Using Digital Twin Technology to Overcome Challenges in Civil Engineering and Construction: A Review

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***Abstract:** The purpose of this review article is to address the existing knowledge gap by presenting an extensive overview of the diverse uses of digital technology (DT) in the fields of construction and civil engineering. Additionally, it seeks to demonstrate how DT can effectively mitigate the challenges faced by the sector. A comprehensive review is conducted by collating insights from recent research papers worldwide and providing a holistic, time-efficient, and tailored understanding of Digital Twin Technology in Civil Engineering and Construction. The review spanned critical areas including infrastructure construction, structural health monitoring, energy efficiency in buildings, seismic evaluation of buildings, safety of heritage buildings, and the diverse applications of digital twins in construction design, monitoring and management. This study acts as a thorough guide for experts, providing them with a consolidated source of knowledge. With the complexities of the construction industry, understanding how digital twins can provide solutions is crucial. Professionals can use this technology to assure not only efficiency but also sustainability, which is becoming increasingly important in today's environment.*

***Keywords:** Digital Twin, Technology, Challenges, Construction, Civil Engineering*

I. INTRODUCTION

The construction sector, recognized as the backbone of the Indian economy, has experienced a considerable surge over the last few decades. As of 2021, the construction industry in India holds a pivotal position, contributing nearly 8% to the country's Gross Domestic Product (GDP). Additionally, it is an employment-intensive domain, providing jobs to approximately 50 million people, making it the second-largest employment generator after the agricultural sector (M. Jaiswal, 2023, [1]).

However, like every burgeoning sector, the construction industry is fraught with challenges both globally and in India. Infrastructure construction often faces issues related to cost and time overruns, frequently due to poor planning and unforeseen ground conditions (Zhang et al.). Ye, 2023, [2]).

Manuscript received on 19 September 2023 | Revised Manuscript received on 30 September 2023 | Manuscript Accepted on 15 October 2023 | Manuscript published on 30 October 2023.
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Structural health monitoring often struggles with accurately predicting the long-term performance and degradation of materials (B. G. Pantoja-Rosero, 2023, [3]). With global warming ringing alarm bells, the urgency for energy efficiency in buildings is evident. Yet, a significant gap remains in translating theoretical energy-efficient practices into on-the-ground reality (A. Clausen, 2021, [4]). Seismic evaluation of buildings is another crucial area, especially for countries in the Pacific Ring of Fire, including parts of India. Many buildings remain non-compliant with seismic standards, posing risks during earthquakes (F. Mokhtari, 2023, [5]). Furthermore, the safety of heritage buildings, which often symbolise a nation's cultural legacy, remains a perpetual challenge. These structures, due to their age, require specialized restoration techniques that maintain their aesthetic and historical essence while ensuring safety (A. Shabani, 2022, [6]). In this context, the concept of a "digital twin" emerges as a beacon of hope. A digital twin, in essence, refers to a virtual representation of a physical entity, enabling real-time monitoring and simulation-based analysis (R. Zhang, 2022, [7]). Its applications span across sectors, from healthcare to manufacturing. The utilisation of digital twins in the fields of construction and civil engineering holds significant potential for transforming conventional techniques. They can predict the outcomes of various strategies, optimize construction processes, enhance monitoring accuracy, and greatly assist in maintaining energy efficiency (J. Feng, 2021, [8]). Several studies have already explored the application of digital twins in the construction and civil engineering sectors. For example, studies from China and the UK have showcased how digital twins can assist in optimizing infrastructure construction (Z. Ye, 2023, [2]); Rogage, Mahamedi, Brilakis & Kassem, 2022 [9]). Research from Switzerland and UK has emphasized the role of digital twins in enhancing structural health monitoring (B. G. Pantoja-Rosero, 2023, [3]; D. Loverdos, 2022, [10]). However, while numerous individual studies exist, there appears to be a conspicuous absence of a comprehensive review that holistically combines these diverse areas of knowledge, especially in the context of mitigating the challenges above. This review paper aims to bridge that gap by providing an extensive overview of the various applications of DT in construction and civil engineering, and demonstrating how it can mitigate the challenges faced by the sector.

By collating insights from recent research papers worldwide and providing a holistic, time-efficient, and tailored understanding, this review aims to empower professionals in the sector, enabling them to navigate challenges and capitalise on the numerous benefits of digital twin technology.

The study aims to investigate the following research questions in detail:

RQ1: What are the applications of digital twin technology in construction and civil engineering?

RQ2. To what extent does DT technology help mitigate the challenges faced by the construction and civil engineering?

II. DIGITAL TWINS: CONCEPT AND APPLICATIONS

The digital twin is a technological innovation that integrates various components, including sensing mechanisms, networking capabilities, big data analytics, artificial intelligence algorithms, and sophisticated modelling techniques. A digital twin refers to a dynamic and up-to-date depiction of a physical system that actively observes and assesses the state of its constituent elements (R. Zhang, 2022, [7]). It consists of both a virtual and a real machine. Every machine (model) is depicted as a simulation, a reflection, or a replica of the other. Hence, the digital twin can document the complete life cycle of the physical entity, including individuals, objects, or processes.

The digital twin is a technological innovation that integrates several physical, spatial, and disciplinary attributes. It concurrently exhibits the characteristics of real-time synchronisation, precise mapping, and exceptional fidelity. The system shows the ability to facilitate the interaction and integration of the physical and informational domains (Zayed, Attiya, El-Sayed & Hemdan, 2023, [11]).

The concept of a digital twin serves as a means of connecting the physical realm with the realm of information, thereby facilitating the exchange of data over the life cycle of a product. By doing so, it enhances the manufacturing processes by offering services that are characterised by real-time responsiveness, efficiency, and intelligence.

Digital twin has three fundamental levels. First, the industrial layer is responsible for managing complex systems and is fundamentally reliant on both physical environments and digital twins. Second, the application layer is determined by the characteristics and content of a virtual vision. The communication layer focuses on cyber-physical connections (G. Mezzour, 2020, [12]).

Digital twins are utilised in various industries, including the military, aerospace, agriculture, oil and gas, construction, automotive, power generation, and smart cities.

A. Applications of Digital Twin in Civil Engineering and the Construction Industry

Numerous researchers have applied DT to civil engineering applications, including collaborative heritage building information modelling (HBIM) that integrates tangible and intangible cultural heritage (D. Heesom, 2020, [13]); a semi-automated process for creating precise BIM facade models for existing structures using laser and image data (C. Dore, 2014, [14]); and manually enriched semantics from laser scanner point clouds to create a Building Energy Performance Simulation (BEPS) model (D. Heesom, 2020, [13]).

To facilitate the design of new projects or retrofit designs, DT can be generated for the surrounding environment and current projects that are linked to the target projects, as well as prior generations of the target projects. Although there are few instances of DT applications for the design of new civil engineering projects, they do exist (J. Feng, 2021, [8]). The idea of DT is currently implemented in project maintenance, operation and construction due to the development of IoT (Hou et al., 2020, [15]).

III. DIGITAL TWINS IN CIVIL ENGINEERING

The stages in which DT can be used in civil engineering are the material components, the design phase and the construction phase.

DTs can be generated for structures and components. Engineers can use the DT from a prior building or bridge project to research and simulate a new one. This category includes the majority of DT uses in prefabricated structure design. Designing target project renovations, expansions, and new construction can also be done with DT (J. Wang, 2020, [16]).

In the design stage, planning, task definition, preliminary design, conceptual design, virtual verification and detailed design might benefit from DT. Designers can use DT to plan a project, make decisions, identify constraints, and give a framework and outline (G. Schrotter, 2020, [17]). DT can use data from related projects, the environment, the nearby area, design papers, and other sources for conceptual, preliminary, and detailed design. By utilising data from multiple sources, designs that can be efficiently modified, enhanced, updated, and validated with the least amount of time, money, and labour can be analysed using DT. (M. Eguaras-Martínez, 2014, [18]).

DT can aid in the monitoring and management of the construction phase, including the management and monitoring of the construction safety, quality, employees, progress, apparatus, and materials. (Y. Türkan, 2014, [19]). DT can also be applied to create an innovative framework for safety management on building sites. Enabling on-site risks related to people, machinery, and other factors to produce warnings and be controlled (W. Jiang, 2020, [20]) by developing models that can analyse previous fatal construction workplace accidents and aid in their prevention (O. Golovina, 2019, [21]). DT can help monitor, manage, and regulate construction equipment to ensure efficiency, accuracy, and safety. Additionally, DT can substantially improve asset management in numerous instances (P. Love, 2019 [22]) by assessing the condition of physical components, diagnosing problems, and making informed decisions using geometric information, sensors, and physical-virtual links. For comprehensive asset management, including disaster mitigation and prevention, DT can verify both geometric and non-geometric data and manage the physical components of ongoing projects using photogrammetry, IoT, GIS, sensing, and laser scanning (D. P. Welch, 2014, [23]). DT can prove very useful in both reconstruction and dismantling projects.

By generating a virtual representation of real-world entities and environments, including geometric and non-geometric data, DT can aid in the reconstruction, retrofitting, and demolition of obsolete structures (Angjeliu, Coronelli

Retrieval Number:100.1/ijeat.A43051013123
DOI: 10.35940/ijeat.A4305.1013123
Journal Website: www.ijeat.org

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& Cardani 2020, [24]). Using 3D laser building scanning and BIM2BEM, DT can expedite energy optimisation and decision-making based on analysis for retrofitting existing structures (S. Kim, 2016, [25]).

IV. INFRASTRUCTURE PROJECTS

A. Tunnel Construction Safety

Insufficient construction organisation and supervision, complex geological conditions, adverse construction environments, and an increase in the number of tunnels despite increased capital investment lead to frequent tunnel construction accidents (Z. Zhou, 2015, [26]).

Traditional tunnel monitoring is primarily manual; however, early warning and prediction methods for tunnel accidents are often inadequate. The application of digital twin technology in the realm of construction safety and initial warning, particularly in tunnel engineering, is still in its early stages of development. The application of DT for tunnels strongly depends on data that must be gathered from real-world objects, computer simulations, and specialised knowledge(G. Yu, 2021, [27]).

By incorporating multi-source data from tunnel construction, researchers have recently presented a platform for smart early warning and safety management based on the notion of DT (Z. Ye, 2023, [2]).

B. Earthwork Equipment Monitoring

In massive infrastructure projects like highways, rail lines, and energy projects, earthwork is one of the most expensive and vital operations, and heavy earthmoving equipment like bulldozers, excavators and trucks make for a sizable amount of construction project expenditures (Sartori et al., 2014, [28]). Such kind of machinery is commonly blamed for project delays, and is a significant source of air pollution and congestion both on and off-site (Giusti et al., 2014, [29]). The accurate reporting of earthmoving equipment productivity and utilisation is a key challenge for large projects. Current methods, such as on-site observation notes, timesheets, drones, or on-board telematics systems, are prone to error and impractical for large projects (M. Kassem, 2021, [30]). With DT, there is potential to reduce emissions, costs, and delays associated with earthwork activities. DT has emerged as the industry leader in data-centric construction management technology improvement (B. Hong, 2022, [31]). Some studies have attempted to achieve enhanced operational efficiencies on construction sites through DT. Rogage, Mahamedi, Brilakis, and Kassem (2022) [9] created a DT framework to give a precise and effective method for measuring the degree of equipment utilisation and keeping track of the effectiveness and efficiency of earthwork efforts in significant infrastructure projects. This system features a digital dashboard that enables the comparison of performance metrics for activities and resources with visual representations of construction sites. The application programming interfaces (APIs), system actors, artificial intelligence (AI), data, and dashboard visualisation are its five main components. By identifying patterns, this DT solution enhances equipment productivity by providing analytical and visual insights into the use of earthwork equipment in near real-time.

C. Highway Asset Management

Operation and maintenance, Road network design, traffic simulation and analysis, expansion, and reconstruction are all ongoing maintenance procedures for existing roadways. This requires detailed data about the current condition of existing roads (A. Ragnoli, 2018, [32]). Due to missing or insufficient archives, there may not be enough data available on old roads, most of which were built without digital drawings (Cheng, Lu & Deng, 2016, [33]). Even if some existing data can be located, it is typically unstructured and ranges from paper illustrations to PDF files. M. W. Grieves, (2016, [34] [35]) hypothesised that a digital twin can address these problems by providing a high-fidelity digital duplicate on the go as well as structured and integrated data. Creating a digital twin of an ancient road poses numerous challenges. These challenges include the difficulty of representing the long and complex shape of the infrastructure digitally, as well as incorporating various road components, such as vertical and horizontal alignments, cross falls, central reserves, cross-sections, verges, lanes, hard strips, side slopes, and shoulders, among others. Additionally, there is the issue of addressing defects resulting from the survey state of the downloaded map data, which is characterised by its low quality and limited scope. Additionally, it is imperative to acknowledge and rectify the existing deficiencies in the ancient road infrastructure, including pavement deterioration resulting from vehicular activity and various external sources, erosion of the adjacent slopes, and the lack of clear demarcation between distinct road elements (J. Feng, 2022, [36]). J. Feng, (2022, [36]) given a method for systematic digital twinning of extant old highways that takes into account various highway components about the topography and uses readily accessible extant online map data. This method enables highway-related digital twins to be independent of field surveys and extraordinary circumstances, reduces the impact of the old highway's spikes, outliers, and defects on the digital counterpart, and ensures that the digital twin of the road aligns with the engineering representation of the roadway. The suggested solution has been effectively implemented on a segment of the A1(M) motorway in the United Kingdom.

V. STRUCTURAL HEALTH MONITORING

Buildings and Infrastructure undergo routine visual assessments or prompt evaluations following a natural disaster to ensure compliance with structural regulatory guidelines. A proper assessment prevents any structural breakdowns and minimises the repercussions, like the potential for physical harm to people and economic losses (B. G. Pantoja-Rosero, 2023, [3]).

Engineers seek to visually identify and assess structural component deterioration during an inspection to determine whether the object can be used as-is, requires further investigation, may need some upgrades, or should be scrapped altogether.

Lack of objectivity, lengthy execution time, high costs, and challenges in demonstrating damages are the key shortcomings of the conventional approach (B. G. Pantoja-Rosero, 2023, [3]).

These disadvantages underscore the need for novel assessment methods, such as imaging technologies and artificial intelligence. Fractures are the most prevalent type of damage detected during inspections, especially in brittle structures such as concrete or masonry, making it crucial to segment fractures from photographs accurately. Computer vision techniques, such as deep learning and photogrammetry methods, are now used in conjunction with image data to lessen the subjectivity and operation time of conventional inspections. Convolutional neural networks (CNNs), for instance, have been the subject of extensive study for their potential in damage detection, classification, and segmentation. (Nag et al., 2020, [37]). Several researchers (A. H. Rezaie, 2021, [38]; Gehri et al., 2022, [39]) have pushed for the use of image-based methodologies, and crack widths and shear displacements can be calculated using digital image correlation. Their findings are generally accurate, but they are restricted by the necessity of a particular configuration of image devices and, in some situations, the structure itself. Several recent studies that use DTs to evaluate the structural health of buildings have yielded encouraging findings. L. Barazzetti, (2015, [40]), for example, described a method for generating GDTs in the format of Heritage Building Information Models (HBIM) to be utilised in augmented and virtual reality applications. Hoskere et al. (2018, [40]) presented condition-aware structural models that incorporated a textured three-dimensional (3D) building model. The authors employed deep learning models to locate faults within the building model and subsequently mapped these faults using UV mapping techniques. P.-A. Jouan, (2020, [41]) employed HBIMs as DTs to aid in the preservation of heritage sites. A. Shabani, (2022, [6]) explored a range of issues and methodologies about the utilisation of decision trees (DT) in the analysis of building response across different load scenarios. C. Rainieri, (2022, [42]) introduced the utilisation of Decision Trees (DT) in the context of Building Information Models (BIM) for monitoring and establishing guidelines for structural maintenance. The DT framework for post-earthquake building evaluation was established by N. Levine (2022, [43]) utilising drone imagery, component identification, and damage assessment. Instead of approaching building damage inspection duties individually, B. G. Pantoja-Rosero (2023,[3]) propose the development of a holistic pipeline that enables the automated generation of a comprehensive three-dimensional (3D) model, which incorporates damage information in the form of a digital twin. The researchers utilised geometric digital twins (GDT), which refer to three-dimensional models that encompass comprehensive data about the geometric characteristics of a real asset. The GDTs were combined with picture data containing damage information, specifically cracks and their characterisation, to create a digital twin that incorporates damage (referred to as DADT). The employed methodology resulted in the development of a DADT model with a low weight, making it suitable for expedited inspections. Furthermore, this model facilitated the incorporation of semantic information derived from image data. Importantly, it exhibited the advantage of not being constrained to a singular asset, thereby offering versatility for application to various forms of infrastructure. Moreover, this model proved to be adaptable and applicable in both routine inspection scenarios and the context of natural disasters.

VI. SEISMIC EVALUATION

Hybrid simulation (HS) is a flexible and effective method for assessing the seismic behaviour of structures, quantifying the factors influencing seismic response, generating information for the development and improvement of numerical modelling methods, and evaluating and improving seismic design guidelines. There are two primary HS methodologies in seismic engineering: pseudo-dynamic hybrid simulation (PsDHS) and real-time hybrid simulation (RTHS).

The basic principle of conventional hybrid simulation (CHS) involves the division of a structure into two distinct substructures that can be computed in parallel: the well-established components that are simulated numerically using the finite element method, and the crucial element(s) anticipated to exhibit inelastic behaviour, such as seismic fuses, which are physically tested in a laboratory setting. The computation of interfacial node displacements will be carried out in each time step by solving the governing equation of motion, which will then be applied to the physical specimen. The restoring forces of the specimen will thereafter be quantified and reintegrated into the numerical model for the forthcoming analytical increment (D. McCrum, 2016, [44]).

Although CHS offers advantages compared to alternative seismic testing methods, the accuracy of its results may be compromised when limited physical testing is conducted on only a few potentially significant components. This limitation arises owing to constraints such as laboratory capacity or budgetary restrictions. Due to the limited capacity of existing structural testing facilities, it is challenging to conduct comprehensive physical tests on all essential components, even at a smaller scale. Consequently, the seismic behaviour of multi-storey structures, which often incorporate numerous seismic fuses or highly nonlinear elements, may not be accurately depicted using conventional computational hybrid simulation (CHS) methods. Consequently, the majority of previous hybrid simulations have predominantly employed a limited number of physical specimens to represent significant components of the structure. Meanwhile, the remaining portions of the structure, including certain highly nonlinear crucial aspects, have been described using numerical means (Hashemi et al., 2017, [45]).

To address these challenges, F. Mokhtari (2023, [5]) proposed a new digital twin-based multi-element hybrid simulation (DMHS) framework that combines a data-driven model, i.e., a digital twin, with an active (real-time) training feature to more efficiently address biased CHS results for structures with multiple critical components.

The primary function of the digital twin is to proactively forecast the nonlinear dynamic reaction of essential components that have not undergone physical testing, and afterwards transmit the anticipated response to the numerical substructure during high-stress conditions. In comparison to CHS, the proposed framework aims to provide a more realistic seismic response evaluation, which may or may not consider the dynamic properties of components

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during HS. The suggested DMHS exhibits exceptional computational efficiency, making it potentially applicable to RTHS.

VII. ENERGY EFFICIENCY

A. Enhancing Energy Efficiency and Optimising Occupant Comfort

Buildings consume around 40% of overall energy consumption in industrialised nations (X. Cao, 2016, [46]). Consequently, the integration of building instrumentation devices, such as controllers, actuators, and sensors, presents both opportunities and challenges for enhancing energy efficiency. The objective of this advancement in intelligent building technology is to facilitate energy-efficient automation of buildings, while concurrently prioritising the comfort of individuals occupying these spaces. (J. D. Billanes, 2017, [47]). Model Predictive Control (MPC) is one of the approaches that has recently gained traction in both research and industry (J. Drgoňa, 2020, [48]). Model Predictive Control (MPC) is a collection of control systems that heavily rely on physical models (C. L. García, 1989, [49]) and necessitate a tangible installation interface within the intended structure. The installations include sensors and actuators that are configured, constructed, and deployed based on the physical characteristics of the building and the degree of building automation. In their study, A. Clausen (2021, [4]) introduced a digital twin framework explicitly designed for MPC-based building automation. The utilisation of this framework enables the creation of a digital representation of a building's tangible surroundings, providing facility managers with the opportunity to gain innovative operational perspectives, enhance energy efficiency, and proficiently oversee the structure's performance. The paper explains the diverse applications related to building control, occupancy prediction, and the implementation of a standard data format utilising the sMAP framework. The framework comprises a Zone Model that can be adjusted based on parameters and can be validated using controlled zones, whether they are virtual or physical. Additionally, the framework includes a Zone Control Application that is parameterised, allowing for customisation of temperature and CO2 objectives.

At the University of Southern Denmark, Campus Odense, a customised implementation of the suggested framework was developed to manage a classroom in room U182 of the OU44 building. Experiments demonstrated that the proposed system maintained comfort levels comparable to those achieved by commercial building management systems, while also enabling the implementation of new control strategies to enhance energy efficiency. This demonstrates the potential to increase energy efficiency.

B. Classification of a building's operational energy performance

In the construction industry, there is a pressing need for more effective operational building evaluation procedures. Despite advancements in the technology and design of energy-efficient buildings, many structures continue to perform below their design values, which raises energy costs, boosts carbon emissions, and reduces occupant comfort (L. Brady, 2017, [50]). The difference in energy performance across buildings can have a significant impact on economic, sustainable, and energy-efficient practices.

P. Spūdys, (2023, [51]) presented the feasibility of utilising Building Information Modelling (BIM) files, smart sensors, and DT technology for operational building assessments. They specifically examined the practicality of using DT technology to address the shortcomings of current operational building assessment practices. The researchers showcased a technique for establishing a physical-to-virtual link for monitoring data, employing DT technology. This technology enables the collection and analysis of a substantial volume of data in real-time, leading to a more accurate evaluation of a building's energy efficiency. BIM data was employed as the primary source of building information.

Using the suggested methodology, the operational effectiveness of a university campus facility in Nicosia, Cyprus, was evaluated. A contemporary, mixed-use building with a surface area of 1,441 m², Frederick University's new wing building, constructed in 2007, features three above-ground floors and one basement floor. The findings demonstrated that building occupants used more energy than was necessary to maintain interior thermal comfort. Comparing building spaces for different uses revealed that the bottom level, where the canteen was located, used substantially more energy than the first and second floors, which were used for offices and classrooms. This capability offered the chance to identify underperforming buildings and take measures that may be connected to tenant behaviour or system performance.

C. Heritage

The evaluation of the structural susceptibility of a heritage building is an essential element of a risk reduction strategy aimed at preserving these invaluable cultural assets for nations. The most cutting-edge methods should be used to maintain heritage structures because they are significant remnants of past civilizations (A. Shabani, 2020, [52]). The repair of historic structures would be aided by the potential to create precise digital simulation models that can foresee damage to these structures (A. Shabani, 2022, [6]).

The use of relative structured information in the form of 3D models is a key focus of research on enhanced conservation strategies in the field of cultural heritage (F. I. Apollonio, 2018, [53]). Modern digital tools can facilitate maintenance tasks and aid in the preservation of cultural heritage (Tommasi et al., 2007, [54]). Additionally, they can have a substantial positive economic impact through cultural tourism (D. S. Noonan & Rizzo, 2017, [55]).

Predictive degradation models, which can be highly helpful for detecting degradation causes and mechanisms, planning and documenting maintenance actions, and lowering risks of cultural heritage corrosion, can be created with the use of 3D digital twins (Dzikic & Radin, 2019, [56]). The crucial steps in creating the process for digital twins are geometrical survey and enhanced 3D numerical models of cultural heritage assets (A. Shabani, 2022, [6]). The Moorish Castle in Sintra was subjected to an integrative methodology developed by M. G. Gomes & Tome (2023, [57]) for heritage modelling and deterioration mapping using digitization.

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This research proved to be an effective means of obtaining high-quality data to map, display and assess the diseases. It also supported the deployment of innovative contactless 3D automatic survey technologies.

D. Detection of flaws

DT aids in detecting and protecting historic construction defects. D. Antón, (2018, [58]) investigated the precision of 3D modelling in the construction of historical building information models (HBIM) using point clouds, photographs, and the Rhino BIM software. DTs were utilised by G. Angjeliu (2020, [24]) to examine the structural system reaction, including preventative maintenance and potential strengthening actions, as well as the structural system integrity of historic masonry buildings. A. Mol, (2020, [59]) modelled, analysed, and stored geometric data, degradation levels, and timber structure material in a three-dimensional space using standard HBIM software, non-destructive testing, and geometric surveying. Ancient structures have fewer standard components. Thus, their digital twinning strategies may not apply to other historic structures, but the procedures are still helpful.

VIII. RESULTS AND DISCUSSION

Civil engineering and construction have consistently been integral to the growth and progress of societies, but they have not been without challenges. This study undertakes a thorough examination of the various ways the concept of digital twins is being applied in the construction industry. The exploration spanned critical areas including infrastructure construction, structural health monitoring, energy efficiency in buildings, seismic evaluation of buildings, safety of heritage buildings, and the diverse applications of digital twins in construction design, monitoring and management.

Beginning with the domain of infrastructure construction, the paper explained the issues of time and cost overruns, safety management and operation and maintenance. By integrating information from tunnel construction from multiple sources into an automated platform for safety management and early warning, DT technology provides a specific approach to addressing these issues (Z.). Ye, 2023, [2]) is an effective and precise way to track earthwork programmes in big infrastructure projects (Rogage et al., 2022, [9]) and a method for systematic digital twinning of extant old highways (J. Feng, 2022, [52]). In the area of structural health monitoring, where the accurate prediction of long-term performance and material degradation is crucial, DT technology is ideal for rapid inspections, both for routine maintenance and in response to natural disasters, to detect cracks (B. G. Pantoja-Rosero, 2023, [3]).

Energy efficiency in buildings is not just an economic concern but a pressing environmental one. This paper highlights the challenges associated with implementing energy-efficient practices. It demonstrates how DT can help improve energy efficiency and occupant comfort, as well as classify the operational energy performance of buildings (A. Clausen, 2021, [4]; P. Spūdys, 2023,). Furthermore, the importance of seismic evaluation of buildings cannot be understated, especially for earthquake-prone regions. While conventional techniques have made significant progress, the integration of digital twins offers an advanced layer of predictive analytics, potentially saving countless lives by ensuring structures comply with seismic standards (F. Mokhtari, 2023, [5]). Preserving the past for future generations is a responsibility of the current generation. In the context of heritage building safety, digital twins can be game changers. By creating virtual replicas of these historic structures, restorative measures can be planned meticulously, ensuring their longevity while maintaining historical essence (A. Shabani, 2022, [6]; M. G. Gomes, 2023,). Lastly, this paper provided an extensive overview of digital twins in construction design, monitoring, and management. From planning to dismantling, the entire construction lifecycle can benefit immensely from this technology. Virtual replicas enable professionals to monitor progress, manage resources more efficiently, and even plan the eventual dismantling or renovation of structures.

A. Theoretical and Practical Implications

From a theoretical perspective, this review highlights the importance of integrating modern technological advancements, such as digital twins, into traditional civil engineering and construction research. It calls for an interdisciplinary approach, where computer science, data analytics, and engineering unite to pave the way for a new era of construction. The practical implications are manifold. First, this review serves as a comprehensive guide for professionals, offering them a consolidated source of knowledge. With the challenges in the construction industry being complex, having insights into how digital twins can provide solutions is invaluable. By leveraging this technology, professionals can not only ensure efficiency but also sustainability, a concern that is becoming increasingly critical in today's world.

IX. CONCLUSION

To conclude, the integration of digital twins in the civil engineering and construction domain stands as a testament to how technological advancements can reshape industries.

Through this comprehensive review, it becomes abundantly clear that the future of construction lies in the harmonious melding of traditional practices with modern innovations. By embracing the potential of digital twins, we are not only looking at a more efficient and sustainable future, but also one that is safer and more inclusive.

DECLARATION STATEMENT

Funding/ Grants/ Financial Support	Yes, received research funding from the Ministry of Education and Culture, Research and Technology of the Republic of Indonesia.
Conflicts of interest	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, this article does not require ethical approval or consent to participate, as it is based on evidence.
Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	I am the sole author of the article.

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