(1), 48. https://doi.org/10.3390/systems13010048

Liu, J., Duan, L., Lin, S., Miao, J., & Zhao, J. (2024). Concept, creation, services and future directions of digital twins in the construction industry: A systematic literature review. *Archives of Computational Methods in Engineering*, *31*(3), 1221–1253. https://doi.org/10.1007/s11831-024-10140-4

Lu, Q., Chen, L., Li, S., & Pitt, M. (2020). Semi-automatic geometric digital twinning for existing buildings based on images and CAD drawings. *Automation in Construction, 115*, 103183. https://doi.org/10.1016/j.autcon.2020.103183

Madubuike, O. C., Anumba, C. J., & Khallaf, R. (2022). A review of digital twin applications in construction. *Journal of Information Technology in Construction, 27*, 145–172. https://doi.org/10.36680/j.itcon.2022.008

Marocco, M., & Garofolo, I. (2021). Integrating disruptive technologies with facilities management: A literature review and future research directions. *Automation in Construction, 131*, 103917. https://doi.org/10.1016/j.autcon.2021.103917

Melesse, T. Y., Pasquale, V. D., & Riemma, S. (2021). Digital Twin models in industrial operations: State-of-the-art andfuture research directions. *IET Collaborative Intelligent Manufacturing*, *3*(1), 37–47. https://doi.org/10.1049/cim2.12010

Nagalingam, G., Jayasena, H. S., & Ranadewa, T. (2013). Building information modelling and future quantity surveyor's practice in Sri Lankan construction industry. In Prof. Y. G. Sandanayake & Dr. N. G. Fernando (Eds.), *Proceedings of the 2nd World Construction Symposium 2013* (pp. 81–92). Ceylon Institute of Builders. http://dl.lib.mrt.ac.lk/handle/123/10750

Omrany, H., Al-Obaidi, K. M., Ghaffarianhoseini, A., Chang, R.-D., Park, C., & Rahimian, F. (2025). Digital twin technology for education, training and learning in construction industry: Implications for research and practice. *Engineering, Construction and Architectural Management*. (In press)

Opoku, D.-G. J., Perera, S., Osei-Kyei, R., Rashidi, M., Bamdad, K., & Famakinwa, T. (2023). Barriers to the adoption of digital twin in the construction industry: A literature review. *Informatics, 10*(1), 14. https://doi.org/10.3390/informatics10010014

Parvin, S. (2021, December). *Success factors of an enterprise-wide digital twin strategy* [Conference presentation]. Abu Dhabi International Petroleum Exhibition & Conference, Abu Dhabi, UAE. https://doi.org/10.2118/207248-MS

Priyadarshani, K., Karunasena, G., & Jayasuriya, S. (2013). Construction safety assessment framework for developing countries: A case study of Sri Lanka. *Journal of Construction in Developing Countries, 18*(1), 33–51.

Qamsane, Y., Moyne, J., Toothman, M., Kovalenko, I., Balta, E. C., Tilbury, D. M., & Barton, K. (2021). A methodology to develop and implement digital twin solutions for manufacturing systems. *IEEE Access, 9*, 44247–44265. https://doi.org/10.1109/ACCESS.2021.3065971

Radzi, A. R., Azmi, N. F., Kamaruzzaman, S. N., Rahman, R. A., & Papadonikolaki, E. (2024). Relationship between digital twin and building information modeling: A systematic review and future directions. *Construction Innovation, 24*(3), 811–829. https://doi.org/10.1108/CI-07-2022-0183

Revolti, A., Gualtieri, L., Pauwels, P., & Dallasega, P. (2024). From building information modeling to construction digital twin: A conceptual framework. *Production & Manufacturing Research*, *12*(1), Article 2387679. https://doi.org/10.1080/21693277.2024.2387679

Sacks, R., Brilakis, I., Pikas, E., Xie, H. S., & Girolami, M. (2020). Construction with digital twin information systems. *Data-Centric Engineering, 1*, 26. https://doi.org/10.1017/dce.2020.16

Shahzad, M., Shafiq, M. T., Douglas, D., & Kassem, M. (2022). Digital twins in built environments: An investigation of the characteristics, applications, and challenges. *Buildings, 12*(2), 120. https://doi.org/10.3390/buildings12020120

Singh, M., Fuenmayor, E., Hinchy, E. P., Qiao, Y., Murray, N., & Devine, D. (2021). Digital twin: Origin to future. *Applied System Innovation*, *4*(2), 36. https://doi.org/10.3390/asi4020036

Tuhaise, V. V. (2023). Technologies for digital twin applications in construction. *Automation in Construction, 152*, 104931. https://doi.org/10.1016/j.autcon.2023.104931

Ullah, K., Lill, I., & Witt, E. (2019). An overview of BIM adoption in the construction industry: Benefits and barriers. In I. Lill & E. Witt (Eds.), *10th Nordic Conference on Construction Economics and Organization* (Vol. 2, pp. 297–303). Emerald Publishing Limited. https://doi.org/10.1108/S2516-285320190000002052

Wang, L., Teng, D., Jin, R., Guo, X., Meng, X., Liu, G., Luo, X., Sun, C., & Su, Z. (2025). The development of prefabricated buildings and intelligent construction based on digital twins. *Journal of Intelligent Construction, 3*(1), 1–25. https://doi.org/10.26599/JIC.2025.9180080

West, T. D., & Blackburn, M. (2017). Is digital thread/digital twin affordable? A systemic assessment of the cost of DoD's latest Manhattan Project. *Procedia Computer Science, 114*, 47–56. https://doi.org/10.1016/j.procs.2017.09.003

Wijekoon, S. B., & Attanayake, A. M. C. T. K. (2012). *Study on the cost overruns in road construction projects in Sri Lanka* [Conference presentation]. Undergraduate Research Symposium, University of Moratuwa, Sri Lanka. http://dl.lib.mrt.ac.lk/handle/123/8969