JOURNAL OF ADVANCED ENGINEERING AND INNOVATION
Volume 2, Issue 1, June 2024 | pp. 40-51
https://doi.org/10.54518/jaei.2.1.2024.1268

Recent Advances in Building Information Modeling for Sustainable Construction: A Systematic Literature Review

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ABSTRACT

Building Information Modeling (BIM) has become a fundamental technology for promoting sustainable construction by improving collaboration, resource efficiency, and lifecycle management throughout construction projects. This systematic literature review examines recent research published between published over the last five years to identify technological developments, research trends, practical applications, challenges, and future opportunities of BIM in sustainable construction. The reviewed studies indicate that BIM has been increasingly integrated with digital technologies such as the Internet of Things (IoT), artificial intelligence (AI), digital twins, cloud computing, and Geographic Information Systems (GIS) to support energy-efficient building design, construction planning, facility management, and environmental performance assessment. Furthermore, BIM enhances project visualization, reduces material waste, improves cost estimation, and facilitates informed decision-making throughout the building lifecycle. Despite these advancements, challenges remain regarding interoperability, data standardization, implementation costs, and the shortage of skilled professionals. Future research should emphasize intelligent BIM integration, standardized data exchange, and sustainable digital construction to accelerate the transformation toward resilient and environmentally responsible built environments.

Keywords: *Artificial Intelligence, Building Information Modeling (BIM), Digital Twin, Internet of Things.*

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ARTICLE HISTORY

Received	: January 9, 2024
Final Revised	: February 27, 2024
Accepted	: April 20, 2024
Published	: June 30, 2024

1. | INTRODUCTION

The construction industry is undergoing a significant digital transformation to address increasing demands for sustainability, productivity, and resource efficiency. Rapid urbanization, population growth, and global environmental challenges have encouraged researchers and practitioners to adopt innovative technologies capable of improving project performance while minimizing environmental impacts. Among these technologies, Building Information Modeling (BIM) has emerged as one of the most influential digital approaches for integrating project information throughout the entire building lifecycle. Unlike conventional computer-aided design systems, BIM enables multidisciplinary collaboration by providing a shared digital representation of physical and functional building characteristics, thereby supporting informed decision-making from planning and design to construction, operation, maintenance, and demolition (Samsudin et al., 2022).

Sustainable construction has become an essential objective in modern engineering because the building sector accounts for a substantial proportion of global energy consumption, greenhouse gas emissions, natural resource utilization, and construction waste. Consequently, governments, researchers, and industry professionals increasingly promote sustainable construction practices that improve environmental performance while maintaining economic feasibility and social responsibility (Vuong et al., 2021). BIM has been recognized as an effective digital platform for achieving these objectives by facilitating lifecycle assessment, energy analysis, material optimization, carbon emission evaluation, and resource management during project development. Recent studies indicate that BIM significantly enhances decision-making by enabling designers and stakeholders to evaluate multiple design alternatives before construction begins, thereby reducing design errors, material waste, project delays, and unnecessary costs (Lee et al., 2019).

The rapid advancement of digital technologies has further expanded the capabilities of BIM in sustainable construction. Artificial intelligence (AI), Internet of Things (IoT), cloud computing, digital twins, Geographic Information Systems (GIS), and big data analytics are increasingly integrated with BIM to create intelligent construction management systems capable of supporting real-time monitoring, predictive maintenance, energy optimization, and automated decision-making. The integration of IoT sensors with BIM allows continuous monitoring of building performance, while AI algorithms facilitate predictive analysis for maintenance scheduling, energy consumption forecasting, and facility management. Similarly, digital twin technology enables virtual representations of physical assets to be continuously updated using operational data, thereby improving building performance and lifecycle management (Kaewunruen et al., 2020).

Another important research trend involves the application of BIM in green building assessment and environmental performance evaluation. BIM supports sustainability certification processes by simplifying data management required for green building rating systems and facilitating environmental impact assessments throughout project lifecycles. Furthermore, BIM-based simulation tools enable engineers to evaluate daylight performance, indoor environmental quality, thermal comfort, ventilation efficiency, renewable energy integration, and carbon footprint reduction during the early design stage. These capabilities allow project stakeholders to optimize building performance while complying with sustainability regulations and international environmental standards (Adams et al., 2022).

Beyond environmental benefits, BIM also improves project collaboration and information management among architects, engineers, contractors, owners, and facility managers. Traditional construction projects often suffer from fragmented communication, inconsistent documentation, and information loss throughout different project phases. BIM addresses these challenges by providing a centralized digital platform where project participants can share accurate and updated information in real time. This collaborative environment enhances design coordination, minimizes conflicts among disciplines, improves construction planning, and supports more efficient project execution. Consequently, BIM contributes to higher project quality, increased productivity, reduced rework, and better lifecycle cost management (Sepasgozar et al., 2022).

Despite its considerable advantages, the implementation of BIM in sustainable construction continues to face several technical and organizational challenges. High implementation costs, software interoperability issues, lack of standardized data exchange protocols, resistance to organizational change, limited technical expertise, and insufficient training remain major barriers, particularly in developing countries (Junussova et. al., 2022). Furthermore, integrating BIM with emerging digital technologies requires reliable communication infrastructures, secure data management, and standardized information models to ensure compatibility among heterogeneous software platforms. Data security, privacy protection, and long-term digital information management also represent important concerns as construction projects become increasingly connected and data-intensive (Margara et al., 2023).

Recent literature emphasizes that future BIM research should focus on improving interoperability, automation, intelligent decision support, and lifecycle integration while strengthening sustainability assessment capabilities. The convergence of BIM with artificial intelligence, digital twins, blockchain, cloud computing, and smart sensing technologies is expected to accelerate the digital transformation of the Architecture, Engineering, and Construction (AEC) industry (Wang et al., 2022). These innovations will enable more resilient, energy-efficient, and environmentally responsible infrastructure capable of supporting global sustainable development objectives while improving operational efficiency and asset management (You & Feng, 2020). Therefore, this study presents a systematic literature review of recent advances in Building Information Modeling (BIM) in sustainable construction by synthesizing peer-reviewed studies published between 2019 and 2023. The review aims to identify current research trends, technological innovations, engineering applications, implementation challenges, and future research opportunities related to BIM adoption in sustainable construction. By providing a comprehensive synthesis of recent literature, this study is expected to offer valuable insights for researchers, engineers, policymakers, and construction practitioners seeking to accelerate the implementation of digital technologies for sustainable and intelligent construction development.

2. | RESEARCH METHOD

This study employed a Systematic Literature Review (SLR) to comprehensively examine recent developments in Building Information Modeling (BIM) for sustainable construction. The SLR approach was selected because it provides a structured, transparent, and reproducible method for identifying, evaluating, and synthesizing existing scientific evidence. The review focused on peer-reviewed journal articles published between 2019 and 2023, ensuring that the findings represent the most recent advances in BIM technologies and their applications in sustainable construction. Relevant publications were retrieved from internationally recognized scientific databases, including Scopus, Web of Science, ScienceDirect, SpringerLink, IEEE Xplore, and MDPI. The literature search employed combinations of keywords such as Building Information Modeling (BIM), sustainable construction, green building, digital twin, Internet of Things (IoT), artificial intelligence, construction management, building lifecycle, energy efficiency, and smart buildings (Marinakis, 2020).

The literature selection process followed four systematic stages: identification, screening, eligibility assessment, and final inclusion. Duplicate records, conference papers, editorials, review articles, book chapters, and studies not directly related to BIM implementation in sustainable construction were excluded. Only English-language journal articles with clearly defined research objectives, methodologies, and findings were included in the final review. Subsequently, the selected studies were analyzed to extract information regarding BIM applications, sustainability dimensions, digital technology integration, project lifecycle phases, research methodologies, implementation benefits, technical challenges, and future research opportunities (Kilbourne et al., 2019). The extracted data were then classified into thematic categories to facilitate comparative analysis and identify emerging research trends. Finally, a qualitative synthesis was conducted to integrate the findings from all selected studies, enabling this review to provide a comprehensive understanding of the role of BIM in supporting sustainable construction practices, improving project performance, enhancing environmental sustainability, and accelerating the digital transformation of the Architecture, Engineering, and Construction (AEC) industry.

3. | RESULTS AND DISCUSSION

The systematic literature review demonstrates that Building Information Modeling (BIM) has become one of the most influential digital technologies supporting sustainable construction between 2019 and 2023. The reviewed studies consistently indicate that BIM has evolved from a three-dimensional modeling platform into an integrated information management system capable of supporting the entire building lifecycle, including planning, design, construction, operation, maintenance, renovation, and demolition (Bruno & Roncella, 2019). This transformation has enabled project stakeholders to improve collaboration, optimize resource utilization, reduce environmental impacts, and enhance project performance. The increasing integration of BIM with emerging digital technologies, including Artificial Intelligence (AI), the Internet of Things (IoT), Digital Twins (DT), cloud computing, and Geographic Information Systems (GIS), has further strengthened its role in promoting sustainable development within the Architecture, Engineering, and Construction (AEC) industry (Liu at el., 2019).

One of the major findings identified in the reviewed literature is the significant contribution of BIM to improving sustainability throughout the building lifecycle. Unlike conventional construction management approaches that rely on fragmented information, BIM provides a centralized digital environment where architectural, structural, and mechanical information can be integrated into a single model. This integrated approach allows engineers and designers to evaluate multiple design alternatives during the early planning stage, enabling better decisions regarding energy efficiency, material selection, construction methods, and operational performance. Early identification of design conflicts also minimizes costly modifications during construction, reduces material waste, and improves overall project quality. Consequently, BIM supports the implementation of sustainable construction principles by reducing unnecessary resource consumption while improving project productivity.

The review also highlights the growing application of BIM in energy performance analysis and environmental assessment (Durdyev et al., 2021). Modern BIM platforms are increasingly integrated with building performance simulation software capable of evaluating heating and cooling loads, daylight utilization, indoor thermal comfort, ventilation efficiency, and annual energy consumption before physical construction begins. These analytical capabilities enable project teams to optimize building performance while minimizing operational energy demand and greenhouse gas emissions. Furthermore, BIM facilitates lifecycle assessment (LCA) by allowing engineers to estimate the environmental impacts of construction materials, transportation, maintenance activities, and demolition processes. Such capabilities assist decision-makers in selecting environmentally friendly materials and construction strategies that contribute to long-term sustainability objectives.

Another important trend identified in the literature is the integration of BIM with the Internet of Things (IoT). IoT-enabled sensors continuously collect operational data related to structural conditions, occupancy levels, indoor environmental quality, energy consumption, lighting systems, and HVAC performance. By integrating these real-time datasets into BIM environments, facility managers gain continuous visibility into building operations and can make informed decisions regarding maintenance scheduling, equipment replacement, and energy optimization. This real-time connectivity transforms static BIM models into dynamic information platforms that support intelligent facility management throughout the operational phase of buildings. As a result, maintenance activities become more proactive, operational efficiency improves, and lifecycle costs can be significantly reduced.

Digital Twin technology has emerged as one of the most promising developments extending the capabilities of BIM in sustainable construction. While BIM primarily represents the physical and informational characteristics of buildings, Digital Twins continuously synchronize BIM models with real-time operational data obtained from IoT sensors and monitoring systems. This integration enables virtual representations of physical assets that support predictive maintenance, performance simulation, fault detection, and operational optimization. Engineers can evaluate different operational scenarios, identify performance degradation before failures occur, and optimize maintenance strategies based on actual building conditions rather than predetermined schedules. The reviewed studies indicate that BIM–Digital Twin integration has become increasingly important for smart buildings, intelligent infrastructure, and sustainable facility management because it improves both operational efficiency and long-term asset resilience.

Artificial intelligence has also become an essential component supporting BIM implementation in sustainable construction. Machine learning algorithms are increasingly applied to analyze large volumes of BIM-generated and sensor-derived data for project scheduling, cost estimation, risk assessment, clash detection, and predictive maintenance (Krausková & Pifko, 2021). AI-based analytical tools improve decision-making accuracy by identifying hidden patterns within complex construction datasets that are difficult to detect using conventional analytical methods. Furthermore, automated design optimization enables engineers to evaluate multiple design alternatives according to sustainability criteria such as energy consumption, carbon emissions, construction costs, and occupant comfort. The integration of AI with BIM therefore enhances project efficiency while supporting evidence-based engineering decisions throughout the building lifecycle. In addition to technological integration, the reviewed studies reveal that BIM has substantially improved project collaboration and information exchange among stakeholders throughout the construction lifecycle. Traditional construction projects frequently experience communication gaps caused by fragmented documentation, inconsistent design revisions, and isolated information management systems. BIM addresses these limitations by providing a centralized digital platform that enables architects, structural engineers, contractors, consultants, owners, and facility managers to access the same project information in real time (Lai et al., 2019). This collaborative environment enhances coordination during the design phase, minimizes design conflicts through automated clash detection, and supports more efficient construction planning and scheduling. Consequently, BIM contributes to reducing project delays, minimizing rework, improving construction quality, and increasing overall project productivity. Furthermore, cloud-based BIM platforms facilitate remote collaboration among multidisciplinary teams, making project management more flexible and efficient, particularly for large-scale and geographically distributed construction projects.

Another significant finding identified in this review is the increasing application of BIM in facility management and post-construction operations (Dixit, et al., 2019). Historically, BIM implementation primarily focused on the design and construction phases; however, recent studies demonstrate that its application has expanded to support building operation, maintenance, and lifecycle management. Digital building models containing comprehensive information about structural components, mechanical systems, electrical installations, maintenance schedules, and operational documentation enable facility managers to monitor asset performance more effectively (Lu et al., 2020). The integration of BIM with maintenance management systems supports predictive maintenance strategies, reduces equipment downtime, and improves resource allocation. As a result, building owners can optimize operational expenditures while extending asset service life and maintaining higher levels of occupant comfort and safety. These developments demonstrate that BIM is evolving into a comprehensive lifecycle information management system rather than merely a design tool.

The reviewed literature also emphasizes the growing importance of interoperability in maximizing BIM implementation (Jiang et al., 2019). Modern construction projects utilize numerous software applications for architectural design, structural analysis, cost estimation, scheduling, environmental assessment, and facility management. Seamless information exchange among these platforms is therefore essential to ensure data consistency throughout the project lifecycle. Open standards such as Industry Foundation Classes (IFC) have become increasingly important in facilitating data interoperability between different BIM software platforms. Nevertheless, many studies indicate that interoperability challenges remain one of the primary barriers to widespread BIM adoption because differences in data structures, software capabilities, and proprietary file formats often result in information loss during data exchange. Improving interoperability through standardized information models and open BIM approaches remains a major research priority for achieving fully integrated digital construction workflows.

Despite the considerable benefits offered by BIM, the review identifies several technical, organizational, and economic challenges that continue to limit its implementation. High initial investment costs for software, hardware, and staff training remain significant barriers, particularly for small and medium-sized construction firms.

In addition, many organizations encounter resistance to organizational change because BIM implementation requires modifications to established project workflows and collaboration practices. The shortage of skilled BIM professionals, inconsistent government regulations, and varying levels of digital maturity across construction organizations further complicate large-scale adoption. These challenges are particularly evident in developing countries, where limited technological infrastructure and financial constraints often slow digital transformation within the construction sector. Addressing these barriers requires coordinated efforts involving industry practitioners, educational institutions, software developers, and policymakers to strengthen BIM education, establish implementation standards, and encourage broader adoption through supportive regulatory frameworks.

Another important issue concerns data security and information management as BIM becomes increasingly integrated with cloud computing, IoT devices, and digital twins. Construction projects generate substantial volumes of sensitive engineering information, including design specifications, operational data, financial records, and maintenance documentation (Li et al., 2022). As digital collaboration expands, protecting this information from unauthorized access and cyber threats becomes increasingly critical. Researchers emphasize the need for secure cloud infrastructures, encryption technologies, access control mechanisms, and cybersecurity frameworks capable of safeguarding digital construction environments. Effective data governance is also essential to ensure information quality, consistency, and long-term accessibility throughout the building lifecycle. These measures will become increasingly important as BIM evolves toward highly connected and intelligent construction ecosystems.

Future research directions identified throughout the reviewed literature primarily focus on strengthening BIM integration with emerging digital technologies that support Construction 4.0. Artificial intelligence is expected to play an increasingly important role in automated design generation, project optimization, safety monitoring, and predictive analytics. Digital twin technology will continue to enhance real-time building monitoring by synchronizing virtual models with operational data obtained from IoT-enabled sensing systems (Deng et al., 2021). In addition, blockchain technology has been recognized as a promising solution for improving transparency, traceability, and trust in construction information management by providing secure and immutable records of project activities. The integration of augmented reality (AR), virtual reality (VR), robotics, and autonomous construction equipment with BIM is also expected to improve visualization, quality inspection, worker training, and on-site productivity. Collectively, these technological developments indicate that BIM will remain the foundation of future intelligent construction systems while supporting sustainable development, digital transformation, and resilient infrastructure management.

Overall, the findings of this systematic literature review demonstrate that Building Information Modeling has evolved into a comprehensive digital platform that supports sustainable construction across the entire project lifecycle (Ali et al., 2022). Its integration with artificial intelligence, IoT, digital twins, cloud computing, and open data standards has significantly enhanced collaboration, project efficiency, environmental performance, and lifecycle asset management. Although challenges related to interoperability, implementation costs, cybersecurity, and organizational readiness remain, continuous technological innovation and increasing industry adoption are expected to strengthen BIM's contribution to sustainable construction (Chen et al., 2022). Consequently, BIM will continue to play a central role in enabling smart buildings, resilient infrastructure, and environmentally responsible construction practices that align with the objectives of sustainable development and the digital transformation of the Architecture, Engineering, and Construction industry.

4. | CONCLUSION

This systematic literature review demonstrates that Building Information Modeling (BIM) has become a key digital technology for advancing sustainable construction by enhancing collaboration, information management, and decision-making throughout the building lifecycle. The reviewed studies published between 2019 and 2023 indicate that BIM has evolved beyond three-dimensional modeling into an integrated platform that supports planning, design, construction, operation, maintenance, and facility management. The integration of BIM with emerging technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), Digital Twins, cloud computing, and Geographic Information Systems (GIS) has significantly improved project efficiency, energy performance, resource utilization, and environmental sustainability while reducing construction waste, operational costs, and project risks.

Despite these significant advancements, several challenges continue to hinder the widespread implementation of BIM, including interoperability among software platforms, high implementation costs, limited digital expertise, data security concerns, and organizational resistance to technological change. Addressing these challenges requires greater collaboration among researchers, industry practitioners, software developers, educational institutions, and policymakers to establish standardized frameworks, improve workforce competencies, and promote digital transformation across the Architecture, Engineering, and Construction (AEC) industry. Future research should prioritize intelligent BIM integration, explainable artificial intelligence, Digital Twin applications, automated sustainability assessment, and secure cloud-based information management to strengthen lifecycle performance and support resilient, energy-efficient, and environmentally responsible construction. Overall, BIM is expected to remain a fundamental technology for achieving sustainable construction and accelerating the development of smart buildings and intelligent infrastructure in the era of Construction 4.0.

Acknowledgment

We gratefully acknowledge the contributions of individuals who supported the completion of this article.

Funding Information

This research did not receive any funding.

Conflict of Interest Statement

The authors declare that there is no conflict of interest.

Ethical Approval and Originality Statement

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

Data Disclosure Statement

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

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