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DIGITALIZATION IN CONSTRUCTION: PROGRESS TRACKING AND ESTIMATION

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ABSTRACT

The construction sector is evolving as new technologies seek to boost productivity, efficiency, and sustainability. Nevertheless, construction projects in developing nations continue to experience high failure rates, often due to budget overruns, schedule delays, and quality shortfalls (Pinto and Mantel1990). This phenomenon is still evident in the Indian construction sector. Among these challenges, construction project failure remains the most persistent challenge. Failure in construction projects is widely defined as the inability to achieve principal performance milestones, such as cost, time, technical specifications, and client satisfaction, which represent internal inefficiencies and ineffective project control (Pinto and Mantel 1990). Human mistakes and poor monetary administration are two of the most crucial underlying causes of delays, which result in project abandonment Shahhosseini et al. (2018). One of the most effective solutions to this problem is digitalization in the construction industry. Digitalization is the integration of industrialized technical approaches with digital technologies to improve the profitability and sustainability of construction projects Dauda et al.(2024). Digitalization in the construction industry must be implemented in various construction cycles. The demand for digitalization is apparent as construction companies strive to meet the growing demands for faster delivery, reduced costs, and improved quality. Dauda et al. (2024) describe how digitalisation assists organisations in accomplishing their objectives by simplifying operations, facilitating quicker communication, integrating systems, and improving overall asset productivity. Such processes reduce delays, errors, and waste in conventional building processes. However, the journey towards complete

digital adaptation is not smooth, especially in developing countries such as India. The strongest issue faced in tackling this challenge is the resistance to change within the organization, which is caused by a lack of awareness of the long-term benefits of digitalization. The second significant hindrance is the communication gap between individuals and technology in the construction life cycles (Nývlt and Kubečka ND).

For the effective implementation of digitalization in the construction life cycle, modifications should be adopted in the construction sector. Building Information Modelling (BIM) must be integrated into ERP systems employed in construction (Nývlt and Kubečka N.D). This study focuses on optimizing the construction process through digitalization by utilizing building information modeling (BIM) and real-time tracking tools to address long-standing challenges such as labor inefficiencies, scheduling delays, and the lack of data-driven planning, while also bridging the gap between planned project activities and actual on-site progress. This project suggests an applied proof of digitalization in the construction life cycle based on the use of Autodesk Revit, a 3-dimensional building model. This will serve as the basis for cost estimation, construction planning, and the breakdown of daily tasks. Additionally, by integrating real-time progress tracking, this project aims to provide a unified digital workflow that addresses common challenges in project planning and monitoring. This approach not only reflects the future of smart construction but also offers a feasible solution for improving project outcomes in resource-constrained environments in the future.

KEYWORDS: Construction industries, developing countries, Project failure, Digitalisation in construction, building information modelling (BIM), Autodesk Revit, Real-time progress tracking, Cost estimation, 3D model, Scheduling, sustainability.

INTRODUCTION

In 2025, the construction sector will account for approximately 9% of India's Gross Domestic Product (GDP). It still has a workforce of more than 70 million, which is the nation's second-largest employment base after that of agriculture. Therefore, the construction sector is a key determinant of the economic growth of all nations. Nevertheless, it still grapples with ongoing issues, especially in developing countries such as India. To overcome such longstanding problems, the construction sector is increasingly embracing digitalization. Different studies have reported the advantages of digitalizing the construction process. Hashim et al. (2013) asserted that digitalization enhances process quality, cost reduction, better client satisfaction, and responsiveness. Staub-French and Fischer (2017) reported that digital tools enable the early identification of design clashes, simplification of schedules, and minimization of excessive rework, resulting in resource savings. Despite these advantages, the uptake of this technology exhibits non-systematic patterns during different project phases.

Article History

Castagnino et al. (2016) emphasized that digital technologies possess transformative capacity in every step of the design, construction, and operations processes. Industry practices concentrate on the initial stages, specifically design and feasibility. This concurs with the findings of Jung and Lee (2015), who noted the minimal application of BIM in African nations, particularly during the post-construction phase. A similar trend is evident in India, where digital uptake is concentrated at the design level, with minimal implementation at the construction monitoring level. Osunsanmi et al. (2018) focused on cost estimation, planning, and design writing, whereas maintenance and operation phases are usually neglected in digital solutions. This projects a probable gap in lifecycle digitalization, indicating strategic and holistic implementation.

Literature review

J. K. Pinto and S. J. Mantel described the failure of important milestones such as cost, time, quality, and customer satisfaction due to internal inefficiencies and a lack of control over the project, a trend that is still rampant in the construction industry today, particularly in developing nations. Their research identified the absence of control as the leading factor for project failure. They comprised vague project objectives, ineffective team communication, insufficient planning, and erroneous cost estimation. They also cited improper personnel selection as a common root cause, resulting in rework, delay, and poor execution. Another significant issue is the absence of formal monitoring and control systems; therefore, deviations from the plan were identified too late to be rectified effectively. This study further emphasizes that without stringent internal controls, even well-capitalized projects collapse, an investigation that later vindicates the industry's transition towards digital options such as real-time monitoring, automated tracking, and built-in planning tools. This information formed the basis for examining the causes of project failure in the construction sector. In the early 2000s, researchers began exploring the practical uses of digital tools to reduce inefficiencies in construction processes.

H. Rivard (2000) conducted a national survey on the impact of information technology on Canada’s architecture, engineering, and construction (AEC) industry. The study found an increasing usage of CAD and computer-aided drafting tools, with 71% of design drawings produced entirely on computers. However, more critical areas, such as resource tracking, project scheduling, and cost control, remain under-digitized. Although email and Internet access have expanded, paper-based document exchange remains dominant, particularly among builders and contractors. While technology use has improved productivity, quality, and communication, it has also introduced new challenges, such as skill development, complexity, training needs, and higher investment costs. Most notably, Rivard’s survey captured the industry's growing demand for computer-integrated construction workflows and standardized data formats as an early signal of the future push towards BIM and compatibility standards. In India, the transition from conventional 2D drafting to digital modelling has been evolutionary. J.V. Kumar and M. Mukherjee specified the three evolutionary stages of architectural documentation in India, such as manual drafting before the 1980s, 2D CAD adoption in the 1990s, and later towards BIM in the early 2000s. They explain how the escalating intricacy of building systems and interdisciplinary coordination has made it mandatory to use a more integrated system, such as BIM.

To resolve these problems, Rivard et al. (2004) conducted in-depth case studies of Canadian construction firms to investigate how digital tools were beginning to reshape project execution. They inferred that while the industry was still highly fragmented, some firms had adopted technologies such as 3D CAD for design modelling, web-based portals for real-time drawing access, and in-house databases for managing project workflows. Mattamy Homes created a centralized digital system to effectively handle scheduling, budgeting, and customer service, acting as a precursor to fully integrated BIM platforms. Despite these advancements, the use of compatibility standards such as the IFC is still lacking, and field-level adoption remains limited due to technical skill gaps. These findings provide real-world confirmation of the disconnect between digital innovation and site-level execution, reinforcing the need for more cohesive, scalable, and user-friendly digital construction environments.

The Canadian case studies showcased the early adoption of digital tools in fragmented ways. R. Navon (2005) addressed a core limitation of these emerging systems and their reliance on manual data input. Therefore, he proposed the concept of Automated Project Performance Control (APPC), a shift towards data-driven monitoring using sensor-based feedback loops, unlike traditional reporting systems that are time-consuming and erroneous. Furthermore, the use of tower cranes is an indirect measure to gauge activities on the construction site, along with global positioning system (GPS)-based equipment tracking and worker location data to infer productivity and detect delays in real time. Navon also introduced the use of “work envelopes,” where a worker's physical presence in a defined spatial zone was linked to specific construction tasks. This model enables automated and continuous performance evaluation without interrupting site operations. His research laid the groundwork for the integration of the Internet of Things (IoT) and automated monitoring tools, which are now central to modern smart construction practices. To address emerging problems, workforce optimization, planning, scheduling, and human resource monitoring through digital tools are necessary. Effective workforce management not only guarantees task-level understanding and productivity but also minimizes idle time, improves safety, and enhances overall coordination, optimizing resources. Therefore, based on this requirement for better utilization of the workforce, Wang and Dunston conceptualized a training system called the Augmented Reality-based Training System (ARTS) for training construction equipment operators. Unlike conventional approaches, where off-site training is unrealistic and on-site training is costly and risky, ARTS superimposes virtual instructions, safety alerts, and performance feedback on real-world construction sites. This system enables novice operators to learn how to use actual equipment while interacting with immersive, computer-enhanced situations. Their system combines real-time tracking, a head-mounted display, haptic feedback, and digital equipment databases, copying many of the technologies already applied in BIM-based site management systems. Notably, Wang and Dunston recognized the same issues in AR deployment interoperability, immature sensor technology, and data constraints, which are also common in current BIM-to-3DCP workflows. Their research shows that immersive training environments can be a great asset in workforce optimization, particularly in resource-limited areas where safety concerns, skill shortages, and low productivity are chronic issues.

The construction industry is usually recognizable for its low productivity and reluctance to change, which are believed to be drawbacks in the architecture, engineering, and construction (AEC) industries. (Begić et al.2022). The failure of construction projects remains a persistent challenge, especially in the presence of resource constraints, weak planning, and inadequate project governance. Numerous studies have investigated the causes of such failures and identified patterns that transcend project types and contexts. A critical review of the existing literature reveals two predominant root causes: financial mismanagement and improper contractor or personnel selection. (Shahhosseini et al.2018). El-sokhn et.al. (2014) noted that financial instability, lack of skilled personnel, and weak communication among stakeholders are consistent risk factors. These issues are predominant in developing countries, where outdated practices, limited digital adoption, and a shortage of skilled workers compound inefficiencies along with the industry's segmented structure, often resulting in communication gaps, duplication of efforts, and under-utilization of resources. In response to these persistent issues, researchers have turned their attention to digitalization as a potential solution.

According to Begić et al. (2022), the construction and maintenance phases of a project remain the least digitized, despite being labor-intensive and having the most potential for automation.

To overcome these problems, workforce optimization, strategic planning, scheduling, and monitoring of human resources using digital tools are required. Efficient workforce management ensures task-level clarity and productivity, reduces idle time, improves safety, and enhances overall coordination. Such results can be obtained through the emergence of new technologies such as Building Information Modelling (BIM), the Internet of Things (IoT), and real-time progress tracking tools. Workforce optimization is no longer a manual or reactive process but can be automated and integrated across all project phases (Begić et al. 2022), (Memon et al. 2006).

One of the most notable digital tools in construction is Building Information Modelling (BIM). Ibem and Laryea (2014) noted that BIM adoption shifted the industry's focus towards digital awareness. However, this awareness often remains at the conceptual level, with full implementation not yet being the norm. This partial adoption reflects the transitional phase of the industry, where digitalization is acknowledged but not deeply integrated into all facets of construction activities. In comparison to CAD, which produces independent 2D drawings, BIM is an object-based model in which every component (example- beam and wall) has attached properties such as material, load-bearing capacity, and size. According to Kumar et al. (2009), integrating these enables the automatic coordination of changes to all drawings, plans, elevations, and sections, thereby reducing errors and enhancing quality. BIM improves project efficiency and accuracy across building phases by reducing errors through early-stage virtual modelling (Papuraj et al. 2025). BIM helps reduce the time spent on projects by allowing the early detection of work clashes and the simulation of implementation methods (Toyin and Mewomo 2023). Evidence from the Indian industry also illustrates BIM's efficiency benefits of BIM. Kumar and Mukherjee (2009) reported that companies employing BIM achieved tangible time savings of up to 91% in checking and coordination activities over conventional CAD-based approaches. These results attest to BIM's real-world utility of BIM in resource-scarce settings, where cost and time management are paramount.

Due to such advantages of BIM, the construction industry is looking forward to integrating two revolutionary technologies, BIM and 3D concrete printing(3DCP). 3DCP is an excellent example of workforce optimisation as it directly addresses the two biggest labour-related challenges, such as reducing dependency on manual labour and enhancing efficiency through automation. Concrete construction can benefit significantly from automation towards reducing labour, construction time, improving quality, and reducing environmental impact. By removing the need for formwork, which accounts for 35–54% of total construction cost and 50–75% of total construction time, 3DCP eliminates a key labour-heavy component of concrete work (Paul et al. 2018). A BIM model will be developed to identify design and construction conflicts in a project in advance. This digital model will then serve as the basis for 3DCP, enabling accurate, clash-free physical construction directly from the coordinated virtual environment. Though 3DCP appears to be a simple and efficient process, its practical application presents significant challenges. One of the main drawbacks is the issue of interoperability: BIM stores data in formats like IFC (Industry Foundation Classes). Most 3DCP systems are not yet developed to effectively convert these formats into machine-readable printing instructions such as G-code (Anane et al. 2023).

In India, 3DCP is gaining momentum with notable projects such as the first 3D-printed post office in Bengaluru, the country’s longest 3D-printed wall in Chennai, the first 3D-printed temple in Siddipet, and the first 3D-printed villa constructed in Pune Still, further study is required for the development of this technology. This present study focuses on optimising the construction process through digitalisation by utilising Building Information Modelling (BIM) and real-time tracking tools to address long-standing challenges such as labour inefficiencies, scheduling delays, and the lack of data-driven planning, while also bridging the gap between planned project activities and actual on-site progress.

Methodology

The evolution of digitalization in construction methodologies can be traced from early studies in the 1990s to advanced integrated workflows in recent years. This progression is visually summarized in Figure 1. (Pinto and Mantel 1990) used qualitative project failure analysis through case reviews to identify internal inefficiencies such as poor planning, weak communication, and inadequate monitoring, highlighting the urgent need for more structured, data-driven project control. This finding established a foundation for performance-tracking systems. Building on this, Rivard (2000) Examined how web-based collaboration platforms could improve project information exchange by reducing document delays through centralized, Internet-enabled environments, paving the way for cloud-based project management tools. Rivard et al. (2004) further addressed interoperability challenges by advocating for Industry Foundation Classes (IFC) and proposing a framework for integrating multiple stakeholders into a common digital data model, which later became a core principle in open BIM standards which later became a core principle in open BIM standards. Navon (2005) introduced Automated Project Performance Control (APPC) methods using real-time data acquisition via sensors and GPS and indirect productivity tracking through equipment location and crane telemetry, enabling timely comparisons between actual and planned progress. This study laid the groundwork for IoT-enabled site monitoring. Kumar and Mukherjee (2009) studied India's gradual digital evolution from manual drafting to 2D CAD and then to BIM, identifying adoption barriers such as lack of awareness, training gaps, and cost concerns, which guided targeted BIM training initiatives in developing countries. Ibem and Laryea (2014) applied surveys and interviews to reveal that BIM adoption in Africa was largely conceptual, with limited practical implementation across project phases. Their findings highlight the need for capacity building and practical demonstration projects to move beyond awareness. Castagnino et al. (2016) compared digital technology use across the project lifecycle and found strong adoption in the design phases but minimal integration into construction and operations, prompting a greater focus on lifecycle BIM. Paul et al. (2018) experimentally evaluated 3D Concrete Printing (3DCP) and quantified its benefits in eliminating formwork, reducing costs by up to 54% and cutting construction time by as much as 75%, demonstrating automation's potential to address labour shortages. Marzouk and Abdelhamid (2023) conducted BIM simulations to benchmark cost and time reductions against traditional approaches, validating BIM's role as a decision-support tool for project optimization. Dauda et al. (2024) integrated 4D and 5D BIM into case projects to enhance schedule and cost control through improved workflow modelling and communication, accelerating project delivery timelines. Most recently, Papuraj et al. (2025) applied early-stage BIM simulations for virtual clash detection and construction method planning, demonstrating significant efficiency gains, error reduction, and improved coordination, thereby solidifying BIM as a core enabler of automated and intelligent construction workflows.

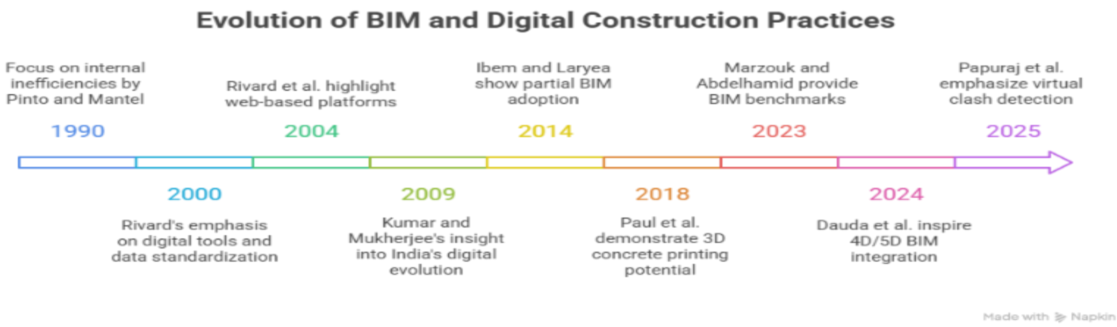

Figure 1: Evolution of BIM and Digital Construction Practices (Source: Napkin.ai)

RESULTS AND DISCUSSION

While previous research has launched digitalization in construction, there is still much research to be conducted, as methodological limitations have contributed to a disconnection between theoretical potential and practical, scalable solutions. The earliest work by Pinto and Mantel (1990) was primarily diagnostic, identifying planning errors, weak communication, ineffective monitoring, and poor control as the key drivers of project failure. However, their study stopped short of offering structured, technology-enabled solutions that could directly resolve these issues. This meant that while the problems were well understood, there was no roadmap for correcting them using modern tools. Rivard (2000) and Rivard et al. (2004) progressed the discussion by examining web-based systems and data standardization for collaboration. However, these systems lack real-time feedback mechanisms, so deviations from plans can only be identified after significant delays. They also failed to achieve interoperability, meaning that data could not move seamlessly across platforms or stakeholders, causing duplication of effort and errors. Furthermore, the technology of the time, including limited Internet speeds, primitive software capabilities, and minimal cloud infrastructure, restricted their practical impact.

In the Indian context, Kumar and Mukherjee (2009) documented the shift from manual drafting to 2D CAD and the early BIM stages. While historically valuable, their work was descriptive in nature; it recorded the transition but did not quantify the resulting benefits in terms of time savings, cost reduction, and quality improvement. Without empirical evidence, industry stakeholders have no concrete justification for widespread investment in digitalization. By the mid-2010s, Ibem and Laryea (2014) revealed that although awareness of BIM had grown, most adoption remained partial or conceptual, particularly in resource-constrained settings. BIM models are often created during the design phase but are not integrated into construction execution or monitoring, leaving a significant gap between planned and actual progress.

Castagnino et al. (2016) recognized the transformative potential of digital technologies throughout the project lifecycle, but their scope excluded the post-construction and maintenance phases. This is a major omission, as the operational stages often hold the greatest opportunities for cost savings, energy efficiency, and long-term asset performance improvements. Without full lifecycle integration, digitalization efforts risk delivering only short-term benefits. Across all these studies, a recurring theme is the absence of a unified, measurable, and continuous digital workflow that links planning, design, execution, and operation in real-time.

CONCLUSIONS

This project was specifically designed to bridge the gaps left by earlier research. Where Pinto and Mantel (1990) only diagnosed inefficiencies in planning, communication, monitoring, and control without actionable remedies, this study implements an Autodesk Revit–based BIM workflow that integrates cost estimation (5D), scheduling (4D), and daily task breakdown with real-time progress tracking to enable both measurable improvements and live performance feedback. Rivard (2000) and Rivard et al. (2004) lacked real-time feedback and interoperability; in response, the proposed system links live site updates directly to the BIM model, making it accessible to all stakeholders and exportable in open formats, such as IFC, to ensure seamless data exchange. Kumar and Mukherjee (2009) provided a descriptive account of India's digital shift without quantifying its benefits, whereas this project captures and compares the planned versus actual values for cost, schedule, and work output. To counter the partial or conceptual BIM adoption reported by Ibem and Laryea (2014), the model is embedded throughout the full project cycle from design to execution and monitoring, demonstrating complete workflow integration even in resource-constrained contexts. Castagnino et al. (2016) excluded post-construction phases; however, in this study, solar analysis extends the model's usefulness into operations by optimizing building orientation and energy performance. Furthermore, the inclusion of workforce deployment analysis through daily task breakdown addresses an overlooked area in earlier studies, while exploratory work on BIM-to-3D concrete printing interoperability positions the workflow for future automation, making it both comprehensive and forward-looking within the Indian construction context. This project follows a mixed method of optimising the construction process using Building Information Modelling (BIM), real-time monitoring tools, and solar analysis. This methodology integrates digital design, simulation, scheduling, and workforce planning using Autodesk Revit to bridge the gap between conventional workflows and automated construction. Using Autodesk Revit, a detailed BIM model of a construction project is developed, incorporating not only architectural and structural elements but also key project management components such as cost estimation, construction time calculation, and daily task breakdowns. The model also includes solar analysis, which assesses the sun's path and exposure on the building at different times of the day and year. This analysis is crucial for determining the best orientation for natural lighting, planning and placement of solar panels, and improving energy efficiency from the design stage. In addition, the model will be designed to support real-time progress monitoring, enabling site managers to compare the actual work completed with the planned schedules daily. This integrated digital approach enhances task clarity, improves coordination, reduces idle time, and supports more efficient workforce deployment, which are key elements of workforce optimization.

Data Availability

No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflict of Interest

The authors declare that they have no conflict of interest.

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