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Review Article

Digital Twins in the Construction Industry for Continuous Process Improvement: A Systematic Literature Review

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Abstract *- This systematic literature review analyzes fifty peer-reviewed studies that address the use of digital twin technology in the construction industry. The objective of the review is to examine how digital twins contribute to process improvement and productivity enhancement when compared with conventional monitoring and control approaches. The study selection process was conducted using the PRISMA methodology, supported by the PICOC framework, and focused on publications indexed in the Scopus database. The analyzed literature reports that the implementation of digital twins enables measurable gains in operational productivity-frequently reported at around 30%-and contributes to error reduction on construction sites through real-time data integration, advanced simulation models, and data-informed decision-making. Despite these reported benefits, adoption in the construction sector remains limited. Common barriers identified include insufficient digital competencies, regulatory and organizational constraints, and the complexity associated with managing large volumes of heterogeneous data. Based on the reviewed evidence, this study highlights the need for coordinated digital transformation strategies, greater interoperability with technologies such as Building Information Modeling (BIM) and cyber-physical systems, and clearer implementation guidelines to strengthen the role of digital twins as a practical and sustainable tool within construction processes.*

Keywords *- Construction industry, Digital twin, Productivity, Continuous improvement, Technology.*

1. Introduction

The last decade has seen significant progress in construction project applications of technologies such as digital twinning in the context of digital transformation. This system, which acts as a virtual representation of the physical structure, enables real-time monitoring and performance evaluation [1]. In addition, more than 40 academic studies have been examined and validated, identifying six main application areas: building information modeling (BIM), resource management, logistics operations, energy simulation, structural monitoring, and maintenance management [1, 2]. Research shows that the implementation and development of digital twins can improve operational efficiency by about 30% and reduce operational errors by up to 25%, mainly due to the ability to consistently and accurately transmit data [3]. At the same time, construction projects need to systematically improve efficiency, quality, and performance metrics to achieve continuous improvement and increase productivity [3]. However, they still face several challenges, such as manual guidance, human error, lack of automation, and limited digital integration [3, 5]. In this regard, research shows that about 59% of project managers rely on manually collected, incomplete, and untimely data, and 65% miss potential project changes due to delays and unreliable data sources, resulting in biased data interpretation in decisions [4]. More than 40 case studies of digital twin technology applications have been documented to overcome these shortcomings, aimed at improving transparency, coordination, and control of projects across the industry [1]. Recent studies report 34 key organizational and technical barriers affecting the implementation of digital twins in construction, with data governance and workforce training emerging as the most persistent challenges [4, 5]. Despite these limitations, digital twins are increasingly recognized as a transformative mechanism that enables real-time process visibility and supports evidence-based decision-making, leading to improvements in design coordination and project control [5]. Their capacity to integrate with Building Information Modeling (BIM) and cyber-physical systems, together with the growing need for digital skills among construction professionals, positions digital twins as a relevant competitive asset for the sector [3]. Although previous literature reviews have successfully outlined the technological scope and application areas of Digital Twins (DTs) in the construction sector [1, 3-5], an important research gap remains unresolved. Most prior studies do not incorporate a quantitative or comparative approach that allows a systematic assessment of the efficiency improvements attributed to DTs in relation to conventional monitoring and management methods. In addition, the reported evidence is frequently fragmented, as it is confined to isolated application domains such as structural health monitoring or energy management and rarely considers organizational and human factors, which are decisive for large-scale implementation.

In response to these limitations, this systematic literature review presents an integrated analysis that: (i) consolidates and quantitatively examines performance indicators reported in empirical studies (for example, efficiency improvements of approximately 30% and error reductions close to 25%); (ii) applies the PICOC framework to enable a structured comparison between DT-based solutions and traditional process improvement practices; and (iii) discusses technical, data-related, and organizational constraints within a unified analytical framework, with the aim of identifying practical pathways to support successful adoption. Consequently, this review extends beyond a descriptive inventory of applications and offers a critical evaluation of the real impact and practical feasibility of DTs as instruments for continuous improvement in the construction industry.

The remainder of this paper is structured as follows. Section 2 describes the research methodology, including the formulation of research questions using the PICOC framework, the definition of inclusion and exclusion criteria, and the study selection process guided by PRISMA guidelines. Section 3 presents the main findings derived from the analysis of the selected studies.

2. Methodology

This SLR was conducted following the PRISMA protocol to ensure a complete and accurate presentation of procedures and findings [6]. Thus, the PICOC research question (Problem, Intervention, Comparison, Results, and Context) was formulated based on this; complementary questions were formulated, and the keywords used to construct the Scopus search equation were identified.

2.1. PICOC Question and Its Components

To guide this systematic literature review, a research question was formulated according to the PICOC approach, allowing a precise delineation of the key elements of the study. The research question is presented below:

QP: What digital twin applications have been developed in the construction industry to replace traditional monitoring methods and help address low productivity?

Likewise, the components of the PICOC model that structure the research question are detailed in Table 1, allowing a clear and focused approach to the analysis of those digital twin applications in the construction industry.

Table 1. PICOC components

P	I	C	O	C
Problem	**Intervention**	**Comparison**	**Results**	**Context**
Low Productivity	Implementation of digital twins	Traditional manual monitoring methods	Improved productivity and decision-making	Construction industry

In this regard, the following complementary questions are presented:

- Q1: What is the current state of productivity in the construction industry?
- Q2: What specific uses of digital twins have been developed?
- Q3: What differences exist between digital twins and traditional manual control methods?
- Q4: What benefits have been reported after implementing these technologies, and what limitations have they presented?
- Q5: What studies have been conducted in the construction industry, and with which populations or units of analysis?

2.2. Relevant Specialized Keywords

Below are the standardized keywords in English for each field of the PICOC method (see Table 2), seeking to use these keywords to help reach a larger information base in order to answer the research question.

Table 2. Keywords

P	Low productivity, inefficiency, manual processes, and digital integration
I	Digital twin, BIM integration, real-time monitoring, predictive maintenance, cyber-physical systems
C	Traditional monitoring, manual inspection, analog methods, and non-digital control
O	Improved productivity, operational efficiency, cost reduction, error reduction, sustainability, and decision-making
C	Construction industry, building sector, infrastructure projects, civil engineering

2.3. Scopus Search Equation

For this database, the five PICOC components were incorporated using Boolean operators (OR, AND), truncation (*), and quotation marks (“ ”) were used, thus obtaining the following equation:

("productivit*" OR "efficien*" OR "decision making") AND ("digital twin*") AND ("construction*" OR "infrastructure" OR "building*") AND ("continuous improvement" OR "optim*") AND ("visuali*" OR "traditional method*")

2.4. Inclusion and Exclusion Criteria

The selection criteria were defined to ensure that the reviewed studies offered relevant, recent, and verifiable evidence on the application of digital twins in the construction sector.

Only journal articles and review papers were considered. These works had to deal with productivity issues in construction and include a clear application of digital twins, supported by numerical results and a comparison with traditional or manual control methods.

Studies not directly related to the construction sector were excluded from the review. Likewise, conference proceedings, academic theses, and non-indexed sources were not considered. Only publications written in English or Spanish and released from 2020 onward were retained, in order to concentrate the analysis on recent studies supported by verifiable data.

2.5. Selection Process

Articles were selected using the PRISMA methodology. Initially, 6,702 records were retrieved. Subsequently, in the first screening stage, 3,120 records were eliminated from excluded records, leaving 2,952 records for review. 1,852 records from unretrieved publications were eliminated, leaving 1,100 records.

Of these, 95 records were discarded under Reason 1 (R1) records were discarded for not addressing productivity in the construction industry; 60 records were excluded under Reason 2 (R2) for not describing the applications of digital twins; 93 records were removed under Reason 3 (R3) did not clearly report statistical results from the application of these methods; 46 records were excluded under Reason 4 (R4)because they were not developed in construction industry settings; 67 records were discarded under Reason 5 (R5)did not specifically describe the difference in the use of traditional manual control methods; 242 records were excluded under Reason 6 (R6) were not original articles or reviews; 79 records were removed under Reason 7 (R7) were documents in languages other than English and Spanish; and 367 records were excluded under Reason 8 (R8) were documents published before 2020. Finally, 50 articles relevant to the research topic were selected.

In this sense, a step-by-step graphic representation of this PRISMA methodology was created, visually, as shown in Figure 1 below:

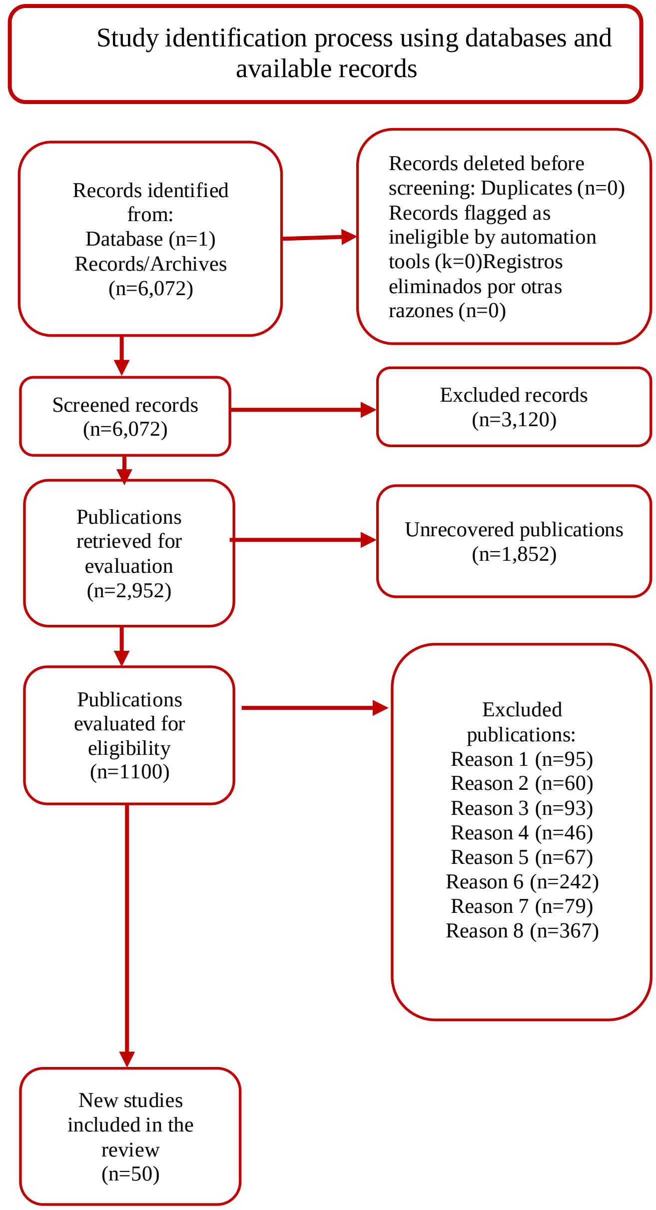

Fig. 1 PRISMA methodology

3. Results

The analysis considered a total of 50 publications. Of these, 38 were published in 2025 and the remaining 12 between 2021 and 2024, reflecting a strong emphasis on recent research related to digital twins in the construction sector. The selected works include both empirical studies and systematic reviews, covering a range of methodological perspectives.

For example, Figure 2 shows the classification of the documents studied according to their type. These articles were selected based on systematic reviews of research areas [7-9, 15-21, 33, 37-43], while articles [2, 10-14, 22-32, 34-36, 44-55]. Therefore, information exchange between twin products is a suitable basis for implementing digital twin impact tests in real construction scenarios.

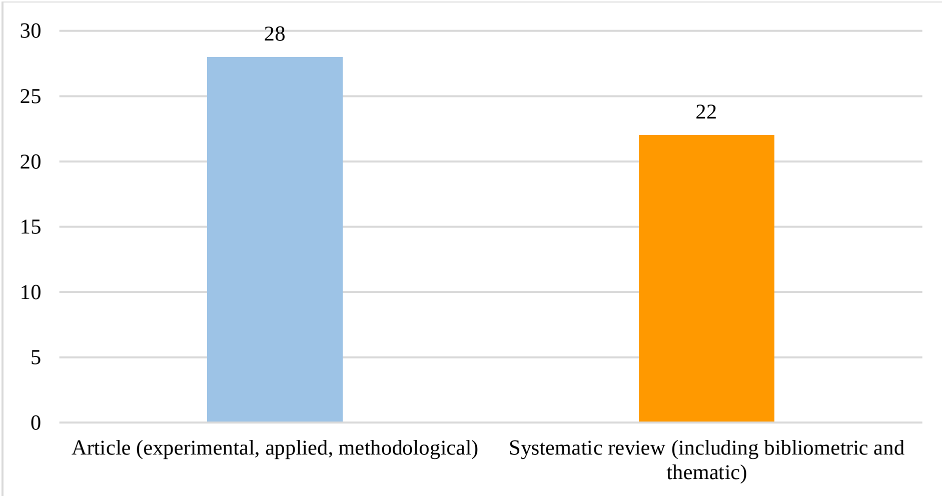

Fig. 2 Type of scientific studies

3.1. Current Status of Productivity in the Construction Industry

The analysis of the fifty reviewed documents reveals the current state of productivity in the construction sector. In this regard, some studies offer explicit definitions, while others link it to operational or energy efficiency, or, failing that, to the reduction of time and costs. Thus, this variability reflects the lack of consensus in understanding, although there is a tendency to understand it as part of the overall efficiency of the construction environment.

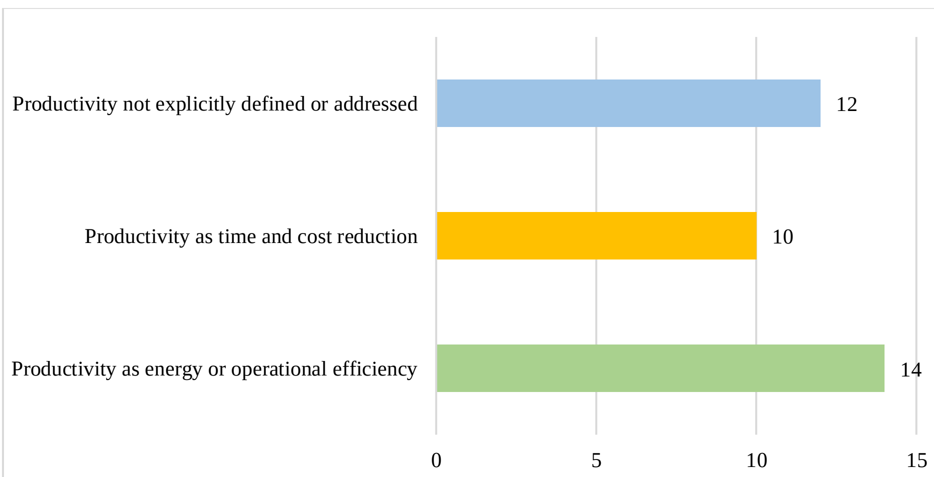

Fig. 3 Interpretation of productivity in the analyzed studies

In Figure 3, the main factors that negatively impact productivity are related to the lack of digital integration [7, 24, 32], the poor interoperability between platforms [13, 15, 29, 38] and the persistence of manual processes and disconnected data [23, 25, 27, 39].

These limitations have common consequences, such as delay in schedules, increase in operating costs, low energy sustainability, and failures in structural accuracy, as observed in articles [9, 11, 20, 30, 33, 34, 36, 41].

3.2. Specific Uses of Digital Twins in Construction

Digital twins have been used in various construction contexts, reflecting a range of uses that include predictive maintenance, visualization, environmental monitoring, and urban planning, among others [10-42]. Accordingly, Figure 4 classifies the studies according to the identified applications. Of the total reviewed studies (see Table 3), 25% focus on predictive maintenance, with articles such as [21, 22, 26, 30, 32-34, 36, 42] standing out.

This is followed by energy optimization with 22.2%, as in [14, 23, 25, 29, 31, 35, 38, 40]. Advanced visualization and inspection represent 19.4% of the cases ([13, 15, 17, 20, 27, 30, 41]), while urban planning [10, 18, 19, 24, 28, 39] and complementary applications [11, 12, 16, 22, 34, 36] each cover 16.7%.

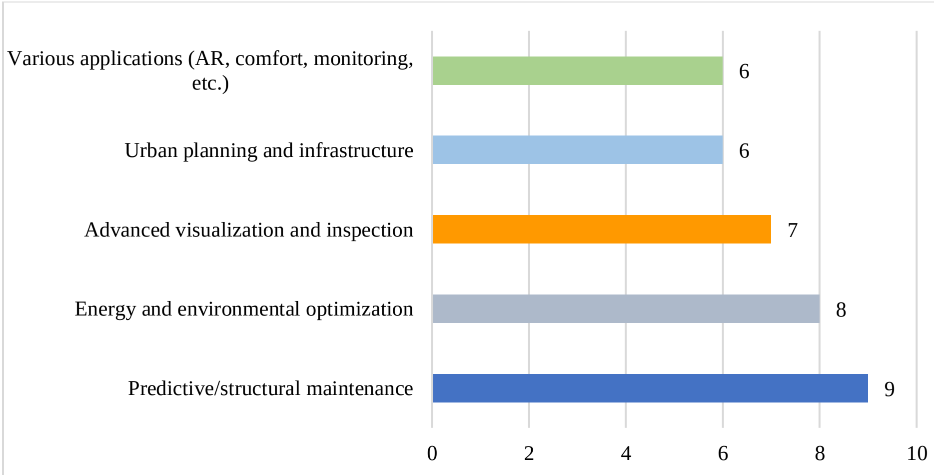

Fig. 4 Categories of use of digital twins

Table 3. Percentage by type of scientific studies

Category of Use	Percentage (%)
Predictive/Structural Maintenance	25.0%
Energy and Environmental Optimization	22.2%
Advanced Visualization and Inspection	19.4%
Urban Planning and Infrastructure	16.7%
Miscellaneous Applications	16.7%

3.3. Contrast with Traditional Methods

Moreover, the studies also show an explicit comparison between the use of digital twins and traditional methods. Among the main ones (see Figure 5), some cases, such as [7, 13, 15, 17, 30, 31, 39, 40], still employ analog approaches, while others report a transition toward more integrated and predictive digital tools [12, 20, 22, 26, 28, 29, 33, 35, 41].

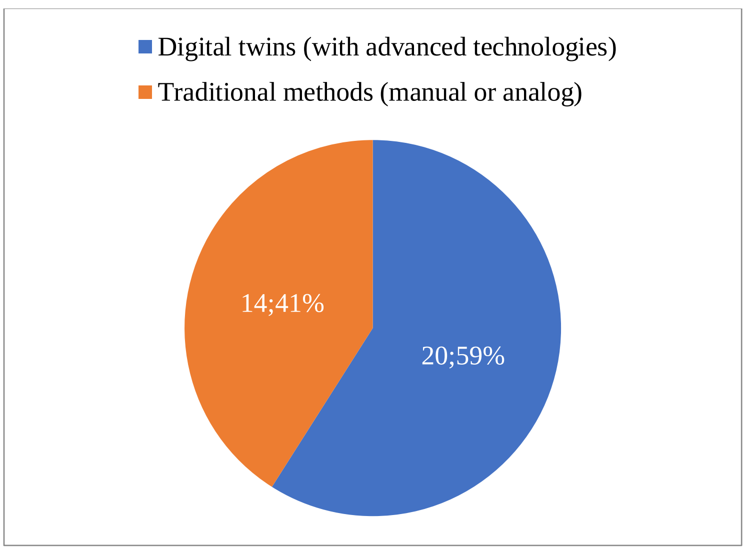

Fig. 5 Types of tools used in the studies

This review found that 59% (20 papers) of the reviewed studies initially used numerical blinding methods, while 41% (14 papers) relied on traditional methods. This change has been shown to increase knowledge, and studies using historical data have shown that their performance has improved [22, 26, 35].

3.4. Benefits and Limitations of Implementation

Several studies have documented the benefits of creating and deploying digital twins, such as the effects on teams' planning, maintenance, and sustainability [9-42]. Figure 6 illustrates these concepts. The benefits of implementing digital twins in construction are widely reflected in various technical and operational aspects.

Project planning and control is the most frequent category, representing 36.4% of the analyzed studies ([7, 9, 11, 12, 14, 16, 18, 20, 22, 23, 25, 27, 29, 31, 33, 35]). Secondly, resource, time and energy savings were identified in 29.5% of the cases ([8, 10, 13, 17, 19, 21, 26, 28, 30, 32, 34, 37, 38]). For its part, the optimization of production processes appears in 20.5% of the studies ([15, 24, 36, 39, 40, 41, 43, 45, 46]).

Finally, an increase in sustainability was identified in 13.6% ([2, 42, 44, 48-50]), demonstrating a growing interest in environmental efficiency through digital technologies.

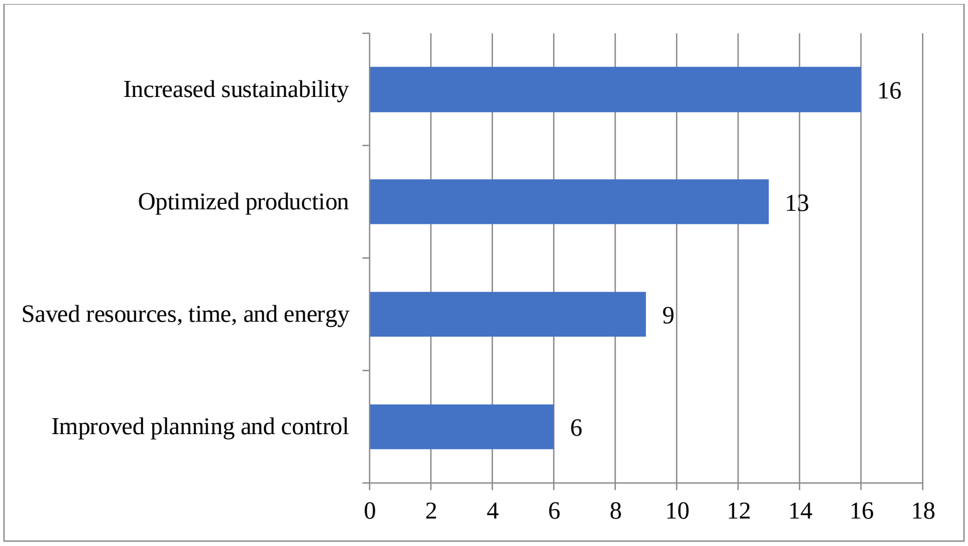

Fig. 6 Type of benefit achieved

Table 4. Percentage by Type of Benefit Achieved

Type of benefit achieved	Percentage (%)
Improved planning and control	36.4%
Saved resources, time, and energy	29.5%
Optimized production	20.5%
Increased sustainability	13.6%

3.5. Units of Analysis in the Studies Reviewed

Three predominant units of analysis were identified in the reviewed articles: constructed infrastructure, industry professionals, and digital systems or integrated sensors. The frequency with which these categories appear is summarized in Figure 7.

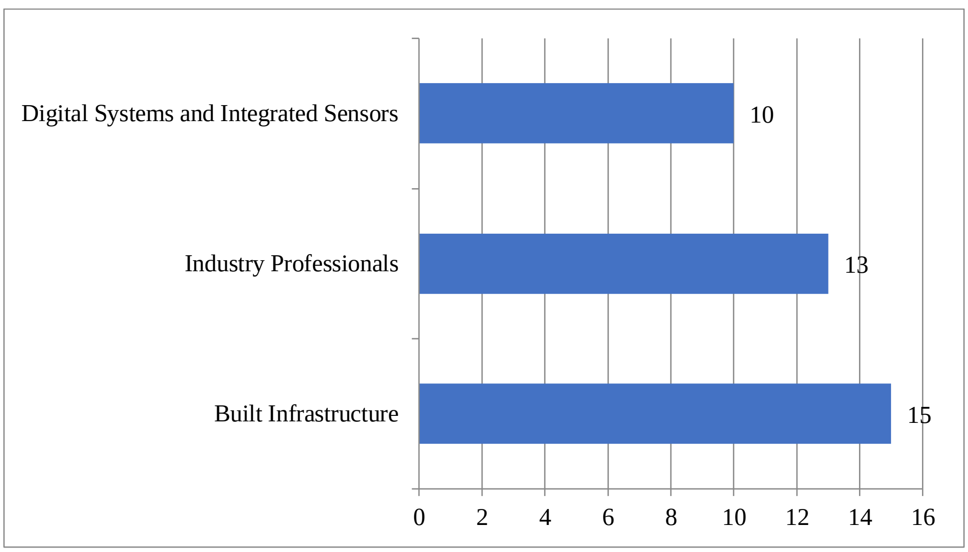

Fig. 7 Type of benefit achieved

Studies that address built infrastructure as a unit of analysis include [7, 9, 11, 14, 16, 18, 20, 23, 25, 28, 30, 32, 34, 36, 38]. On the other hand, [8, 10, 12, 15, 19, 21, 24, 27, 29, 31, 33, 35, 37] consider industry professionals. Finally, [13, 17, 22, 26, 39, 40, 41, 42, 43, 44] focus on digital systems or sensors. In proportional terms, the percentages associated with each unit of analysis are presented in Table 5.

Table 5. Percentage of units under analysis

Primary Unit of Analysis	Percentage (%)
Built Infrastructure	39.5 %
Industry Professionals	34.2 %
Digital Systems and Integrated Sensors	26.3 %

4. Discussions

This review compiles evidence from fifty peer-reviewed studies to explore how Digital Twins are being used to support continuous improvement in the construction industry. Overall, the results do not point to a disruptive technological shift.

Instead of showing a disruptive change, the results describe a sector where digital tools are being introduced slowly and with caution. In many situations, the decision to use Digital Twins is linked to immediate operational problems rather than to long-term digital strategies. At the same time, several limitations are still present. These include internal organizational issues, differences in workforce skills, and problems related to data access and quality. The following sections discuss these aspects in relation to previous studies and consider what they mean for practical application and future research.

4.1. Selective Adoption and Domain-Specific Value

Figure 4 indicates that digital twins in construction are mainly applied to a narrow range of use cases, especially predictive maintenance and energy management, where problems are clearly identified, and results can be verified with relative ease.

This pattern reflects the project-based nature of construction, where digital twins are mainly adopted to support short-term, site-specific tasks such as scheduling, monitoring, and resource management, while their use in urban-scale applications or long-term strategic planning remains limited.

4.2. The Pace of Transformation: Incremental Integration over Disruption

The results indicate that a change in the construction sector is occurring progressively rather than through a sudden transformation. As shown in Figure 5, digital twin solutions are often used alongside conventional practices, which remain part of everyday operations instead of being fully replaced.

This pattern is largely explained by practical conditions within organizations, such as the level of digital readiness, workforce skills, and reliance on established routines. Construction activities are commonly spread across multiple subcontractors and geographically separated sites, making uniform digital workflows difficult to implement and sustain.

4.3. Resolving Contradictions: Data Access versus Reported Efficacy

The literature highlights a gap between the efficiency gains reported in research and the data constraints found in construction practice. Sensor-based studies often show clear improvements, while organizational analyses point to fragmented data, interpretation difficulties, and limited trust in digital outputs, issues that are intensified by the temporary and multi-stakeholder nature of construction projects.

4.4. Implications and Future Pathways

- The results indicate that broader adoption of digital twins in construction depends on both technical integration and organizational practice. While interoperability with BIM and existing systems is required, it alone does not address the operational challenges encountered on site.
- Equally important is the way digital information is integrated into daily on-site decisions and work practices. Future studies should therefore focus on long-term case analyses that consider organizational adaptation, user involvement, and implementation costs, in order to better understand how digital twins can be sustainably embedded in regular construction operations.

5. Conclusion

A review of recent studies indicates that digital twins are increasingly used in the construction sector to address supply chain constraints and to overcome limitations associated with conventional management approaches. It is clear that real-time data acquisition accurately represents the physical location, which can save between 30% and 25%. It was found that 59% of data collectors reported fragmentation due to manual work. 65% of those who accessed the system reported a change in status. This is because the data can be used to identify and analyze the potential impact of digital twins. The primary uses of digital twins are data modeling, facility management, electrical modeling, equipment maintenance and upkeep, with the greatest impact on planning, technical knowledge, weather data maintenance, and employee training.

A variety of engineering tools for the first time, including twin engineering, BIM techniques, and engineering physics. We propose a hybrid approach for the analysis, combining traditional methods with digital twins to achieve a fully digital approach. Connecting twins and maximizing real-time monitoring is the best way to eliminate traditional tools on complex or highly complex projects.

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References

[1] De-Graft Joe Opoku et al., "Digital Twin Application in the Construction Industry: A Literature Review," *Journal of Building Engineering*, vol. 40, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[2] Abiola A. Akanmu, Chimay J. Anumba, and Omobolanle O. Ogunseiju, "Towards Next Generation Cyber-Physical Systems and Digital Twins for Construction," *Journal of Information Technology in Construction*, vol. 26, pp. 505-525, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[3] Tran Duong Nguyen, and Sanjeev Adhikari, "The Role of BIM in Integrating Digital Twin in Building Construction: A Literature Review," *Sustainability*, vol. 15, no. 13, pp. 1-26, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[4] Ashtarout Ammar et al., "Digital Twins in the Construction Industry: A Perspective of Practitioners and Building Authority," *Frontiers in Built Environment*, vol. 8, pp. 1-23, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[5] Pedro Mêda et al., "Incremental Digital Twin Conceptualisations Targeting Data-Driven Circular Construction," *Buildings*, vol. 11, no. 11, pp. 1-27, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[6] Matthew J. Page, "The PRISMA 2020 Statement: An Updated Guideline for Reporting Systematic Reviews," *Rev Panam Salud Publica*, vol. 46, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[7] Yang Wen, and Fangliang Yu, "Construction of Wireless Underground Footwork Mobile Training and Monitoring Sensor Network in Venues of Major Sports Events," *Journal of Sensors*, vol. 2021, no. 1, pp. 1-11, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[8] Gaoyang Liang, Peng Cao, and Yang Liu, "Optimization and Simulation of Labor Resource Management Information Platform based on Internet of Things," *Wireless Communications and Mobile Computing*, vol. 2021, no. 1, pp. 1-11, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[9] John N. Hodul et al., "Poly(5-Carboxyindole)-β-Cyclodextrin Composite Material for Enhanced Formaldehyde Gas Sensing," *Journal of Materials Science*, vol. 57, no. 24, pp. 11460-11474, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[10] Menglong Li et al., "Establishment of Web-Based Digital Twin System for Truss Gantry Crane," *IEEE Access*, vol. 11, pp. 146282-146296, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[11] Mohammadali Farahpoor, Oscar Esparza, and Miguel C. Soriano, "Comprehensive IoT-Driven Fleet Management System for Industrial Vehicles," *IEEE Access*, vol. 12, pp. 193429-193444, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[12] Jinqiang Bi et al., "Research on the Construction of a Digital Twin System for the Long-Term Service Monitoring of Port Terminals," *Journal of Marine Science and Engineering*, vol. 12, no. 7, pp. 1-16, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[13] Haksun Kim et al., "Bluetooth Load-Cell-Based Support-Monitoring System for Safety Management at a Construction Site," *Sensors*, vol. 22, no. 10, pp. 1-29, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[14] G.S. Arun Kumar et al., "A Comprehensive Approach to Real-time Site Monitoring and Risk Assessment in Construction Settings using Internet of Things and Artificial Intelligence," *SSRG International Journal of Electrical and Electronics Engineering*, vol. 10, no. 8, pp. 112-126, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[15] Bin Yang et al., "Semantic Segmentation-Based Framework for Concrete Pouring Progress Monitoring using Multiple Surveillance Cameras," *Developments in the Built Environment*, vol. 16, pp. 1-16, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[16] Yogesh Gautam, and Houtan Jebelli, "Autoencoder-Based Photoplethysmography Signal Reliability Enhancement in Construction Health Monitoring," *Automation in Construction*, vol. 165, pp. 1-14, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[17] Douglas Nascimento et al., "Current Sensor Optimization based on Simulated Transfer Function under Partial Discharge Pulses," *Sensors and Actuators A: Physical*, vol. 329, pp. 1-10, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[18] Łukasz Bednarski et al., "New Hydraulic Sensor for Distributed and Automated Displacement Measurements with Temperature Compensation System," *Sensors*, vol. 21, no. 14, pp. 1-20, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[19] Piotr Sowiński et al., "Frugal Heart Rate Correction Method for Scalable Health and Safety Monitoring in Construction Sites," *Sensors*, vol. 23, no. 14, pp. 1-19, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[20] Rajitha Ranasinghe, Arooran Sounthararajah, and Jayantha Kodikara, "An Intelligent Compaction Analyzer: A Versatile Platform for Real-Time Recording, Monitoring, and Analyzing of Road Material Compaction," *Sensors*, vol. 23, no. 17, pp. 1-24, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[21] Song Shi et al., "Recognition System of Human Fatigue State based on Hip Gait Information in Gait Patterns," *Electronics*, vol. 11, no. 21, pp. 1-11, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[22] Jing Hung Chan, and Chee Yong Lau, "Enhancement of Jaibot: Developing Safety and Monitoring Features for Jaibot using IoT Technologies," *International Journal of Technology*, vol. 14, no. 6, pp. 1309-1319, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[23] Aydin Jadidi et al., "Beam Offset Detection in Laser Stake Welding of Tee Joints using Machine Learning and Spectrometer Measurements," *Sensors*, vol. 22, no. 10, pp. 1-15, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[24] Cheng Chang et al., "Rapid Quality Control for Recycled Coarse Aggregates (RCA) Streams: Multi-Sensor Integration for Advanced Contaminant Detection," *Computers in Industry*, vol. 164, pp. 1-14, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[25] Wenping Wu, and Biao Lu, "Construction of Wireless Sensor Network Video Surveillance System for Multimedia Classroom Education and Teaching under 5G Communication Network," *Journal of Sensors*, vol. 2022, pp. 1-12, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[26] Celso O. Barcelos et al., "Integration of Payload Sensors to Enhance UAV-Based Spraying," *Drones*, vol. 8, no. 9, pp. 1-12, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[27] Namhoon Ha, Han-Seung Lee, and Songjun Lee, "Development of a Wireless Corrosion Detection System for Steel-Framed Structures using Pulsed Eddy Currents," *Sensors*, vol. 21, no. 24, pp. 1-12, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[28] Tiago Rabelo Chaves et al., "Application Study in the Field of Solutions for the Monitoring Distribution Transformers of the Overhead Power Grid," *Energies*, vol. 14, no. 19, pp. 1-15, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[29] Lauren C. Tindale et al., "Wearable Biosensors in the Workplace: Perceptions and Perspectives," *Frontiers in Digital Health*, vol. 4, pp. 1-11, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[30] Mohammadali Khazen, Mazdak Nik-Bakht, and Osama Moselhi, "Monitoring Workers on Indoor Construction Sites using Data Fusion of Real-Time Worker's Location, Body Orientation, and Productivity State," *Automation in Construction*, vol. 160, pp. 1-21, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[31] Caterina Amici et al., "Framework for Computerizing the Processes of a Job and Automating the Operational Management on Site-A Case Study of Demolition and Reconstruction Construction Site," *Buildings*, vol. 12, no. 6, pp. 1-17, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[32] Lu Zhang et al., "Characterization of Damage Progress in the Defective Grouted Sleeve Connection using Combined Acoustic Emission and Ultrasonics," *Sensors*, vol. 22, no. 21, pp. 1-18, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[33] Yelbek Utepov et al., "Performance of a Wireless Sensor Adopted in Monitoring of Concrete Strength," *International Journal of Geomate*, vol. 23, no. 95, pp. 73-80, 2022. [Google Scholar] [Publisher Link]

[34] Elham Mahamedi et al., "Automating Excavator Productivity Measurement using Deep Learning," *Proceedings of the Institution of Civil Engineers Smart Infrastructure and Construction*, vol. 174, no. 4, pp. 121-133, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[35] Tan Kai Noel Quah et al., "Real Time Assessment of Smart Concrete Inspection with Piezoelectric Sensors," *Electronics*, vol. 12, no. 18, pp. 1-22, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[36] Alireza Ansaripour et al., "ViPER+: Vehicle Pose Estimation using Ultra-Wideband Radios for Automated Construction Safety Monitoring," *Applied Sciences*, vol. 13, no. 3, pp. 1-20, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[37] Jianwei Wang et al., "A Tubular Flexible Triboelectric Nanogenerator with a Superhydrophobic Surface for Human Motion Detecting," *Sensors*, vol. 21, no. 11, pp. 1-11, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[38] Shubham Bhokare et al., "Smart Construction Scheduling Monitoring using YOLOv3-Based Activity Detection and Classification," *Journal of Information Technology in Construction*, vol. 27, pp. 240-252, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[39] Zhiming Ding et al., "An Internet of Things based Scalable Framework for Disaster Data Management," *Journal of Safety Science and Resilience*, vol. 3, no. 2, pp. 136-152, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[40] Chen Chen et al., "Investigation of Edge Computing in Computer Vision-Based Construction Resource Detection," *Buildings*, vol. 12, no. 12, pp. 1-12, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[41] Baydaa Hashim Mohammed et al., "Nexus between Building Information Modeling and Internet of Things in the Construction Industries," *Applied Sciences*, vol. 12, no. 20, pp. 1-22, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[42] M. Chen, and Alfredo I. Hernández, "Towards an Explainable Model for Sepsis Detection based on Sensitivity Analysis," *IRBM*, vol. 43, no. 1, pp. 75-86, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[43] Tushar Bansal et al., "Embedded Piezo-Sensor-Based Automatic Performance Monitoring of Chloride-Induced Corrosion in Alkali-Activated Concrete," *Sustainability*, vol. 14, no. 19, pp. 1-15, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[44] Anastasios Drougkas et al., "Design of a Smart Lime Mortar with Conductive Micro and Nano Fillers for Structural Health Monitoring," *Construction and Building Materials*, vol. 367, pp. 1-11, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[45] Harrison Fugate, and Hani Alzraiee, "Quantitative Analysis of Construction Labor Acceptance of Wearable Sensing Devices to Enhance Workers' Safety," *Results in Engineering*, vol. 17, pp. 1-8, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[46] Roshan Panahi et al., "Bottleneck Detection in Modular Construction Factories using Computer Vision," *Sensors*, vol. 23, no. 8, pp. 1-23, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[47] Min Deng, Carol C. Menassa, and Vineet R. Kamat, "From BIM to Digital Twins: A Systematic Review of the Evolution of Intelligent Building Representations in the AEC-FM Industry," *Journal of Information Technology in Construction*, vol. 26, pp. 58-83, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[48] Tae Wook Kang, and Yunjeong Mo, "A Comprehensive Digital Twin Framework for Building Environment Monitoring with Emphasis on Real-Time Data Connectivity and Predictability," *Developments in the Built Environment*, vol. 17, pp. 1-12, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[49] Kinzo Kishida et al., "Distributed Optical Fiber Sensors for Monitoring of Civil Engineering Structures," *Sensors*, vol. 22, no. 12, pp. 1-18, 2022. [CrossRef] [Google Scholar] [Publisher Link]
[50] Nabeeha Ehsan Mughal et al., "EEG-fNIRS-Based Hybrid Image Construction and Classification using CNN-LSTM," *Frontiers in Neurorobotics*, vol. 16, pp. 1-17, 2022. [CrossRef] [Google Scholar] [Publisher Link]
[51] Michele Scarpiniti et al., "Deep Belief Network based Audio Classification for Construction Sites Monitoring," *Expert Systems with Applications*, vol. 177, pp. 1-33, 2021. [CrossRef] [Google Scholar] [Publisher Link]
[52] Daigo Terutsuki et al., "Real-Time Odor Concentration and Direction Recognition for Efficient Odor Source Localization using a Small Bio-Hybrid Drone," *Sensors and Actuators B: Chemical*, vol. 339, pp. 1-10, 2021. [CrossRef] [Google Scholar] [Publisher Link]
[53] Zifeng Qiu, Huihui Bai, and Taoyi Chen, "Special Vehicle Detection from UAV Perspective via YOLO-GNS based Deep Learning Network," *Drones*, vol. 7, no. 2, pp. 1-18, 2023. [CrossRef] [Google Scholar] [Publisher Link]
[54] Yue Gong et al., "Wearable Acceleration-Based Action Recognition for Long-Term and Continuous Activity Analysis in Construction Site," *Journal of Building Engineering*, vol. 52, 2022. [CrossRef] [Google Scholar] [Publisher Link]
[55] Ruihan Bai et al., "Automated Construction Site Monitoring Based on Improved YOLOv8-seg Instance Segmentation Algorithm," *IEEE Access*, vol. 11, pp. 139082-139096, 2023. [CrossRef] [Google Scholar] [Publisher Link]