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DIGITAL TECHNOLOGIES IN CONSTRUCTION PROJECT MANAGEMENT

The construction industry represents one of the most complex and risk-intensive sectors of the global economy, significantly contributing to national Gross Domestic Product (GDP) while simultaneously facing persistent challenges such as budget overruns, schedule delays, low productivity, and fragmented decision-making processes. Large-scale and megaprojects, in particular, frequently exceed their initial budgets and timelines due to inaccurate cost estimation, insufficient planning, unclear project scopes, and the predominance of experience-based rather than data-driven managerial decisions. In this context, digital transformation has emerged not merely as an innovation trend but as a strategic necessity for improving efficiency, transparency, and risk management in construction project management. This study investigates the role and impact of four major digital technologies—Building Information Modeling (BIM), the Internet of Things (IoT), Artificial Intelligence (AI), and Digital Twin systems—within the lifecycle of construction projects. The research adopts a comprehensive analytical and literature-based approach, examining recent academic studies, industry reports, and global case examples to evaluate the effectiveness, implementation levels, and strategic contributions of these technologies. The findings indicate that BIM significantly enhances interdisciplinary coordination, conflict detection, visualization, sustainability analysis, and cost-time management, with the highest impact observed during early project phases where cost influence potential is greatest. IoT technologies contribute to real-time monitoring of safety conditions, environmental parameters, equipment performance, and resource utilization, thereby improving operational control and reducing on-site risks. Artificial Intelligence enables advanced data analytics, predictive modeling, and decision-support mechanisms, particularly when integrated with BIM and IoT platforms, although its adoption in construction remains comparatively limited due to data standardization and organizational barriers. Digital Twin systems extend beyond static modeling by establishing real-time synchronization between physical assets and digital replicas, allowing continuous lifecycle optimization and performance monitoring. The study concludes that the integrated application of BIM, IoT, AI, and Digital Twin technologies forms a synergistic digital ecosystem capable of transforming construction project management into a data-driven, predictive, and strategically optimized discipline. Despite existing challenges such as traditional management culture, fragmented data structures, and resistance to change, the adoption of digital technologies is essential for reducing project risks, improving productivity, and enhancing global competitiveness in the construction industry.

Keywords: Construction, Technology, BIM, IoT, AI, Digital Twin.

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ЦИФРОВІ ТЕХНОЛОГІЇ В УПРАВЛІННІ БУДІВЕЛЬНИМИ ПРОЄКТАМИ

Будівельна галузь є однією з найскладніших і найбільш ризикоємних сфер світової економіки, роблячи значний внесок у національний валовий внутрішній продукт (ВВП) та водночас стикаючись із постійними проблемами, такими як перевищення бюджету, затримки у виконанні графіків, низька продуктивність і фрагментованість процесів прийняття рішень. Великомасштабні проєкти та мегапроєкти особливо часто перевищують початкові бюджети й терміни реалізації через неточне оцінювання вартості, недостатнє планування, нечітке визначення обсягу робіт і переважання управлінських рішень, заснованих на досвіді, а не на даних. У цьому контексті цифрова трансформація постає не просто як інноваційна тенденція, а як стратегічна необхідність для підвищення ефективності, прозорості та якості управління ризиками в будівельних проєктах. У цьому дослідженні розглядається роль і вплив чотирьох ключових цифрових технологій – інформаційного моделювання будівель (BIM), Інтернету речей (IoT), штучного інтелекту (AI) та систем цифрових двійників – протягом усього життєвого циклу будівельного проєкту. Дослідження базується на комплексному аналітичному та оглядовому підході, що включає аналіз сучасних наукових публікацій, галузевих звітів і міжнародних практичних прикладів з метою оцінки ефективності, рівня впровадження та стратегічного внеску цих технологій. Отримані результати свідчать, що BIM суттєво покращує міждисциплінарну координацію, виявлення колізій, візуалізацію, аналіз сталості та управління вартістю й термінами, причому найбільший вплив спостерігається на ранніх етапах проєкту, коли потенціал впливу на витрати є найвищим. Технології IoT забезпечують моніторинг у реальному часі умов безпеки, параметрів довкілля, роботи обладнання та використання ресурсів, що сприяє підвищенню операційного контролю та зниженню ризиків на будівельному майданчику. Штучний інтелект дозволяє здійснювати розширену аналітику даних, прогнозне моделювання та підтримку прийняття рішень, особливо за умови інтеграції з платформами BIM і IoT, хоча його впровадження у будівництві залишається відносно обмеженим через проблеми стандартизації даних та організаційні бар’єри. Системи цифрових двійників виходять за межі статичного моделювання, забезпечуючи синхронізацію фізичних об’єктів із їхніми цифровими копіями в режимі реального часу, що дозволяє здійснювати безперервну оптимізацію життєвого циклу та моніторинг ефективності. У підсумку встановлено, що інтегроване застосування технологій BIM, IoT, AI та цифрових двійників формує синергетичну цифрову екосистему, здатну трансформувати управління будівельними проєктами у керовану даними, прогнозну та стратегічно оптимізовану систему. Незважаючи на наявні виклики, зокрема традиційну управлінську культуру, фрагментовані структури даних і опір змінам, впровадження цифрових технологій є необхідною умовою для зниження проєктних ризиків, підвищення продуктивності та зміцнення глобальної конкурентоспроможності будівельної галузі.

Ключові слова: будівництво, технології, BIM, IoT, штучний інтелект, цифровий двійник.

1. Introduction. The construction industry is a sector characterized by dynamic and complex procedures, the involvement of diverse resources and supply chains, the influence of external factors such as weather conditions, and the execution of unique, time-constrained projects [1]. Due to the participation of multiple engineering disciplines in the planning, design, construction, and management of projects, the construction sector can account for approximately 3–30% of a country’s Gross Domestic Product (GDP), depending on the scale of activities [2]. As buildings represent the primary output of this large-scale sector, the total global building floor area exceeded 260 billion square meters during 2023–2024 [3]. Considering that the majority of this share belongs to developed countries, the significant influence of the construction industry on the global economy becomes evident.

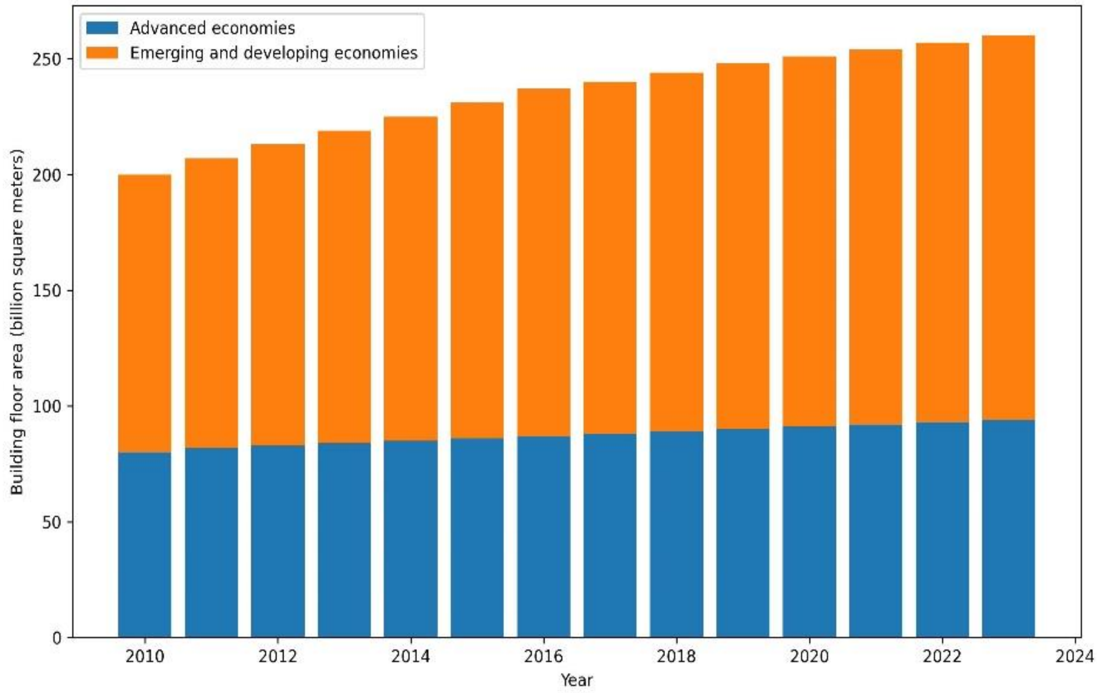

Fig.1. Building floor area vs Year [3]

On the other hand, projects executed within such a large-scale sector involve substantial risks. While a successful construction project is defined as one completed within the allocated budget, specified timeframe, and required quality standards, particularly large-scale projects often face high levels of risk throughout their lifecycle due to the complexity of management procedures. In many cases, these risks directly contribute to project failure. According to McKinsey analyses, cost overruns in megaprojects frequently reach up to 80% of the initial budget [4], meaning that a project planned with a budget of USD 1 billion may ultimately cost USD 1.8 billion. Additionally, such megaprojects are completed on average 20 months later than planned [4], which directly contributes to unsuccessful project outcomes.

Several key factors can be identified as the primary causes of construction project failure. Research indicates that inaccurate cost estimates, improper planning, unclear project scopes, and the lack of skilled labor are among the main reasons for unsuccessful project completion [5]. These factors may affect projects at different stages and with varying degrees of severity. Regardless of the specific cause, the common underlying reason for failure is the adoption of incorrect decisions by project managers. Decisions made without data-driven analysis and instead based solely on personal or corporate experience play a critical role in construction projects, and the execution of incorrect decisions directly impacts project success.

To minimize risks arising from human-related decision-making processes, the application of digital technologies has become a necessity in the construction sector. Although construction is traditionally considered a conservative industry, studies show that data-driven decision-making can reduce project budgets by 5–10% and improve planning efficiency by 10–20% [6]. Given the direct influence of cost and planning factors on project success, the adoption of modern trends such as data analytics has become inevitable. Moreover, digital technologies contribute positively to improving work quality, enabling tasks to be completed in shorter periods with lower energy and resource consumption [7]. Considering these factors, the application of digital technologies—particularly artificial intelligence, big data, and related modern tools—plays an indispensable role in reducing risks and increasing success rates in construction projects.

2. Digital Technologies in Construction Project Management

2.1. Building Information Modeling (BIM)

Building Information Modeling (BIM) is defined as a collaborative, interdisciplinary management approach that enables the systematic collection, coordination, and management of information throughout the entire lifecycle of a construction project, including planning, design, construction, operation, maintenance, and demolition [8]. Initially emerging as a concept in the 1970s and 1980s, BIM systems were first practically implemented in Hungary in 1982 through the ArchiCAD software. With the advancement of computer technologies in the 1990s, BIM adoption in real projects increased, reaching a significant milestone in 2000 with the introduction of Revit. BIM technology ensures transparent and efficient communication among architectural, structural, and MEP disciplines, allowing conflicts and inconsistencies to be identified and resolved before the construction phase begins [8].

Advantages of BIM technology	Peculiarity	Efficiency Increase
Conflict detection	Identifies potential conflicts prior to construction to reduce site modifications and rework	89.14%
Visualization and 3D modeling	Helps project managers intuitively understand the design and construction process	87.02%
Sustainability analysis	Supports analysis of building energy efficiency and sustainability factors	84.57%
Continuous updates/records	Constantly updated throughout the lifecycle to provide data for future management	83.21%
Cost and time management	Allows more accurate prediction of costs and timelines, optimizing resources	78.36%
Facility management	Helps maintenance and operations teams manage buildings efficiently	75.03%
Collaborative work	Promotes collaboration and improves communication efficiency	72.98%

Fig.2. The effect of BIM in the construction project management [9]

The results indicate that the highest efficiency improvement is observed in conflict detection (89.14%), enabling early identification of design clashes and reducing rework during construction. Visualization and 3D modeling (87.02%) and sustainability analysis (84.57%) support more intuitive and data-driven decision-making processes. Continuous data updates and records (83.21%) facilitate effective lifecycle management, while cost and time management (78.36%), facility management (75.03%), and enhanced collaboration (72.98%) highlight BIM's strategic value in optimizing resources and improving team coordination. Overall, these findings confirm that BIM systems serve as highly effective tools in construction project management.

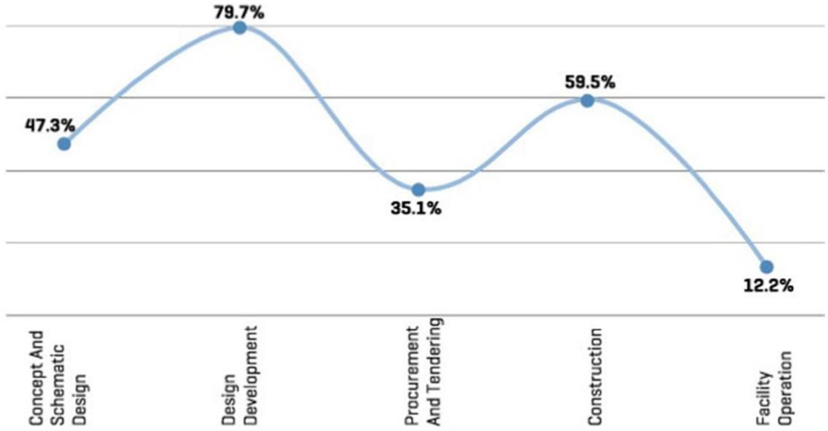

Fig.3. Effect of BIM in different construction stages [10]

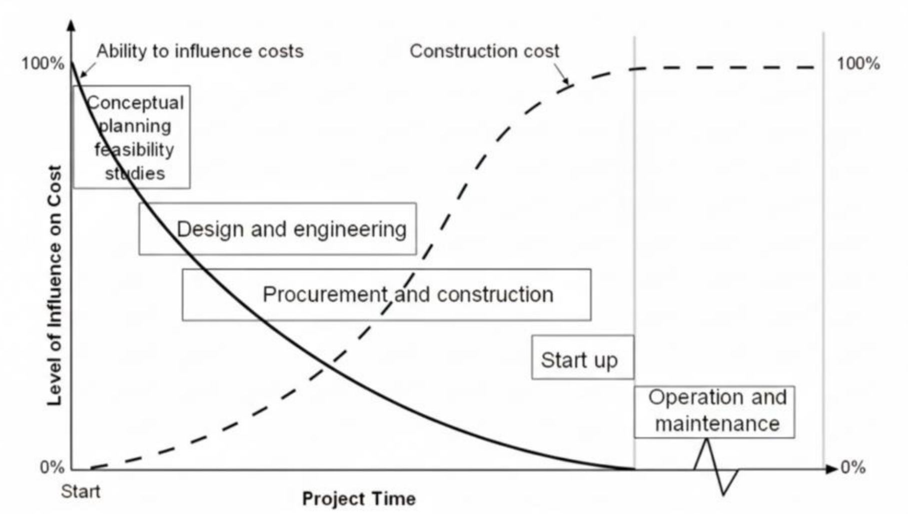

Fig.4. Ability to influence cost in project life-cycle [10]

The presented graphs reveal a direct relationship between BIM utilization across project stages and the ability to influence costs [10]. Figure 4 shows that BIM application reaches its peak during the design phase (79.7%) and declines to its minimum during the operation phase (12.2%), which strategically aligns with the cost influence curve shown in Figure 3. While cost-saving opportunities are highest during early project stages such as conceptual planning and design, they decrease significantly as construction progresses. Consequently, the high BIM adoption rate during design and engineering phases plays a critical role in protecting the overall project budget, whereas its limited use during operation indicates untapped potential for long-term cost optimization.

2.2. IoT

The Internet of Things (IoT) is a global network system that enables physical and digital objects to communicate through shared standards [11]. IoT systems, implemented through sensors, applications, and various tools, offer unique approaches to construction project management [12]. In one study, IoT sensors were deployed on an active construction site to monitor workers' use of Personal Protective Equipment (PPE). Workers entering hazardous zones without PPE were alerted through sensors, preventing potential accidents [13]. In another study, sensors installed in underground construction sites detected oxygen deficiency and toxic gas levels, triggering warning sirens to prevent accidents [14]. When integrated with BIM, IoT tools enable continuous site monitoring, real-time progress tracking, and data-driven decision-making. Given the critical nature of lifecycle decisions, IoT technologies hold vital importance in construction management. IoT technologies are now widely applied on a global scale, contributing significantly to project management efficiency. Figure 5 presents commonly used IoT systems in international construction projects.

Project / Case Study	Country / Company	Applied IoT Technology	Brief Description
Hudson Yards	USA (New York)	IoT sensors (HVAC, elevators, lighting)	Used to monitor energy efficiency and structural integrity of infrastructure components.
FIFA 2022 Stadiums	Qatar	Smart helmets and sensors	Real-time monitoring of workers' health and environmental conditions.
Volvo Electric Site	Sweden	Autonomous IoT sensor-equipped machinery	Monitoring equipment performance, fuel consumption, and maintenance requirements.
DPR Construction – Office	USA (San Francisco)	IoT sensors (lighting, temperature, humidity)	Optimizes energy consumption and indoor comfort levels within the office environment.
Crossrail (Elizabeth Line)	United Kingdom (London)	IoT sensor-based tunnel devices	Enables predictive maintenance by monitoring equipment conditions.
Procore IoT Platform	USA (New York)	Procore (IoT platform)	Monitoring equipment utilization, material logistics, and project communication.
Trimble Connect – Bridge Project	USA (Boston)	Trimble Connect IoT platform	Real-time monitoring of structural integrity.
Autodesk BIM 360 Project	USA (Chicago)	BIM–IoT integration	Combined use of IoT and BIM for subcontractor workflow and document management.
Fieldwire – Residential Construction	USA (Miami)	Fieldwire (IoT platform)	Monitoring work schedules, worker performance, and safety compliance.
Skanska UK – Drones + IoT	United Kingdom	IoT-enabled drones	Site monitoring, safety management, and resource optimization.
Kier Group – Asset Tracking	United Kingdom	IoT-based tracking system	Real-time tracking of equipment and materials.

Fig 5. IoT systems used in construction projects [15]

2.3. Artificial Intelligence

Artificial Intelligence (AI) refers to a set of advanced algorithms and systems that simulate human intelligence to analyze data, identify patterns, and automate decision-making processes [16]. First formalized as a scientific discipline at the Dartmouth Conference in 1956, AI demonstrated strategic reasoning capabilities in the late 1990s through IBM's Deep Blue chess computer. Since the 2010s, the rise of big data and neural networks has marked a renaissance in AI development [17]. The emergence of generative AI models, particularly those based on transformer architectures, has transformed AI from a purely analytical tool into an active participant in creative processes.

Despite the growing adoption of AI, the construction sector significantly lags behind other industries in implementing AI technologies within entrepreneurial systems. As illustrated in Figure 6, while information and communication sectors exhibit the highest AI adoption rates in 2025, construction ranks lowest [18]. This highlights the sector's reliance on traditional methods and suggests that AI integration could lead to transformative improvements.

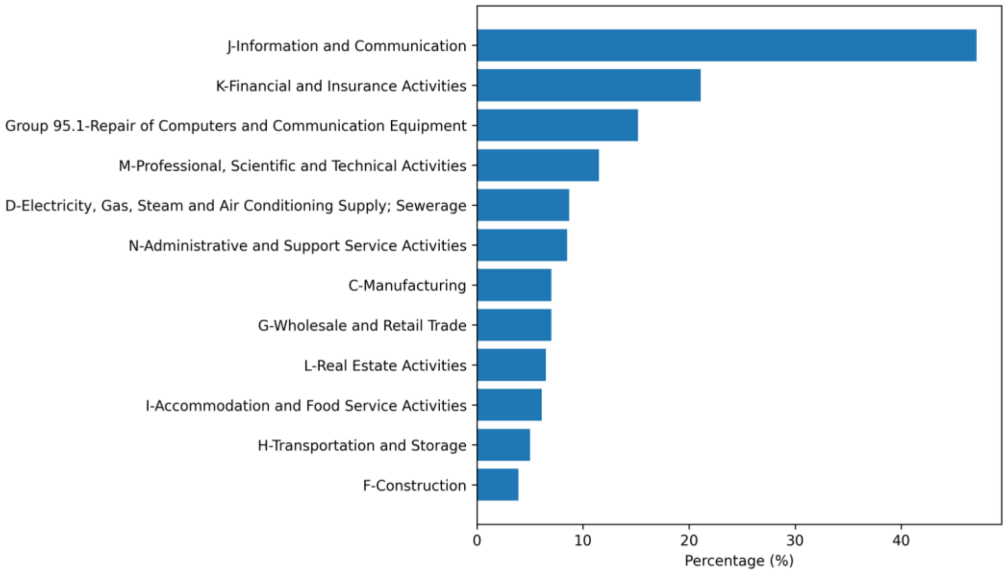

Fig 6. AI application statistics in entrepreneurship industries [18]

AI applications in construction have been explored across multiple disciplines, demonstrating benefits in project planning, cost estimation, site monitoring, and related areas [19]. Particularly when integrated with BIM, AI becomes a powerful tool; however, limitations arise due to non-standardized data, incomplete construction information, shortages of skilled personnel, and organizational resistance. In the future, overcoming these barriers through the combined application of BIM, IoT, and AI may enable AI systems to become reliable partners across nearly all phases of construction projects, especially as effective tools for project managers.

2.4. Digital Twin

Digital Twin technology represents a living, continuously evolving digital replica of a physical construction project, moving beyond static BIM models and synchronizing with real-world conditions in real time [20]. A digital twin consists of three core components: the physical object, its digital counterpart, and the data streams connecting them.

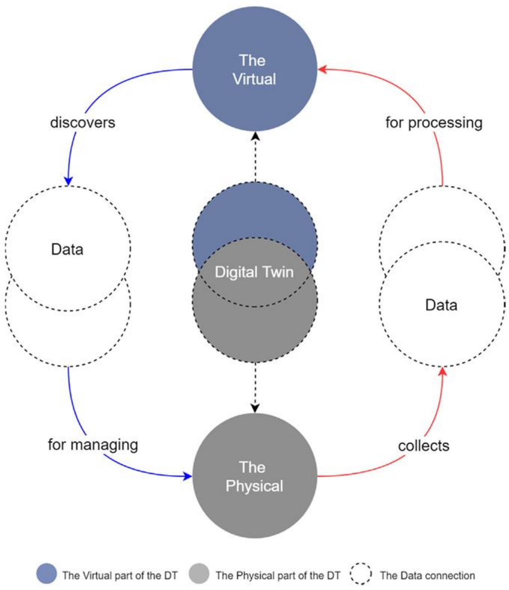

Fig 7. Digital twin procedure [20]

Although digital twin systems share conceptual similarities with BIM, the key distinction lies in real-time synchronization. While BIM provides a static visual representation, digital twins reflect continuously changing project conditions. Through the integration of AI, IoT, and other digital tools, digital twin technology enables real-time analysis of construction progress, actual costs, delays, and other critical parameters, leading to transformative improvements in project management. Despite these advantages, widespread adoption remains limited due to challenges similar to those faced by other digital technologies.

Project Name	Estimated Budget	Completion / Status	Purpose of Using Digital Twin
NEOM / The Line (Saudi Arabia)	~USD 500 billion	Ongoing (phased completion, post-2030)	City-scale digital twin for design simulations, construction logistics, environmental analysis, infrastructure performance, and long-term smart city operations with AI and IoT integration.
Crossrail / Elizabeth Line (UK)	~USD 24 billion (≈ £18.8 billion)	2022	BIM integration with real-time data for progress tracking, clash detection, construction coordination, and operational transition in a complex transport system.
New Istanbul Airport (Turkey)	~USD 22 billion	2018 (operational phases ongoing)	Simulate construction sequencing, manage large-scale logistics, optimize spatial planning, and support operational readiness by connecting design models with performance data.
Hong Kong–Zhuhai–Macao Bridge (China)	~USD 18.8 billion	2018	Structural monitoring using digital twins for stress, vibration, and maintenance planning across one of the world's longest sea-crossing bridges.
Heathrow Airport Expansion / Terminal 5 (UK)	~USD 24–49 billion	2008 (Terminal 5), expansion ongoing	Digital twin for simulating passenger flow, operational logistics, construction phasing, and long-term airport management.

Fig 8. Construction projects which used digital twin systems [21]

3. Conclusion. The conducted analyses indicate that the application of digital technologies in construction project management is no longer an alternative approach but a strategic necessity. In an industry characterized by cost overruns, schedule delays, and high risk levels, technologies such as BIM, IoT, Artificial Intelligence, and Digital Twins enable data-driven decision-making across planning, execution, and operation phases, thereby minimizing risks. BIM's early-stage application maximizes cost influence, while IoT and AI systems provide real-time monitoring and predictive analytics for project optimization.

However, the construction sector's lag in adopting these technologies reflects its dependence on traditional management approaches, non-standardized data structures, and organizational resistance. In the future, the integration of BIM, IoT, AI, and Digital Twin technologies is expected to form a foundational framework for construction project management. Ultimately, digital transformation will enable the execution of larger-scale projects with reduced risk, enhancing the sector's global competitiveness.

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