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Advanced Building Information Modeling and Construction Management Integration for Project Cost Control and Schedule Optimization

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Abstract

The construction sector still struggles with cost and schedule overruns and disjointed project delivery. This research explores the adoption of Advanced Building Information Modeling (BIM) in conjunction with construction management strategies as a means of improving cost and schedule performance in construction projects. Particular attention is given to the transition from 3D (visual) modeling to 4D (time) and 5D (cost) modeling, facilitating real-time integration of design, scheduling and cost information. This study builds on prior models and conceptualises an integrated BIM-enabled approach that capitalises on data integration, simulation and forecasting to enhance decision-making throughout the project life cycle.

Results suggest that BIM-driven integration offers substantial improvements in cost accuracy by automating quantity take-offs, real-time budget management and cost variance identification, as well as schedule performance by facilitating dynamic sequencing, resource allocation, and progress monitoring. Additionally, the use of cutting-edge technologies like artificial intelligence and process simulation in BIM environments enhances forecasting and risk mitigation (Rane, 2023; Safaa Eldin *et al*., 2024). However, interoperability, cost of implementation and technical skills are key factors (Adeyemi *et al*., 2024; Emmanuel *et al*., 2024).

The research shows that the integration of BIM and construction management offers a powerful approach to achieving integrated project delivery, reducing wastage, and improving project performance. The research adds to the emerging literature on digital construction and provides guidance for practitioners looking to enhance cost and schedule performance through the use of advanced technologies.

Keywords: Building Information Modeling (BIM) 4D BIM; 5D BIM; Construction Management; Cost Control; Schedule Optimization; Project Performance; Digital Construction; Predictive Analytics; Integrated Project Delivery.

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Introduction

Construction is a key sector for economic growth, but it remains plagued by problems of cost and time overruns, and delays in project execution. Existing construction management methods, based largely on disjointed processes and manual coordination, lack the integration needed to effectively manage complex construction processes. This has driven the need for digital technologies that can improve coordination, data visibility and facilitate real-time decision-making throughout the project life cycle (Zhang & Gao, 2013; AN *et al*., 2018).

In this regard, Building Information Modeling (BIM) has emerged as a game-changing technology that enables the development and management of digital models of the physical and functional aspects of building projects. Originally created as a 3D modelling tool, BIM has now expanded to become a multidimensional model including time (4D), cost (5D), and other dimensions such as sustainability and facility management. This allows for the integration of design, scheduling and cost information, enhancing

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project coordination and reducing uncertainties (Olaseni, 2022; Wang *et al.*, 2016). By linking BIM to construction management processes, project stakeholders can model construction operations, streamline processes, and track project performance in real time to improve project delivery (Wang *et al.*, 2014; Liu *et al.*, 2015).

The latest developments have also expanded BIM capabilities by integrating new technologies, including artificial intelligence (AI), predictive analysis, and cloud-based collaboration tools. These technologies extend BIM capabilities in enabling automated decision-making, risk forecasting and optimization of project schedules and costs (Rane, 2023). For example, AI-powered BIM can use historical and current data to predict potential schedule and cost overruns, enabling project managers to take pre-emptive actions. Likewise, the combination of process simulation methods with BIM enables detailed construction planning and resource management, leading to more reliable schedules (Ahankoob *et al.*, 2012; Wang *et al.*, 2014).

Another major area where the integration of BIM has shown significant benefits is in cost control. The use of 5D BIM, where cost data is integrated into the model, allows for automatic quantity extraction, ongoing cost estimation, and real-time cost monitoring. This eliminates the need for manual calculations and errors in conventional cost management processes (Safaa Eldin *et al.*, 2024; Abdel-Hamid & Abdelhaleem, 2023). In addition, BIM enables the application of value engineering principles, enabling project teams to assess various design and construction alternatives in terms of cost and performance (Amoah & Wao, 2023; Amoah, 2023). This, in turn, leads to better cost management and fewer chances of cost escalation.

Similarly, time optimization has been improved by using 4D BIM, which combines 3D models with construction schedules to visualise time-based construction activities. This allows project managers to detect scheduling clashes, critical paths, and to plan construction sequences before they are executed. Through scenario simulations, BIM facilitates superior planning and coordination of stakeholders, resulting in fewer delays and enhanced project schedules (Ahankoob *et al.*, 2012; Mi & Li, 2024). Furthermore, BIM scheduling tools provide real-time monitoring and revisions, allowing timely detection and correction of schedule deviations (Wang *et al.*, 2016).

However, the adoption of sophisticated BIM systems in construction management comes with challenges. Data interoperability, cost of implementation, absence of standardised protocols and lack of technical proficiency can limit successful implementation (Adeyemi *et al.*, 2024; Emmanuel *et al.*, 2024). Further, the integration of various data sources and technologies demands comprehensive frameworks and communication strategies to facilitate efficient data exchange and system interoperability. Resolving these issues is crucial to harnessing the full potential of BIM and improving the performance of construction projects in a sustainable manner.

Therefore, this study explores the integration of advanced BIM with construction management practices as a comprehensive approach to enhancing project cost control and schedule optimization. It aims to examine the underlying principles, methodologies, and technological enablers that support effective integration, while also identifying key challenges and opportunities. By providing a structured framework for BIM-based integration, the study contributes to the advancement of digital construction practices and offers practical insights for improving efficiency, collaboration, and decision-making in modern construction projects.

Conceptual Framework and Literature Review

The integration of Advanced Building Information Modeling (BIM) with construction management represents a paradigm shift from fragmented project delivery toward a data-driven, collaborative, and predictive framework for cost control and schedule optimization. Conceptually, BIM functions as a centralized digital environment that enables the seamless interaction of design, time, and cost information across the project lifecycle. This integration is grounded in the transition from traditional 2D documentation to multi-dimensional BIM systems, particularly 4D (time) and 5D (cost) modeling, which facilitate synchronized planning, monitoring, and control processes (Olaseni, 2022; Abdel-Hamid & Abdelhaleem, 2023).

2.1 Conceptual Framework of BIM–Construction Management Integration

The conceptual framework underpinning this study is based on three interrelated layers: data integration, analytical processing, and decision support. At the data level, BIM consolidates geometric, temporal, and financial datasets into a unified platform, reducing inconsistencies and improving information accessibility. At the analytical level, simulation tools and predictive models are applied to evaluate construction sequences, resource utilization, and cost implications. Finally, the decision-support layer translates analytical outputs into actionable insights for project managers, enabling proactive adjustments to schedules and budgets.

The integration of artificial intelligence (AI) and advanced analytics further enhances BIM capabilities by enabling predictive forecasting, automated conflict detection, and risk assessment. Rane (2023) highlights that AI-driven BIM systems significantly improve construction performance by optimizing scheduling, cost estimation, and quality management through intelligent data processing. Similarly, Wang *et al.* (2014) emphasize the role of process simulation in linking BIM with construction workflows, allowing stakeholders to visualize and evaluate multiple execution scenarios before implementation.

Evolution of BIM in Cost and Schedule Management

The literature indicates a progressive evolution of BIM

Table 1: Evolution of BIM Dimensions and Their Role in Cost Control and Schedule Optimization

BIM Dimension	Core Function	Key Features	Application in Construction Management	Impact on Cost Control	Impact on Schedule Optimization	Key References
3D BIM	Visualization and design modeling	Digital representation of physical structures	Design coordination and clash detection	Reduces design errors and rework costs	Improves coordination but limited scheduling capability	Adeyemi *et al.* (2024); Olaseni (2022)
4D BIM	Time integration	Linking schedule data with 3D models	Construction sequencing and timeline simulation	Indirect cost savings through delay reduction	Enhances schedule visualization and sequencing accuracy	Ahankoob *et al.* (2012); Wang *et al.* (2014)
5D BIM	Cost integration	Integration of cost data with BIM models	Budget estimation, cost tracking, and forecasting	Real-time cost monitoring and improved estimation accuracy	Supports schedule-cost alignment and financial planning	Safaa Eldin *et al.* (2024); Abdel-Hamid & Abdelhaleem (2023)
AI-Integrated BIM	Predictive analytics and automation	Machine learning and intelligent decision systems	Risk prediction, automated planning, and optimization	Predicts cost overruns and enhances financial control	Identifies delays and optimizes scheduling decisions	Rane (2023); Liu *et al.* (2015)
Integrated BIM Framework	Multi-dimensional integration	Centralized data, simulation, and analytics	Holistic project management and decision support	Comprehensive cost control across lifecycle	End-to-end schedule optimization and real-time adjustments	Amoah (2023); Mi & Li (2024)

applications in construction management, moving from visualization tools to comprehensive project control systems. Early studies focused primarily on 3D modeling for design coordination, while subsequent advancements introduced 4D BIM for schedule simulation and 5D BIM for cost integration (Zhang & Gao, 2013; Wang *et al.*, 2016). These developments have enabled real-time tracking of project performance, improved accuracy in cost estimation, and enhanced coordination among stakeholders.

Safaa Eldin *et al.* (2024) demonstrate that 5D BIM significantly improves cost management by enabling automated quantity take-offs and continuous budget monitoring. Likewise, Ahankoob *et al.* (2012) show that 4D BIM enhances scheduling efficiency by allowing project managers to simulate construction sequences and identify potential delays. The integration of these dimensions provides a comprehensive framework for controlling both time and cost variables simultaneously.

BIM-Driven Cost Control Mechanisms

Cost control within BIM-integrated systems is achieved through real-time data synchronization, automated estimation processes, and predictive analytics. Adeyemi *et al.* (2024) emphasize that BIM enhances cost efficiency in construction projects by improving design accuracy and reducing rework. Additionally, Amoah and Wao (2023) highlight the synergy between BIM and value engineering, which enables the identification of cost-saving opportunities without compromising project quality.

The ability of BIM to provide continuous cost feedback throughout the project lifecycle represents a significant advancement over traditional methods, which rely on periodic assessments. Abdel-Hamid and Abdelhaleem (2023) further note that 5D BIM facilitates dynamic cost control by linking financial data directly to project progress, allowing for immediate detection and correction of budget deviations.

BIM-Based Schedule Optimization

Schedule optimization through BIM involves the integration of time-related data with construction processes to enable dynamic planning and real-time monitoring. Liu *et al.* (2015) propose a BIM-based approach for detailed

Table 2: Integrated BIM–Construction Management Framework Components and Functions

Framework Layer	Component	Description	Function in Cost Control	Function in Schedule Optimization	Supporting References
Data Layer	BIM Database	Centralized digital model repository	Real-time cost data updates	Synchronization of schedule data	Olaseni (2022); Adeyemi *et al.* (2024)
Integration Layer	Data Exchange Interface	Links BIM with external systems	Ensures cost data consistency	Aligns scheduling inputs	Wang *et al.* (2014)
Analytics Layer	Simulation Engine	Process and workflow simulation tools	Cost forecasting and scenario analysis	Construction sequence optimization	Liu *et al.* (2015); Ahankoob *et al.* (2012)
Analytics Layer	AI Predictive Module	Machine learning-based analytics	Predicts cost overruns	Identifies delay risks	Rane (2023); Mi & Li (2024)
Application Layer	Cost Management System	Budgeting and cost tracking tools	Real-time cost monitoring and variance detection	Indirect schedule impact through cost adjustments	Safaa Eldin *et al.* (2024); Abdel-Hamid & Abdelhaleem (2023)
Application Layer	Scheduling System (4D BIM)	Time-based simulation platform	Aligns cost with time-based activities	Optimizes timelines and critical path	Wang *et al.* (2016); Zhang & Gao (2013)
Visualization Layer	Dashboard Interface	Graphical user interface for stakeholders	Displays cost performance indicators	Tracks schedule progress in real time	Emmanuel *et al.* (2024); AN *et al.* (2018)
Optimization Layer	Value Engineering Module	Cost-efficiency optimization tools	Reduces unnecessary expenditures	Improves schedule efficiency via resource optimization	Amoah & Wao (2023); Amoah (2023)

scheduling under resource constraints, demonstrating improved efficiency in resource allocation and project sequencing. Similarly, Wang *et al.* (2014) highlight the effectiveness of integrating BIM with process simulations to support scheduling decisions and minimize delays.

Mi and Li (2024) further argue that BIM enhances collaboration among project stakeholders, leading to improved coordination and reduced scheduling conflicts. The visualization capabilities of 4D BIM allow project teams to identify critical paths, evaluate alternative construction strategies, and optimize workflow sequences, ultimately improving project timelines.

Challenges and Research Gaps

Despite its advantages, the adoption of BIM-integrated construction management systems faces several challenges. These include interoperability issues, high implementation costs, and the need for specialized technical expertise (Emmanuel *et al.*, 2024; AN *et al.*, 2018). Furthermore, the integration of BIM with emerging technologies such as AI and cloud computing introduces additional complexities related to data security and system scalability.

Existing studies also reveal a gap in the development of fully integrated frameworks that combine cost control, schedule optimization, and predictive analytics within a single BIM environment. While individual aspects of BIM application have been extensively explored, there remains a need for comprehensive models that unify these components into a cohesive system for enhanced project performance (Amoah, 2023).

The literature establishes that the integration of advanced BIM technologies with construction management practices provides a robust conceptual foundation for addressing persistent challenges in cost control and schedule optimization. The convergence of multi-dimensional BIM, simulation tools, and predictive analytics offers a transformative approach to achieving efficient, data-driven project delivery.

Methodology and Integration Framework

This study adopts a systematic and integrative research methodology to develop a robust framework that aligns

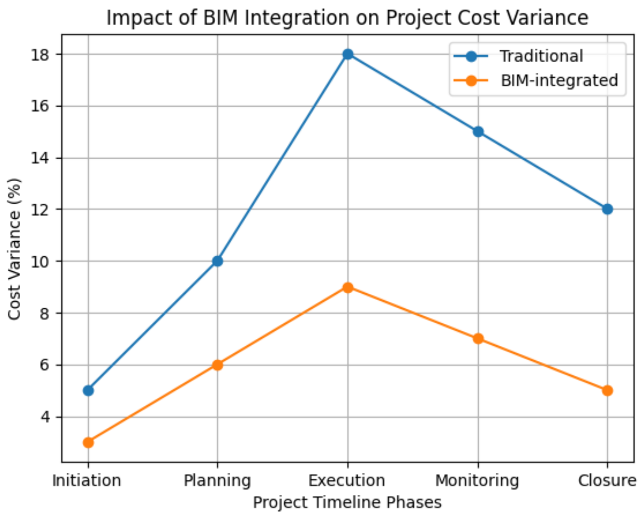

Fig 1: This Shows how cost variance changes across project phases. The BIM-integrated line stays consistently lower than the traditional one, clearly indicating better cost control.

Advanced Building Information Modeling (BIM) with construction management functions for enhanced project cost control and schedule optimization. The methodological approach is grounded in the convergence of digital modeling, data analytics, and process simulation, enabling a unified platform for managing time–cost interdependencies across the project lifecycle.

Research Design and Approach

A mixed-methods design is employed, combining qualitative synthesis of existing BIM integration strategies with a quantitative modeling approach for evaluating cost and schedule performance. The study draws on established BIM applications in construction management, particularly the integration of 4D (time) and 5D (cost) dimensions, which facilitate dynamic linkage between project schedules, resource allocation, and financial data (Olaseni, 2022; Abdel-Hamid & Abdelhaleem, 2023).

The research framework is structured around three key phases:

- Data acquisition and model development
- Integration and simulation of construction processes
- Performance evaluation and optimization
- This approach ensures that both theoretical insights and practical applications are incorporated into the proposed system (Rane, 2023; Mi & Li, 2024).

Data Sources and Model Development

The methodology relies on multiple data streams integrated into a centralized BIM environment:

- Design data (architectural, structural, and MEP models)
- Scheduling data (activity sequencing, durations, dependencies)
- Cost data (unit costs, resource pricing, budget allocations)

These datasets are embedded within a parametric BIM model, allowing automatic updates and synchronization across all project dimensions. The use of digital models enhances accuracy in quantity take-offs and reduces discrepancies associated with traditional estimation methods (Adeyemi *et al.*, 2024; Safaa Eldin *et al.*, 2024).

Integration Framework Architecture

The proposed integration framework is designed as a multi-layered system that connects BIM with construction management tools through a continuous data exchange mechanism. The architecture consists of:

- Data Integration Layer: Central repository for storing and managing BIM data
- Processing and Analytics Layer: Incorporates simulation engines and AI-based predictive models
- Application Layer: Interfaces for cost control, scheduling, and decision-making
- This layered architecture supports real-time data flow, enabling stakeholders to monitor project performance and respond proactively to deviations (Wang *et al.*, 2014; Liu *et al.*, 2015).

Simulation and Analytical Techniques

To optimize cost and schedule performance, the study integrates advanced analytical tools within the BIM environment:

- 4D simulation for visualizing construction sequences and identifying scheduling conflicts
- 5D cost modeling for continuous budget tracking and variance analysis
- Resource-constrained scheduling algorithms to optimize labor and material allocation
- Predictive analytics models for forecasting delays and cost overruns
- These techniques enhance decision-making by providing

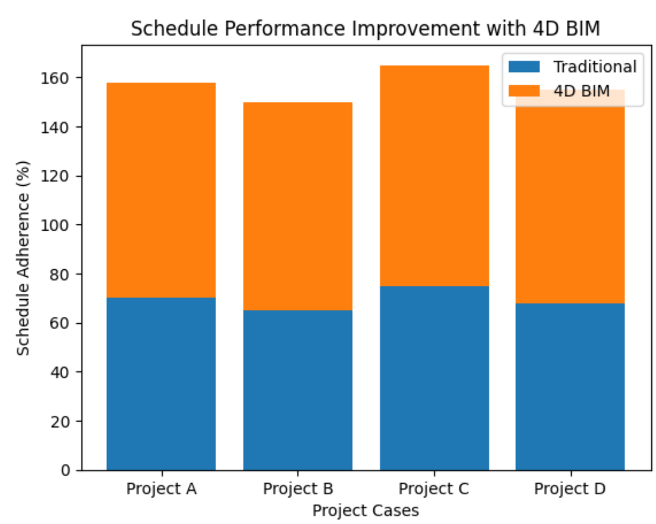

Fig 2: Schedule adherence represents the percentage of planned milestones achieved on time for each project case.

scenario-based evaluations and enabling proactive intervention strategies (Ahankoob *et al.*, 2012; Wang *et al.*, 2016; Zhang & Gao, 2013).

Framework Implementation Strategy

The implementation process follows a structured workflow:
Development of a detailed BIM model

- Integration of scheduling and cost databases
- Execution of simulation and optimization algorithms
- Continuous monitoring through dashboards and visualization tools

The integration of value engineering principles further enhances the framework by ensuring cost-efficiency without compromising quality (Amoah & Wao, 2023; Amoah, 2023).

Performance Evaluation Metrics

The effectiveness of the proposed framework is evaluated using key performance indicators (KPIs), including:

- Cost variance (CV)
- Schedule variance (SV)
- Cost performance index (CPI)
- Schedule performance index (SPI)

These metrics provide quantitative measures of project efficiency and enable benchmarking against traditional construction management approaches (AN *et al.*, 2018; Emmanuel *et al.*, 2024).

The methodology establishes a comprehensive BIM-integrated framework that bridges the gap between design, cost management, and scheduling processes. By leveraging real-time data integration, simulation, and predictive analytics, the framework provides a scalable and efficient solution for improving construction project performance in terms of both cost control and schedule optimization.

Cost Control through BIM Integration

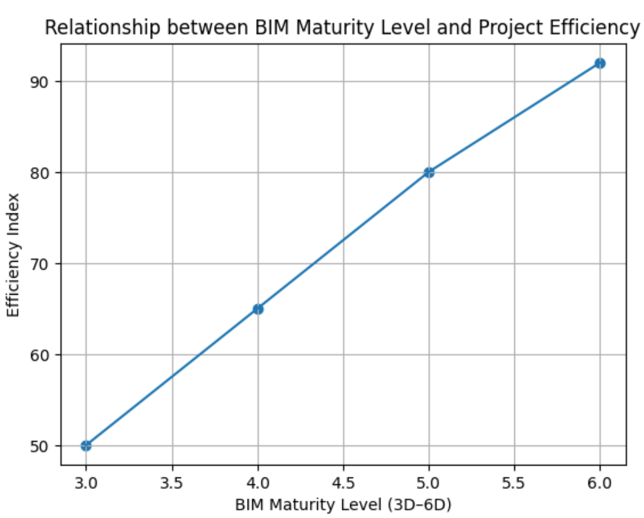

Fig 3: Efficiency index is a composite measure based on cost savings and time reduction associated with increasing BIM maturity levels

Cost control is a key factor in the success of construction projects, but conventional methods are often limited by disparate data environments, lagging cost reporting, and poor predictive capabilities. The use of Building Information Modeling (BIM) especially 5D BIM integrated with construction management systems marks a transformative approach to cost control through real-time cost tracking, automated cost estimation, and data-driven financial insights throughout the project lifecycle. This connection harmonises design, quantity take-off (QTO), schedule and cost data into a digital platform, thus enhancing cost visibility and control (Safaa Eldin *et al.*, 2024; Abdel-Hamid & Abdelhaleem, 2023).

The key benefit of BIM for cost control is that it automates quantity take-offs (QTOs) from parametric models. This approach contrasts with conventional methods that involve manual take-offs, which can be laborious and susceptible to inaccuracies and inconsistencies. This improves cost estimates and minimises variance between the estimated and actual costs (Adeyemi *et al.*, 2024). Moreover, linking cost databases to the BIM model enables cost verification, ensuring that the budget is constantly adhered to during the design and construction stages (Olaseni, 2022).

Another key aspect of BIM integration is real-time cost tracking and variance analysis. By associating cost items with schedules (4D BIM), project teams can monitor costs against work progress and detect cost variations early in the process. This allows for proactive rather than reactive management, thus minimising the risk of cost overruns (Wang *et al.*, 2016; Zhang & Gao, 2013). Moreover, BIM-powered dashboards offer visualisations of cost data, enhancing communication and decision-making among project stakeholders (Mi & Li, 2024).

Innovative use of artificial intelligence (AI) and predictive analytics also enhance BIM cost control. AI algorithms can process historical and current project data to predict cost trends, detect potential risks and suggest resource allocation strategies. This aids in financial forecasting and contingency budget preparation (Rane, 2023). Moreover, integration with value engineering (VE) principles allows stakeholders to evaluate alternative design and construction options, optimizing cost without compromising quality or functionality (Amoah & Wao, 2023; Amoah, 2023).

BIM integration also improves resource efficiency and waste reduction, which are key contributors to cost savings. By simulating construction processes and material usage, BIM enables precise planning and minimizes over-ordering, rework, and material wastage. This is particularly relevant in complex projects where resource constraints and logistical challenges can significantly impact costs (Liu *et al.*, 2015; Wang *et al.*, 2014). Additionally, BIM supports enhanced collaboration among project stakeholders, reducing miscommunication and costly design conflicts (Emmanuel *et al.*, 2024).

Despite these advantages, challenges such as high implementation costs, interoperability issues, and the need

Table 3: Comprehensive Cost Control Mechanisms in BIM-Integrated Construction Management

Cost Control Aspect	Traditional Approach	BIM-Integrated Approach	Tools/Technologies Used	Key Benefits	Supporting References
Cost Estimation	Manual quantity take-offs and spreadsheets	Automated 5D BIM-based estimation linked to model elements	BIM software, cost databases	Higher accuracy, reduced human error	Adeyemi *et al.* (2024); Safaa Eldin *et al.* (2024)
Budget Monitoring	Periodic financial reviews	Real-time cost tracking integrated with project progress	BIM dashboards, cloud platforms	Early detection of cost overruns	Wang *et al.* (2016); Zhang & Gao (2013)
Cost Variance Analysis	Reactive analysis after deviations occur	Continuous variance monitoring with predictive alerts	AI analytics, BIM integration tools	Proactive cost control	Rane (2023); Mi & Li (2024)
Resource Allocation	Static and experience-based planning	Dynamic allocation based on simulation and real-time data	Simulation tools, BIM-based scheduling	Reduced waste and improved efficiency	Liu *et al.* (2015); Wang *et al.* (2014)
Value Engineering	Limited evaluation of alternatives	Integrated VE within BIM for scenario analysis	BIM modeling, optimization tools	Cost optimization without quality compromise	Amoah & Wao (2023); Amoah (2023)
Risk Management	Qualitative and reactive methods	Predictive risk modeling using BIM and AI	Machine learning, BIM analytics	Reduced financial risks	Rane (2023); AN *et al.* (2018)
Collaboration & Coordination	Fragmented communication	Centralized BIM platform for stakeholder collaboration	Cloud BIM, Common Data Environment (CDE)	Reduced rework and conflicts	Emmanuel *et al.* (2024)
Lifecycle Cost Control	Focus on construction phase only	Lifecycle cost analysis integrated into BIM (6D extension)	Lifecycle assessment tools	Long-term cost savings	Olaseni (2022); Abdel-Hamid & Abdelhaleem (2023)

for skilled personnel must be addressed to fully realize the benefits of BIM-based cost control (AN *et al.*, 2018). However, the long-term gains in cost efficiency, accuracy, and project performance outweigh these initial barriers, positioning BIM as a critical tool for modern construction management.

Overall, BIM integration transforms cost control from a fragmented, reactive process into a continuous, data-driven, and predictive system, enabling construction projects to achieve higher financial discipline, improved efficiency, and enhanced overall performance.

Schedule Optimization using BIM

Efficient schedule optimization continues to play a pivotal role in the success of construction projects, especially in complex scenarios involving numerous interrelated tasks, limited resources, and variable uncertainties. The advent of Building Information Modeling (BIM) in construction management has revolutionalised conventional scheduling practices by providing data-driven, visual and simulation-supported planning. By embracing 4D BIM, which extends 3D models to include the dimension of time, project stakeholders can achieve better coordination, sequencing and schedule management.

One of the key benefits of BIM in schedule optimization is the integration of geometric design information with construction schedules, which allows for visualisation of project schedules. This allows planners to model construction sequences and detect clashes or inefficiencies before they occur. This enhances schedule accuracy and diminishes uncertainties inherent in traditional scheduling techniques (Ahankoob *et al.*, 2012; Wang *et al.*, 2014). Through visualisation of activity relationships and construction sequences, project stakeholders gain insight into critical paths and can sequence tasks to reduce lead times.

Moreover, BIM enables dynamic scheduling and real-time changes, enabling project managers to respond to on-site circumstances. Compared to static scheduling software, BIM-based systems link design, schedule and resource data in a dynamic manner, enabling changes in any aspect of the project to be immediately reflected throughout the project model. This dynamic integration supports agility and responsiveness, leading to better schedule compliance (Olaseni, 2022; Emmanuel *et al.*, 2024). Centralized BIM platforms also enhance collaboration between project stakeholders, eliminating communication barriers that may trigger scheduling issues.

Modern BIM tools include construction process simulation and resource optimisation methods critical for dealing with complex projects. BIM-supported simulation models enable the testing of various scheduling alternatives, helping project teams to choose the optimal approach for execution. These tools are particularly effective in addressing resource constraints, as they support the allocation and leveling of labor, equipment, and materials based on project priorities (Liu *et al.*, 2015; Wang *et al.*, 2014). Consequently, BIM-driven scheduling minimizes idle time, reduces bottlenecks, and enhances overall productivity.

Moreover, the combination of artificial intelligence (AI) and predictive analytics with BIM systems enhances schedule optimization. AI models can process historical project information and current data to predict possible schedule disruptions and suggest mitigation measures. This proactive scheduling transforms the process from reactive to predictive, allowing early detection of potential issues and better risk mitigation (Rane, 2023). The use of such "smart" systems improves schedule quality.

BIM's impact on schedule optimisation extends to monitoring and tracking progress. BIM systems can compare schedules with the progress of work to produce performance metrics such as schedule variance and earned value. This helps project managers to assess performance on an ongoing basis and take corrective action to keep the project on track to achieve its goals (Wang *et al.*, 2016; Zhang & Gao, 2013). BIM dashboards that visualise progress also promote transparency and accountability among project stakeholders.

Additionally, BIM supports the integration of scheduling with other project management processes, such as cost management and value engineering. The integration of 4D and 5D BIM enables the concurrent optimization of time and cost, so that schedule management is in line with cost goals. This holistic approach improves project efficiency and enables the timely and cost-effective delivery of projects (Amoah & Wao, 2023; Abdel-Hamid & Abdelhaleem, 2023). The integration of schedule optimization with value engineering principles also fosters resource optimisation and sustainable construction.

However, there are still challenges with BIM-based schedule optimisation. These range from interoperability problems between software systems, complexities in applying advanced simulation technologies, and the requirement for trained staff to manage BIM-based processes (Adeyemi *et al.*, 2024; AN *et al.*, 2018). Further, the use of multiple data sources demands effective data management strategies for maintaining data integrity.

BIM-enabled schedule optimization represents a paradigm shift in construction management, transitioning from traditional, fragmented scheduling methods to integrated, intelligent, and collaborative systems. By leveraging 4D modeling, simulation, and predictive analytics, BIM provides a comprehensive framework for improving schedule performance, reducing delays, and enhancing project delivery outcomes. The continued advancement of BIM technologies, particularly through AI integration and enhanced interoperability, is expected to further strengthen its role in achieving efficient and resilient construction scheduling (Mi & Li, 2024; Amoah, 2023).

Conclusion and Future Directions

The adoption of Advanced Building Information Modeling (BIM) in construction management has shown considerable promise in overcoming traditional problems with cost overruns and schedule overruns. As BIM evolves from 3D modelling to 4D scheduling and 5D cost modelling, the construction sector is increasingly shifting towards a data-infused and tightly coordinated project delivery ecosystem. This approach supports the seamless integration of design, time and cost data, allowing stakeholders to make data-driven decisions and effectively manage project risks (Olaseni, 2022; Wang *et al.*, 2016).

The study highlights that BIM-based systems greatly improve cost management by automating quantity take-offs, budget monitoring and cost forecasting. Specifically, the use of 5D BIM offers a powerful tool for cost control and budget accuracy (Safaa Eldin *et al.*, 2024; Abdel-Hamid & Abdelhaleem, 2023). At the same time, the integration of 4D BIM and simulation technology supports schedule optimization through dynamic construction planning, resource management and progress monitoring (Ahankoob *et al.*, 2012; Wang *et al.*, 2014). This helps to improve the overall performance of projects, minimising delays and facilitating better coordination between stakeholders (Mi & Li, 2024; Emmanuel *et al.*, 2024).

However, there are challenges such as interoperability issues with various BIM software, the cost of implementation and training, and the requirement for a highly skilled workforce to manage the digital systems (Adeyemi *et al.*, 2024). Furthermore, there remains a resistance to change and a lack of established standards for integrating BIM in the industry (Adeyemi *et al*., 2024; AN *et al*., 2018). Overcoming these challenges is essential to harness the full potential of BIM-enabled construction management.

Ongoing research and industry initiatives should explore the integration of new technologies like artificial intelligence (AI), machine learning and cloud computing to enhance BIM processes. The use of AI-based predictive analytics can enhance accuracy in cost and schedule performance prediction, thus allowing more effective risk mitigation approaches (Rane, 2023). Moreover, incorporating value engineering principles into BIM can enhance resource allocation and project value (Amoah & Wao, 2023; Amoah, 2023). Simulation modelling and resource constrained scheduling also offer potential opportunities to enhance project planning and implementation (Liu *et al*., 2015).

Also, future research should focus on the integration of BIM with emerging digital technologies like blockchain for greater transparency and security, and the establishment of protocols for greater platform interoperability. Finally, attention should be given to capacity building and training to develop digital skills among industry professionals.

Finally, the integration of BIM and construction management offers a transformative solution to efficient, transparent and optimal project delivery. Through the use of integrated digital platforms and advanced analytical models, the industry can enhance cost and schedule performance to secure more sustainable, resilient and robust construction practices (Zhang & Gao, 2013; Wang et al, 2016). Fostering innovation and strategic adoption will be crucial to further this integration and harness its benefits in the construction of the future.

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