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Review

A Review of Challenges and Opportunities in BIM Adoption for Construction Project Management

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Abstract. This research investigates the transformative impact of Building Information Modeling (BIM) on construction project management, highlighting its potential to enhance traditional processes through digital innovation. As the construction industry evolves amidst global economic integration and heightened competition, the demand for quality, efficiency, and sustainability escalates, presenting new challenges for project managers. Traditional management practices, while foundational, lack the dynamism and integrative capabilities offered by BIM technology. BIM emerges as a revolutionary paradigm, facilitating a shared digital environment that promotes precision, efficiency, and improved collaboration across the project lifecycle. By integrating BIM with artificial intelligence (AI), this study explores novel synergies that further refine project management methodologies, addressing complex challenges in the design, execution, and maintenance phases. The research employs a comprehensive review of existing literature, case studies, and practical applications to assess the effectiveness of BIM in various project management contexts. The findings reveal that while BIM significantly enhances project outcomes, its adoption faces technological, organizational, and cultural barriers. This necessitates a comprehensive strategy encompassing innovation, education, and policy reform to unlock its full potential. The study underscores the critical role of BIM in driving the future of construction project management, advocating for a collaborative effort among industry stakeholders to foster a conducive environment for BIM adoption and leverage its benefits for sustainable development in the construction sector.

Keywords: BIM, project management, construction industry, technological integration, integrating.

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1. Introduction

In the construction industry, the rapid and continuous development of new technologies and techniques, along with the increasingly high demands for quality, efficiency, and sustainability, have posed significant challenges for project managers [1-4]. Characterized by the diversity of project types, sizes, and working environments, the construction industry requires a high degree of flexibility and specialization in management. Each project is a complex system involving multiple stakeholders, from investors and contractors to suppliers, direct labor, and the surrounding community. Therefore, project management requires not only skills in planning, organizing, directing, and controlling a project but also in communication, negotiation, and conflict resolution [5-7]. In the context of global economic integration and fierce competition, enhancing the project management capabilities in the construction industry contributes not only to the success of each specific project but also to the sustainable development of the entire industry [8]. By applying advanced management techniques and developing the skills of the project management team, the construction industry can face and overcome the challenges of the era while generating added value for society [9-11].

Traditionally, project management has relied on conventional methodologies and tools, but the advent of BIM technology offers a paradigm shift in how projects are conceived, planned, executed, and maintained. The comprehensive nature of BIM facilitates the creation of a shared digital environment, enabling stakeholders to collaboratively engage with project data throughout its entire lifecycle. The use of BIM technology has the potential to revolutionize project management by bringing in a new era of precision, efficiency, and improved cooperation [12-15]. From design coordination and clash detection to schedule optimization and cost estimation, the potential impact of BIM is far-reaching [16, 17]. The purpose of real-world case studies and examples of successful BIM applications in project management is to give a thorough grasp of how BIM can act as a potent enabler, giving stakeholders and project managers the tools they need to successfully navigate the complexity of contemporary projects [18-20]. By examining the various features and capabilities of BIM, we can gain a deeper understanding of how this innovative technology can revolutionize project management practices. To underscore the importance of BIM in project management, this paper will delve into the specific benefits that BIM offers, highlighting how these advantages enhance the overall efficiency and effectiveness of construction project management. The proposed framework has seven main steps: 1) Introduction to BIM Technology: This section delves into the definition and historical evolution of BIM, outlining its key features and components and underscoring its significant role in the contemporary construction industry; 2) Current Landscape of Project Management: An overview of traditional project management practices in construction is provided, highlighting major risks and their impact on project outcomes. Additionally, this part discusses strategies to enhance risk management and points out the limitations of current methodologies in addressing complex project challenges; 3) BIM in Connection with Project Management Knowledge Areas: The integration of BIM with core project management knowledge areas such as scope, schedule, cost, quality, resource, and risk management are examined. This section includes case studies and examples that demonstrate BIM's application in these areas and provides a comparative analysis of project outcomes with and without BIM integration; 4) Integrating BIM and AI to Intelligently Manage Construction Projects: This segment explores the synergies between BIM and AI technologies and presents examples of AI-powered BIM applications in construction projects. It also discusses the future prospects and potential of BIM-AI integration and addresses common challenges in BIM adoption; 5) Addressing Common Challenges in BIM Adoption: Challenges to BIM implementation, such as technological, organizational, and cultural barriers, are identified. Strategies and solutions to overcome these challenges are discussed, along with the role of stakeholders in facilitating BIM adoption; 6) Importance of BIM Education and Training Programs: The importance of education and training in the successful implementation of BIM is emphasized. This includes a review of the current state of BIM education and professional training programs, along with recommendations for developing effective BIM curricula and training methods. The impact of education and training on BIM adoption rates and project success is also examined; 7) Conclusion: The conclusion summarizes BIM's potential to enhance construction project management and recaps the key findings and recommendations from the paper. It issues a call to action for industry, academia, and policymakers to promote BIM adoption and suggests future research directions in the domain of BIM and construction management.

The study addresses a critical gap in the existing body of research by providing a comprehensive evaluation of current project management techniques in the construction industry, with a particular focus on the transformative potential of Building Information Modeling (BIM). Unlike previous studies, which often examine BIM in isolation, this research integrates BIM with traditional project management practices to offer a holistic view of its impacts. Additionally, the study explores the intersection of BIM with emerging technologies such as artificial intelligence (AI), highlighting innovative synergies that have not been extensively covered in existing literature. The findings of this study are expected to inform stakeholders and policymakers about the practical and strategic implications of adopting BIM, thereby contributing to a more resilient and efficient approach to project delivery in the construction sector. This novel integration of BIM with traditional practices and new technologies underlines the unique contribution of the research.

2. Literature review

2.1. Introduction to Building Information Modeling (BIM) Technology

By creating jobs and contributing to the GDP of nations, the construction industry (CI) is essential to the development of infrastructure and raises socioeconomic status. However, because of the growing complexity of construction projects (CPs) and the lack of acceptance of innovative technologies like Building Information Modeling (BIM), their productivity has declined recently. Enhancing the skills of construction practitioners is also crucial in order to fulfill project needs that align with project management knowledge domains [21]. Construction professionals may use collaborative networking to extract, modify, and exchange data from BIM models to help in decision-making. Currently, a wide variety of businesses utilize building information modeling (BIM) to plan, organize, build, run, and maintain many kinds of infrastructures, such as ports, tunnels, highways, bridges, energy/electricity, gas, and communication services. Making decisions amongst the many realistic possibilities accessible, from building construction to building destruction, is facilitated by BIM as well. Construction stakeholders can preview BIM-created deliverables before construction begins [22, 23]. BIM minimizes waste and rework, enabling projects to be completed on time and cost-effectively [24]. BIM is recognized as an information processing tool that supports decision-making for the completion of environmentally friendly building projects.

The maturation of Building Information Modeling (BIM) is segmented into levels ranging from Level 0 to Level 3. At Level 0, BIM involves the use of CAD for planning, with limited collaboration. Level 1 employs 3D CAD for conceptual work and 2D for drafting and implementing CAD standards. Level 2 facilitates teamwork with 3D CAD, reducing rework and improving data management. Level 3 includes collaborative work on a shared project model with enhanced security measures [25]. The Level of Development (LOD) reflects the reliability of element content in BIM models, aiding in execution plans and contracts. LOD specifies content requirements for project stages, including facilities management and decision-making [25, 26]. According to the BIM Forum USA, LOD ranges from 100 for conceptual models to 500 for completed models [27].

3D Building Information Models (3D BIM) provide a clear visual description of building models at the initial construction stage. It supports conflict detection and enhances project time simulation in 4D BIM models. Fourier transformation models track daily resource requirements, and 5D BIM encompasses cost calculations for efficient project management [25, 28-30]. Sustainability analysis and Beyond Sustainability are added as the sixth dimension in 5D BIM models. 6D BIM measures emissions and energy, while 7D BIM includes operational and facilities management. The documentation refers to 8D BIM (data safety integration) and 9D BIM (focused on environmentally friendly development) [29, 31]. BIM stages include Pre-BIM (the initial step) and can be configured to be completed at Stage 4, with BIM completion levels fixed at Stages 1-3 [32]. BIM Stage 1: object-based modeling; BIM Stage 2: model-based collaboration; BIM Stage 3: network-based integration [32]. Pre-BIM Stage (2D Modeling and Documentation): 2D models and documentation represent 3D reality but lack a connection between cost forecasting, quantity take-offs, and specifications. Linear and asynchronous coordination practices exist without collaboration among stakeholders. Single-discipline 3D models using software like Revit facilitate the initial BIM step. Transition to Collaborative BIM: Coordination improves as 2D documents and 3D visuals align. After creating single-discipline models, stakeholders move to the next stage, emphasizing active collaboration and exchange of interactive models. Time analysis (4D) and cost estimation (5D) models are created, allowing collaboration across stages. Full BIM Integration: Data-rich, integrated models are shared in various file formats and common data environments. Stakeholders access interdisciplinary models to make informed decisions about lean construction, green design, lifecycle cost calculations, business information, and sustainable development. Integrated Project Delivery (IPD) becomes feasible, representing BIM's ultimate goal [32, 33]. Integrated Project Delivery (IPD): IPD, the convergence of rules, practices, and technological breakthroughs, represents the ultimate goal of BIM. Terms such as "nD modeling" or "Fully Automated and Integrated Technology" are juxtaposed with IPD for more informative outcomes. IPD enhances collaboration, coordination, communication, and decision support to improve the overall project performance. This approach offers integrated design solutions, optimizing value throughout the building's lifecycle through enhanced information and data management integration [34]. The growing demand for facilities management and interdisciplinary collaboration in sustainable infrastructure design propels the daily use of BIM. When comparing BIM with current Continuous Integration (CI) processes, the three main perspectives – people, process, and product – reveal changes in expectations and perceptions [35].

BIM encompasses a diverse array of technological facets aimed at enhancing project management in the realm of construction endeavors. Chief among BIM's functionalities is its prowess in clash detection [36]. In the collaborative milieu of construction projects involving multiple engineering disciplines, BIM serves as a bulwark against geometric irregularities and structural conflicts, thereby mitigating potential complications within structural sections. Furthermore, BIM facilitates comprehensive assessments, empowering construction stakeholders to engage in informed decision-making

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processes [23, 36-38]. This capability extends to the seamless integration of advantageous technologies into BIM models. For instance, BIM's analytical prowess extends to assessing energy consumption within a project, proffering strategies for its reduction through the alignment of building materials and structural components. Additionally, BIM serves as a discerning arbiter in identifying issues pertaining to motors, lighting, and acoustics [23, 36-38]. Moreover, BIM's utility extends to time and cost estimations, as well as quantity take-offs [36-39]. Equipped with tools for estimating both temporal and financial parameters, BIM empowers project managers with invaluable insights into the various stages of a project's lifecycle. The integration of 4D time estimates and 5D cost estimates during the project's nascent stages facilitates judicious decision-making, preempting potential pitfalls such as cost and time overruns. This proactive approach ensures optimal resource allocation and preemptive measures against deviations from the project's trajectory [36-39]. Integral to BIM's efficacy is its capacity for integration [37]. Through the amalgamation of disparate data streams into cohesive BIM models, project team members hailing from diverse backgrounds converge within a singular digital realm. This amalgamation engenders seamless planning and integration processes, fostering synergy among project stakeholders [37]. Facilitating collaboration and communication stands as another hallmark of BIM's transformative influence [37, 39]. By affording universal access to a singular model, BIM engenders an environment conducive to interdisciplinary collaboration. This democratization of data exchange and evaluation engenders enhanced communication channels, thereby minimizing the likelihood of discordance within construction projects [37, 39].

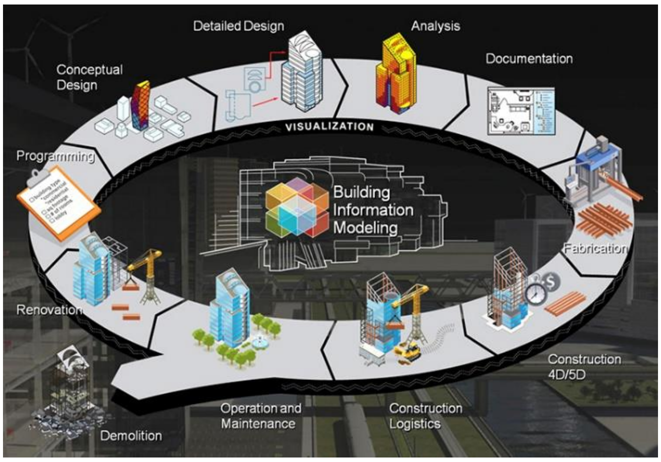

Fig. 1. BIM the operation and maintenance phases of the building's life cycle [40].

The burgeoning complexities of contemporary construction projects underscore the indispensable role played by BIM in fostering efficiency, collaboration, and informed decision-making within the realm of project management. As the technological landscape continues to evolve, the centrality (Fig. 1) of specialized roles such as the BIM manager is poised to become increasingly pronounced, heralding a new era of innovation and efficiency in construction project management [23, 36-39].

2.2. BIM in Connection with Project Management Knowledge Areas

2.2.1. Current Landscape of Project Management

Project management embodies the systematic application of specialized knowledge, competencies, and methodologies aimed at the effective and efficient realization of projects. This domain serves as a strategic asset, enabling organizations to forge a link between project achievements and overarching business strategies, thereby securing a competitive advantage within their respective markets [41, 42]. Within the construction sector, the project manager bears the critical responsibility of assimilating the project owner's requirements with the optimal deployment of standard and bespoke construction methodologies [43, 44]. The domain of construction project management is distinguished by its imperative to adopt an integrative perspective, addressing the entirety of the project scope. This encompasses the navigation of stakeholder dynamics, geographical constraints, and cultural variables, in addition to the management of project financing, procurement strategies, and risk mitigation. The overarching objective is to achieve a harmonious integration across the spectrum of technical and ancillary disciplines, thereby mitigating discrepancies. This integrative imperative is particularly salient in construction project management, given the sector's inherent complexity, which is further compounded by the variability in design and construction life cycles as influenced by comprehensive knowledge areas, including but not limited to project financing [45]. The complexity is accentuated by contractual obligations that mandate meticulous progress and performance reporting, thereby amplifying the exigencies of project execution monitoring and control. In the context of the construction industry, where changes are often anticipated, the implementation of an integrated change control mechanism is deemed critical. The mismanagement of this process frequently precipitates legal disputes, underscoring the importance of adept administrative oversight.

2.2.2. BIM in Connection with Project Management Knowledge Areas

Project management significantly influences a project's ability to mitigate risks stemming from both natural factors and human actions. Ineffective risk management can have substantial consequences on a project. Collaboration is pivotal for project teams to minimize risks, and Building Information Modeling (BIM) is particularly instrumental during the planning, building, and construction management stages [46]. BIM exhibits considerable potential in enhancing quality management for infrastructure projects by identifying and rectifying errors, predicting and preempting issues, proposing improved design solutions, fostering clearer stakeholder communication, and optimizing budget and time constraints [47]. In the building industry, the project management team focuses on ensuring projects adhere to specified time, budget, and quality standards [48]. Integrating BIM with cutting-edge digital technology [49] holds the promise of automating modern building project management, increasing efficiency, and reducing waste and resource consumption. Additionally, studies explore the application of 4D rendering the building business, addressing the knowledge gap between 4D research and BIM principles, with a focus on the Level of Development [50].

In South Africa, the high incidence of accidents, injuries, and property damage on construction sites highlighted the need for BIM to enhance site planning and minimize construction hazards. In Iraq, the inefficiency in construction management due to the rising number of people, documents, and formats requiring collection, exchange, and documentation underscores the critical need for integrating BIM and geographic information system (GIS) methodologies [51]. In Germany, deficiencies in construction project management are evident through poor material and system selection and design decisions, which negatively affect structural performance and contribute to high carbon emissions. Meanwhile, in Chile, the architecture, engineering, and construction sectors face ongoing challenges in managing human and material resources, adhering to construction timelines, crafting precise budgets, and minimizing construction errors, necessitating the adoption of BIM methodologies. Similarly, Peru's construction sector exhibits lower productivity in project management compared to other sectors, attributed to a lack of technological integration in planning and progress visualization, leading to increased execution errors [52]. Consequently, construction firms encounter challenges during project execution and need professionals adept at managing unexpected events [53]. Therefore, these firms should focus on proper BIM implementation throughout the design, production, construction, operation, and maintenance stages to enhance the construction model [54]. through an exploration of BIM's capabilities and real-world applications, readers will gain valuable insights into the future trajectory of project management in the construction industry.

A thorough examination of works underscores the effectiveness of BIM in revolutionizing project management within the construction sector. Comparative analyses of traditional project management methods versus those utilizing BIM illustrate that BIM not only bolsters team coordination and collaboration but also increases transparency and boosts the management of resources [55]. Evidence suggests that BIM's support in decision-making across all phases of a project can lead to marked reductions in both costs and completion times [56]. Additionally, research reveals that BIM's implementation fosters practices conducive to sustainable construction. The capacity of BIM to incorporate comprehensive energy analysis allows for precise evaluations of a building's energy usage, fostering sustainable development practices and diminishing long-term environmental effects [57]. In emerging markets, the lack of widespread BIM adoption has been pinpointed, suggesting that its broader utilization could significantly contribute to the modernization and enhanced competitiveness of the international construction industry [58]. These findings collectively affirm that, despite varying levels of BIM adoption globally, its beneficial impact on the efficiency of project management is universally acknowledged, thereby encouraging a shift towards more efficient and transparent practices within the construction industry. Moreover, the integration of BIM into project management processes has notably elevated construction quality and safety. By employing BIM's analytical and simulation capabilities, it's possible to identify potential issues or conflicts before they manifest in actual construction scenarios [59]. This improvement leads to enhanced quality and safety in construction projects, offering direct benefits to society by lowering construction-related risks and ensuring the construction of higher-quality buildings [60]. The facets of sustainability and energy efficiency have similarly seen positive effects from the integration of BIM into project management. BIM models enable the evaluation and optimization of building energy performance, leading to decreased energy use and lesser environmental impacts. In a world increasingly focused on sustainable and eco-friendly solutions, BIM serves as a crucial tool in advancing sustainable practices in construction projects [61].

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A growing number of academics question the standalone effectiveness of BIM and advocate for its integration with other cutting-edge technologies [62]. GIS, encompassing geospatial modeling and geo-visualization, has been linked with BIM to enhance data management and knowledge flow throughout a project's life cycle [63, 64]. Combining BIM and GIS contributes to smart and sustainable cities, aiding in managing the construction supply chain, emergency response, urban energy use, heritage preservation, climate change adaptation, and environmental evaluation [64]. RFID integration with BIM improves process tracking, safety management, building management, and resource supervision, facilitating real-time data collection and monitoring [62]. VR and AR integration enhances the accuracy of processing and displaying models and data, making it easier for users to work with and simulate designs, along with mapping and tracking functions for real-time cost information and progress monitoring [62]. Specific Applications of this integration include gathering real-time data for the site assembly of pre-manufactured components [65] and monitoring worker location for safety purposes [66, 67]. Cloud Computing, semantic web technology, mobile BIM tools, and 3D printing are additional technologies that can be integrated with BIM for new applications [62, 64, 66-68]. Since 2008, efforts have been made to combine IoT with BIM, offering improvements in lean construction, building parts reuse, emergency response, energy conservation, indoor localization, off-site construction, facility and maintenance management, environmental monitoring, and health and safety management, aligning with Industry 4.0 trends [69-71].

When taken as a whole, BIM complements structural project management and may help structural project operators by cutting down on documentation time and producing better project results. With the advent of BIM and challenges in design management methods, new solutions are required [72-74]. By developing component libraries to increase modeling productivity, simulating the 4D process to increase site construction accuracy, and putting quality management systems in place to analyze problematic components, BIM technology tackles these issues [75-77]. Construction managers can quickly detect and resolve problems by using the BIM model to designate the location of problems. Effective control is mostly dependent on statistical analysis and tracking verification [78]. The production of realistic, project-based classroom assignments for educators is improved by the introduction of BIM-based project management systems. Students may learn different project management techniques and improve project plans by designing class projects that mimic real-world project situations thanks to BIM. Model-based quantity reduction, cost prediction, schedule simulation, and design collaboration are made easier by the data-rich nature of BIM [79, 80]. Potential factors for measuring the extent to which project management knowledge areas are applied, as well as BIM features that can improve project managers' abilities to apply those knowledge areas, were identified through a thorough review of the literature for this review study [81]. The goal of the research was to get a comprehensive understanding of how much BIM contributes to improving project managers' capacity to use project management knowledge areas in building projects.

The application process of all project management knowledge domains was found to be divided into three primary tasks: planning, managing/developing, and monitoring/controlling [82]. Additionally, schedule management is aided by BIM's assistance with time and cost projections, reducing the risk of budget and time overruns. Construction professionals may discover conflicts more easily because of BIM's pre-execution visualization capability, which also reduces mistakes, omissions, and reworks. Additionally, multi-dimensional visualization helps with quality and safety management by monitoring project progress [83, 84]. Stakeholders in building projects enable integration management and communication management while working on a single model. Building Information Modeling (BIM) has several financial advantages (Fig. 2) and improves the standing of construction companies by increasing the productivity of deliverables [85, 86]. Therefore, because of its unique and noteworthy characteristics, BIM technology has great promise for improving project managers' use of project management knowledge domains in building projects. It is clear from the synthesis of research results provided in the overview of BIM applications in construction project management that using BIM to manage projects has several benefits. The findings of a number of studies emphasize the enormous potential of BIM assessment and show how widely used it is in the application process. Prominent agencies and organizations, together with multinational corporations and their subsidiaries, have shown excellent competency in using BIM for project information management [87]. BIM's importance goes beyond its basic function in information modeling and encompasses other dimensions, such as 4D (time), 5D (cost), and even 6D (as-built operations). In order to enable simulation assessments of construction activities, BIM creates connections between data and information in 3D object models in the 4D dimension. Quantity, scheduling, and pricing data are integrated with this information in the 5D dimension. The 6D dimension is an as-built model that may be used throughout a facility's operating stages [88, 89]. The adoption of BIM makes it possible for data to be updated seamlessly and guarantees consistency across all changes. Improved communication between project management stakeholders and frequent dispute resolution provide ongoing updates and monitoring from the start of the project [90]. This simplified procedure guarantees project transparency throughout reviews, facilitates progress monitoring, and helps with mistake reporting.

2.2.3. BIM application in project management fields

BIM and project integration management: A unified composite model created by combining models from different fields offers construction professionals a strong foundation for BIM work. This enhances project efficiency, aiding the team in effective planning, analysis, and implementation. BIM promotes improved teamwork and communication by ensuring access to project information for all partners. Comprehensive documentation provides a holistic view, ensuring swift and accurate project completion. BIM facilitates integrated project delivery (IPD) in project integration management [37, 91-95] by seamlessly integrating diverse fields.

BIM and project scope management: BIM models, composed of elements rather than flat surfaces, allow the entire model to be divided into smaller, distinct parts. The disassembled view of BIM models provides valuable insights into the scale of large projects, facilitating planning, design, and execution of operations [37, 39]. Utilizing BIM in construction projects can enhance internal scope standards. 3D modeling offers a comprehensive understanding of the project, while 5D BIM models enable informed changes with an awareness of their impact on the project. This fosters effective communication among buyers, workers, and builders, ensuring a shared understanding of the project scope within the entire team [96].

Time management for projects and BIM: Traditional project planning can be influenced by the work environment, leading to subjective decisions and potential difficulties in project execution. However, adopting 5D BIM models streamlines the building process, providing a comprehensive overview of project timelines [97]. The 5D BIM system tracks start, end, planned, and actual times, enabling timely schedule checks and error identification during construction [97]. BIM ensures synchronization between design and construction schedules, minimizing project delays and offering buyers a realistic view of the building process [97]. Additionally, BIM provides accurate and efficient cost estimates through automatic number take-offs from BIM models, expediting the feedback process for any plan changes [63]. In the context of Construction Informatics (CI), BIM technology facilitates methodical project management, aiding in the design and visualization of building models to preview plan changes [97, 98].

BIM and project cost management: The integration of schedule and cost control remains a crucial concern in the construction industry. 5D BIM models enable users to accurately estimate project costs through automated quantity take-offs, providing swift feedback on cost changes in the design [63, 99, 100]. Early cost decisions, improved collaboration, and communication contribute to enhanced control over project budgets, leading to higher productivity for construction practitioners [39, 92, 101-103].

BIM and project quality management: Utilizing BIM and related technologies for quality management in construction projects is highly beneficial. BIM's real-time display feature allows for continuous monitoring of work progress [104]. The integration of models from various fields enables thorough checks on structural components and material quality. nD BIM models clarify roles and responsibilities, fostering seamless collaboration and ensuring a high-quality outcome [28, 39, 47]. BIM's clash detection feature reduces the likelihood of mistakes, minimizing waste and rework [23, 105-107]. Timely supervision of construction progress and quality, along with utilizing BIM's features like clash detection, identifies issues promptly, contributing to effective quality management [39, 92, 108-112]. Recording flaws and corrective actions in a quality information store allows building professionals to leverage detailed information for quality improvement, feedback, and necessary maintenance or repairs [92, 94, 99, 102, 108-110].

BIM and project resources management: BIM enhances teamwork, interdisciplinary communication, and collaborative planning, reducing disagreements in building projects. It consolidates human resources based on a unified model created by professionals with diverse expertise [39]. Additionally, BIM plays a crucial role in resource management beyond personnel, offering efficient ways to minimize waste, particularly in construction and demolition projects. This promotes the effective use of materials and supports the circular economy in building projects. Recognized by experts, BIM proves valuable in decision-making for optimizing resource utilization in construction projects [38, 92, 95, 97, 107, 109, 113, 114].

BIM and project communication management: Effective communication and collaboration are essential for successful building projects. Building Information Modeling (BIM) improves the building process by virtualizing and visualizing information, reducing the likelihood of misunderstandings and conflicts [98]. BIM ensures centralized and well-structured data management, presenting information in easily understandable 3D models [115-117]. Unified models and smooth information flow enhance collaboration and understanding [37, 92, 115, 116, 118], making decision-making easier with fewer disagreements. In the pre-construction phase, BIM 5D models facilitate live simulation schedules for construction progress. Early detection of clashes minimizes corrections, changes, and errors. The report output function of BIM predicts material and resource requirements, aiding in effective purchase planning for construction project management [97]. A BIM-based e-procurement system proposed in 2015 utilizes a full BIM model for accurate resource estimation and enhances the bidding process [119]. This approach ensures consistency in information, detailing costs and protecting the integrity of the buying process for managing construction project outcomes. The automated approach also reduces errors and extra work compared to traditional procurement methods [39, 109, 119].

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BIM and project risk management: Due to increased uncertainty and complexity in construction projects within Construction Informatics (CI), various risks have surged. Information technology advancements have introduced new risk management methods, with Building Information Modeling (BIM) being a technology solution for information and communication management [106]. Construction professionals use BIM to identify, record, reduce, and manage risks. The model-based analysis and spatial representation in BIM aid in identifying and addressing risks in design and construction plans, reducing change orders, and enhancing communication and collaboration [37-39, 102, 112]. BIM minimizes the risks of cost and time overruns, promoting constructability by addressing uncertainties [37-39]. It also facilitates safety management through the creation of site safety plans [38, 106]. Utilizing BIM throughout the entire building project lifecycle, from planning to destruction, establishes a knowledge-based risk management model [120, 121]. Consequently, BIM assists building partners in identifying and managing project risks for successful outcomes [39, 92, 106].

BIM and project stakeholders management: In recent years, Building Information Modeling (BIM) has transformed the approach to construction projects, facilitating collaboration among individuals from diverse backgrounds and enhancing project management [39, 99]. Improved collaboration-based networking, as emphasized [94], boosts productivity and overall project quality, contributing to client satisfaction and trust [92, 95, 122, 123]. Affirms that cohesive teamwork results in organizational harmony and effectiveness, leading to superior management across all project stages [124]. BIM usage in construction projects benefits architects by providing more opportunities and return on investment (ROI), simplifying design processes, reducing errors and rework, and offering multi-dimensional views of structural elements [125]. Engineers also find BIM advantageous during the building phase, leading to fewer problems, and changes and increased earnings and efficiency [92, 94, 109]. The consensus among construction professionals is that BIM should be a mandatory requirement in all projects due to its role in minimizing disagreements, fostering connections, and enhancing collaborative work for mutual benefit [92, 123, 126].

Fig. 2. Advantages of BIM in Construction [130].

BIM and project safety management: BIM provides valuable features for efficient safety management in construction projects. However, there is limited literature on incorporating digital technologies like BIM into safety education. The interconnected nature of safety aspects and BIM features allows construction workers to use specific BIM features to address safety issues [127]. Researchers have developed rule-based safety-checking systems by integrating BIM elements with safety standards and activities. These systems can promptly identify potential risks and implement necessary measures, enabling proactive risk planning during the pre-construction phase and promoting safer designs. Utilizing technology such as an automatic safety code checker and exercises can enhance safety communication, saving time and effort for safety staff [128]. Additionally, BIM is also useful for waste management in projects, offering tools that help in the planning, monitoring, and minimizing of waste, which is crucial for sustainable construction practices [129].

2.2.4. Integrating BIM and AI (Artificial Intelligence) to intelligently manage construction projects

The merger of BIM with AI in the realm of construction scheduling heralds a revolutionary shift in the industry, bringing about unparalleled improvements in efficiency, accuracy, and project management optimization [131-137]. BIM acts as a digital twin, encapsulating the physical and functional characteristics of a building, while AI, especially through its machine learning algorithms, interprets this information to facilitate informed decision-making. This synergy enhances construction scheduling, making it more streamlined, economical, and flexible to changes in project conditions [133, 136]. A principal benefit of integrating BIM with AI in construction scheduling is the superior visualization and coordination it offers [132, 136]. BIM creates an exhaustive 3D representation of the project, covering all elements and systems [138, 139]. AI's analytical capabilities allow for early detection of design conflicts, enabling prompt resolution [140, 141]. This forward-looking strategy significantly cuts down on rework and delays, ensuring a more fluid construction process. Additionally, AI's ability to process both historical and current project data predicts potential risks and delays [31, 33, 140, 141]. Utilizing machine learning, construction teams can anticipate obstacles and better allocate resources [45, 142]. AI's analysis of previous project timelines, considering variables such as weather, resource availability, and workforce productivity, aids in formulating more accurate and reliable schedules for upcoming projects. This predictive capability supports construction managers in making well-informed adjustments to schedules and resource distribution, thus reducing project delays and costs. Moreover, the fusion of BIM and AI facilitates the automation of scheduling-related tasks [140, 141, 143]. AI can autonomously generate schedules based on project specifics, resource availability, and limitations. These schedules are continuously refined with new data, keeping the construction timeline and budget on target. Automation also lightens the administrative load on project managers, allowing them to focus on strategic project management aspects. The capability for "what-if" scenario analysis is another significant advantage of this integration [138, 139]. Given the uncertainties inherent in construction projects, such as weather conditions, material shortages, or unforeseen design alterations, BIM provides a manipulable digital model for scenario analysis. AI's simulation of various conditions and their potential impacts on the project schedule enables teams to develop contingency plans and proactive strategies to address potential risks [141, 144].

Table 1. BIM and AI for project management [145].

No.	Aspect	BIM	AI	Integration Methods	Challenges	Future Directions
1	Construction Schedule Management	Utilizes 3D models and clash detection for visualizing construction processes.	Employs AI algorithms for accurate project timeline predictions based on historical data.	Real-time adjustments using predictive analytics.	Data interoperability, varying standards.	Enhanced interoperability, IoT integration, dynamic scheduling via AI.
2	Cost Management	Provides precise quantity takeoffs and cost estimation through 3D models.	Utilizes AI for cost analysis from diverse data sources, ensuring accurate forecasts.	Integrates BIM data into AI algorithms for reliable budgeting.	Cost data accuracy, integration complexity.	Advanced cost data validation algorithms, blockchain for transparent tracking.
3	Quality Management	Facilitates 3D visualization for clash detection and coordination among systems.	Employs AI with image recognition and sensors to monitor construction quality.	BIM 3D models serve as references for AI-driven quality control.	Data accuracy, real-time monitoring complexity.	AI-driven automated quality assurance, advanced real time sensor technologies.
4	Safety Management	Includes safety-related information such as escape routes in 3D models.	Utilizes AI to predict safety hazards and suggest preventive measures.	BIM data on safety features enhances AI driven risk assessment and safety protocols.	Data security, privacy, AI reliability.	Enhanced AI algorithms, privacy preserving techniques, standardized safety data formats.

This exploration of different scenarios helps project managers pinpoint the most effective and economical scheduling approaches, ensuring project resilience against unexpected challenges. Furthermore, the integration of BIM and AI promotes real-time stakeholder collaboration and communication. BIM's digital platform ensures that architects, engineers, contractors, and clients have access to consistent, updated project information. AI processes this collective data to offer actionable insights to all parties, enhancing decision-making [138-140]. For instance, construction managers can receive timely alerts and recommendations from AI systems, facilitating swift issue

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resolution and schedule adherence. This fosters a transparent, efficient workflow, improving project coordination and communication overall. Additionally, this integration advocates for sustainable construction practices and resource efficiency [132, 135]. AI's analysis of material use, energy consumption, and waste production offers insights into sustainable practices. Optimizing schedules with these insights helps reduce environmental impact and promotes green building practices. AI also enhances resource utilization, reducing waste and improving efficiency [141], which not only lowers costs but also bolsters the project's sustainability. In cost estimation and budgeting, the accuracy is significantly improved through AI's analysis of historical cost data and project details, providing precise cost estimates for different project facets. Considering variables like material costs, labor, and equipment expenses, AI produces detailed and reliable cost projections. This precision aids project managers in crafting realistic budgets and effectively allocating resources. AI's real-time monitoring of project costs against the budget, with alerts for overruns, ensures proactive financial management, keeping the project within financial bounds. The convergence of BIM and AI in construction scheduling is a paradigm shift for the industry, revolutionizing project planning, management, and execution towards greater efficiency, fewer delays, reduced costs, and successful, sustainable outcomes (Table 1). This innovative integration redefines traditional scheduling methods, leading to smarter, more efficient, and eco-friendly construction projects.

Virtual Design and Construction (VDC) enhances the functionality of Building Information Modeling (BIM) by merging BIM models with the timelines of the project. This fusion connects 3D models to scheduling information, enabling project managers to visualize the construction timeline in a virtual setting. By employing AI algorithms, VDC facilitates the examination of this combined data to refine construction sequences. Such refinement guarantees that activities are arranged in the most logical sequence. For instance, AI can pinpoint instances where tasks can be carried out concurrently, thus shortening the overall project timeline without sacrificing quality or safety standards.

The integration of Building Information Modelling (BIM) with Artificial Intelligence (AI) offers significant advancements in real-time observation and management of construction operations [45]. On-site sensors and Internet of Things (IoT) devices continuously collect data, which is then fed into a unified BIM-AI framework [146-148]. AI algorithms analyze this real-time data alongside historical records to forecast potential delays and evaluate current site conditions. This proactive system provides project managers with timely alerts, enabling immediate corrective actions to prevent deviations from the planned schedule [149, 150]. For example, during a high-rise construction project, sensors might monitor structural integrity and environmental conditions. The AI system can predict issues such as weather-related delays, allowing for adjustments in the construction timeline and resource allocation. Such integration not only enhances efficiency but also improves safety and reduces costs by mitigating risks before they impact the project

Resource distribution is refined through AI algorithms that take into account the competencies, availability, and geographical positioning of the workforce and machinery. Utilizing data from BIM, AI evaluates the necessities for various construction activities and accordingly assigns resources. For example, AI is capable of pinpointing the closest piece of specialized equipment required for a particular job, guaranteeing the task is completed on time and in line with the project timeline.

In the detection of design conflicts, BIM models are indispensable in identifying potential issues in the early stages of design. With AI integration, these detected clashes undergo automatic examination and resolution. The AI algorithms evaluate how these conflicts might affect the construction schedule and suggest viable alternatives. The rapid settlement of these design issues ensures the construction process proceeds without interruptions, preserving the integrity of the project's timeline.

2.3. Analysis of Construction Engineering Safety Management Based on BIM Platform

This proposal focuses on the data information management center of the construction project, based on the collaborative data management system, integrating production management data, target management data, and information from each participant, such as project owners, supervisors, construction, and design, aiming to promote the construction of intelligent sites [151]. The staff distribution of this center is illustrated in Fig. 3.

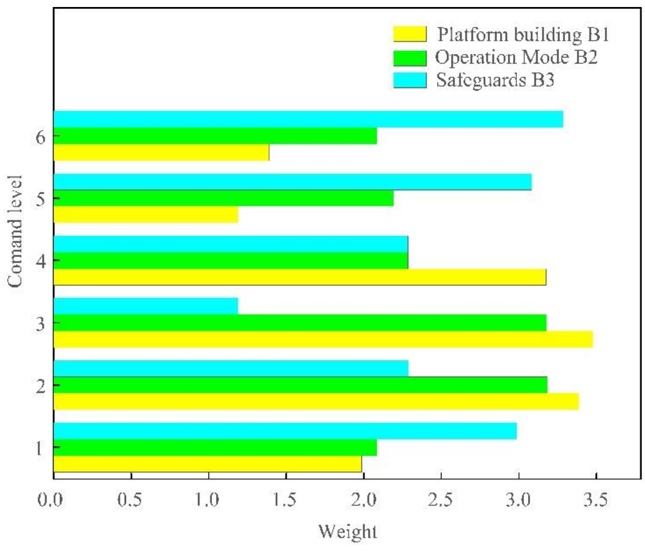

Fig. 3. Center Personnel Organization (DIM) [151].

The paper proposes an evaluation model of the safety management system for practical effectiveness assessment. In the comprehensive evaluation, each indicator is categorized into five levels: V = [V1, V2, V3, V4, V5] = [very good, better, average, poor, very poor], and assigned values V = [5, 4, 3, 2, 1] by 10 experienced personnel for the indicator system. Each expert evaluates the indicator layer individually using a grading system [151]. Due to the vague nature of the indicators, the frequency of each person's scoring can be integrated to determine the degree of affiliation of the indicator to a certain rubric level. The weight of the rubric level agreed upon by the 10 individuals is taken as the affiliation degree, establishing a one-dimensional fuzzy comprehensive judgment matrix, as shown in Fig. 4.

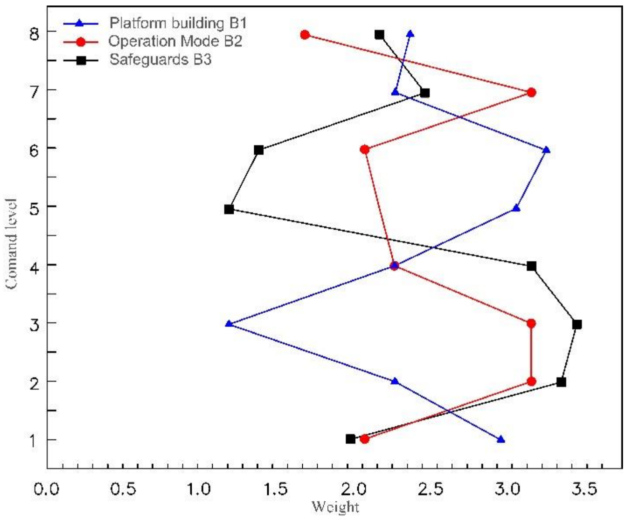

Fig. 4. Evaluation matrix [151].

For the application's effectiveness, based on on-site interviews and multi-level fuzzy comprehensive evaluations, it was found that implementing BIM technology in the construction process of the new archives project in the autonomous region was effective. It essentially achieved pre-defined safety management objectives, completed the planned application of BIM technology in safety management, visualized and managed safety activities throughout the project, and significantly enhanced safety management efficiency. The planned implementation of A+2 technology in safety management was successfully completed, visualizing and managing safety activities throughout the project, effectively enhancing safety management efficiency. This demonstrated the benefits and feasibility of BIM technology in guiding project safety management activities, leading the project to finally win the national construction safety standardization title.

2.4. Addressing Common Challenges in BIM Adoption

The implementation of BIM yielded certain advantages over the conventional approaches used in earlier projects. The simplicity of analyzing design possibilities and the speed at which the internal design approval process may be completed are two major benefits of the conceptual design stage, which, according to laws, falls under the "project preparation phase." Due to the increased clarity and transparency of each equipment system, pipe system, cable tray, etc., BIM demonstrates its efficacy in the phased review of detailed design throughout the project implementation phase. Multidisciplinary cooperation throughout the design coordination process demonstrated the benefits of BIM when it came to making judgments and choosing the best options based on criteria. BIM was useful throughout the construction phase in identifying design conflicts early on and recording the site's functioning characteristics prior to the commencement of on-site construction activity.

The project's use of BIM also revealed several drawbacks in contrast to its advantages, such as the need for more investment and the prolongation and rise in the cost of other processes and activities. For instance, it takes longer to export a BIM model during the conceptual design phase in order to submit 2D drawings to government organizations for review and approval. In comparison to the old technique, the design length and adjustments/changes took longer, and there was also more time invested in assessing BIM proposals and reviewing BIM-related outcomes. During the application process, other elements, such as the construction volume management, the visual layout of the work site, and volume extraction, have not been assessed. Businesses that lack internal BIM experts and qualified workers may find it challenging to develop and then put into practice their adoption strategy. Put differently, businesses are clueless about how to implement BIM. This is further supported by data from the case studies. As stated, Although the company in the case studies may employ a consultant to build its BIM adoption tactics, the company just needs one captain to lead its BIM adoption campaign. A BIM captain, interdisciplinary specialists (in the construction sector, as well as in information technology and BIM), and proficient modelers who are knowledgeable about BIM software are examples of in-house competence, according to case studies. This explains why the most common perceived obstacle to BIM adoption is "Lack of in-house expertise. "The second major perceived impediment is "no clear and effective drivers." The case studies indicate that motivators may include staff members who join the BIM team or the company as a whole adopting BIM. According to the literature, "Low ROI for BIM investment" is another important obstacle to BIM adoption. According to several case study respondents, there is less demand for BIM-enabled projects, which means it takes longer to reach the payback point. Additionally, customers do not find BIM level 1 to be efficient, but because of the high cost of the investments, BIM services are not particularly appealing to clients, and as a result, there is a poor success rate in contract bidding. On that point, one responder has a different opinion. Pricing skimming strategies might be used by businesses that provide BIM services to increase return on investment. Businesses need a supportive atmosphere in order to embrace BIM and begin using it. This explains why, in both the poll and the case studies, the majority of the enterprises identified legal difficulties as a significant impediment. This study has proven many legal difficulties, such as those pertaining to BIM contract forms, rules, cost standards, advice on BIM budget calculations, and the foundation for demonstrating BIM relevance. In addition, there are other concerns like who owns BIM models, what designers should do with them, etc. Relationships and procedures in a BIM-enabled project change greatly from those in a conventional project, yet the standards and rules now in place in the construction industry for management, cooperation, and guidance do not take these new working styles into account. BIM procedures cannot be facilitated by the lack of data management and sharing standards.

Integrating BIM and AI into construction management significantly enhances project efficiency, improving scheduling, cost, quality, and safety, yet it introduces complex challenges [136, 137, 143, 152-159]. These challenges span from the difficulties in bridging the gap between BIM's detailed building data and AI's need for varied, structured information, which is hindered by mismatched data formats and standards, necessitating standardized data handling methods. Additionally, the inherent complexity and the need for scalability in construction projects make it challenging to manage the myriad details and ensure AI can adapt to varied data sets and changing site conditions. The development and training of AI algorithms require sector-specific insights and a wealth of data, which are often scarce, thus demanding ongoing refinement of these algorithms. Ethical and legal concerns also arise with AI's application, focusing on data privacy, security, and accountability, and stressing the importance of adhering to ethical standards and legal frameworks. The success of BIM and AI integration heavily relies on the acceptance and education of industry professionals, who must be willing to adopt and effectively utilize these technologies, underlining the need for comprehensive training programs. Furthermore, construction projects demand real-time data handling and decision-making capabilities, requiring AI systems to process data rapidly to support immediate decisions. The costs associated with adopting BIM and AI technologies pose significant considerations against expected benefits and return on investment, making it crucial to demonstrate the tangible advantages to justify the investments. Moreover, the integration heightens vulnerability to cyber threats, necessitating stringent cybersecurity measures to protect sensitive project information and maintain the integrity of the digital assets [160, 161].

The significance of the human factor is evident as a key prerequisite for the effective adoption and utilization of BIM in construction project schedule management, highlighting the necessity for continuous education and knowledge exchange among personnel. Technological advancements that occur each year pose a challenge in meeting the demand for practical experience. Experienced employees may resist adapting to new technologies and updating their skills, whereas new graduates might struggle to keep pace with the swift progress of technological advancements. This aspect is particularly critical when integrating BIM methodologies, underscoring the need for targeted education efforts. To address this, the Steering Committee organizes online webinars, inviting national and international experts to share their insights on BIM, significantly contributing to the development of a skilled BIM workforce within the country. Moreover, key participants in a construction project, involved in everything from design to construction and operational phases, are encouraged to engage with BIM to fully leverage its benefits. However, the focus of these training sessions is primarily on the AEC (architecture, engineering, and construction) sector, excluding government employees, and aiming instead at educators, researchers, and public management personnel. This approach may offer a temporary solution, but in the long term, it is essential to involve experts and professional bodies in developing new standards and regulations that are relevant locally. Although BIM offers numerous benefits to construction projects, such as cost reductions, early adopters may not immediately see a return on their investment due to the limited market demand for these new services, posing risks for those who pioneer BIM implementation.

3. Discussion

This paper has systematically explored the transformative influence of Building Information Modeling (BIM) technology on the conventional practices of construction project management. Through a detailed examination of the integration between BIM and core project management knowledge areas, it is evident that BIM significantly augments the efficiency and effectiveness of project management through enhanced visualization, improved coordination, and better risk management. The case studies presented illustrate the tangible benefits achieved through BIM integration, highlighting improved outcomes in terms of scope, schedule, cost, and quality management.

However, despite these advantages, the widespread adoption of BIM faces notable challenges. Technological, organizational, and cultural barriers persist, impeding the full-scale integration of BIM within the construction industry. The discussion on these challenges sheds light on the multifaceted nature of BIM implementation, suggesting that a holistic approach encompassing technological innovation, organizational change, and cultural adaptation is required to realize the full potential of BIM.

The integration of Building Information Modelling (BIM) with Artificial Intelligence (AI) in construction project management represents a significant advancement. However, existing research reveals several gaps that need addressing to fully realize the potential of these technologies. Current studies predominantly focus on the theoretical benefits of BIM and AI, often neglecting practical challenges faced during implementation. Further empirical research is required to investigate these challenges, including data interoperability issues, the high cost of technology adoption, and the need for specialized training programs for construction professionals. The practical implications of integrating BIM and AI extend beyond theoretical enhancements; they offer tangible improvements in project efficiency, safety, and cost management. Real-time data analytics provided by AI can lead to more proactive decision-making and risk management, ultimately enhancing project outcomes.

While the synergy between these technologies promises to elevate the construction management practice to new heights, it also introduces new complexities, particularly in terms of data handling, algorithm development, and the integration of AI-driven decision-making processes. Future research should aim to develop standardized protocols for data integration and explore cost-effective solutions for the widespread adoption of BIM and AI in the construction industry.

The role of education and training has emerged as a critical factor in overcoming these challenges. As the construction industry evolves, the demand for professionals skilled in BIM and AI technologies grows. Therefore, the development of comprehensive BIM education and training programs is imperative to equip current and future generations of construction professionals with the necessary knowledge and skills.

4. Conclusions and Recommendations

The study systematically explores the transformative influence of Building Information Modeling (BIM) technology on traditional construction project management practices. By integrating BIM with core project management knowledge areas, significant enhancements in efficiency, effectiveness, and collaboration have been observed. The case studies demonstrate substantial improvements in project scope, schedule, cost, and quality management. BIM's capacity to offer precise visualizations and foster enhanced coordination among stakeholders proves essential in addressing complex project challenges and mitigating risks.

Despite these advantages, the widespread adoption of BIM faces considerable challenges. Technological barriers, organizational resistance, and cultural inertia hinder comprehensive BIM integration within the construction industry. Overcoming these obstacles requires a holistic approach that includes technological innovation, organizational restructuring, and cultural adaptation. A concerted effort from industry stakeholders, policymakers, and educational institutions is vital to create a conducive environment for BIM adoption.

Future research should continue to address practical implementation challenges, including data interoperability issues and the high costs associated with technology adoption. Emphasizing the importance of comprehensive training programs for construction professionals will ensure that the workforce is adequately prepared to leverage BIM's full potential. Additionally, integrating BIM with artificial intelligence (AI) can further enhance project management capabilities, offering predictive analytics and real-time decision-making support. The study underscores the necessity for ongoing innovation and collaboration to realize the full benefits of BIM in construction project management.

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