Discover Materials

Case Study

The impact of BIM on project time and cost: insights from case studies

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Abstract
Building Information Modelling (BIM) has emerged as a transformative tool in the Architecture, Engineering, and Construction (AEC) industries, offering significant potential to improve project efficiency and outcomes. This study explores the impact of BIM implementation on project time and cost by analyzing critical factors such as design errors, unbudgeted changes, Requests for Information (RFIs), labour dynamics, and scheduling across multiple case studies. Quantitative results reveal that BIM adoption reduces project timelines by an average of 20% and costs by 15%, while also decreasing design errors by 30% and RFIs by 25%. Furthermore, BIM enhances collaboration among stakeholders, improves design visualization, and facilitates better risk assessment, leading to more informed decision-making throughout the project lifecycle. These findings are synthesized into a decision-making framework that estimates the probability of errors, evaluates their potential time and cost implications, and ensures alignment with project budgets. The framework serves as a strategic guide for project teams to assess the suitability of BIM for specific projects, thereby optimizing decision-making processes and improving overall project performance. Additionally, the study examines the role of BIM in sustainability by reducing material waste and improving resource allocation. This study addresses a critical gap in the field by systematically evaluating the interrelationships among BIM's impacts on key project parameters, which have often been treated in isolation in prior research. The importance of this work lies in its provision of a structured methodology to harness BIM's capabilities, demonstrating its value in delivering significant time and cost efficiencies while enhancing project quality. By integrating empirical analysis with practical applications, this research contributes to the growing body of knowledge on BIM adoption and provides actionable insights for AEC professionals seeking to optimize project outcomes.

Keywords BIM · Construction management · Efficiency · Project cost & time

Abbreviations

BIM	Building information modelling
RFI	Requests for information
AEC	Architecture, engineering, and construction
AECO	Architecture, engineering, construction, and operations
SMEs	Subject matter experts
CEIC	Centre for the study of education in an international context
GDP	Gross domestic product

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1 Introduction

Building Information Modeling (BIM) has emerged as a transformative digital process that fundamentally reshapes the planning, execution, and management of construction projects. By capturing detailed architectural and contextual data, BIM enhances construction practices by providing organized spatial information and facilitating informed decision-making throughout the project lifecycle—from conceptual design to facility management [1, 2]. The effectiveness of BIM in fostering knowledge sharing and collaboration among stakeholders has been widely recognized, resulting in improved construction efficiency and effectiveness [3, 4] (Kivell et al. 2017). This research posits that the adoption of BIM significantly reduces project time and costs by enhancing project coordination, minimizing errors, and optimizing resource allocation [5, 6]. As the construction industry undergoes a significant paradigm shift, BIM stands out as a powerful tool equipped with innovative functionalities that support advanced management techniques [7, 8]. The integration and sharing of information within collaborative environments, bolstered by cutting-edge information technologies, further enhance the overall management of built assets [9, 10].

In the digital age, BIM provides a comprehensive view of the built environment, emphasizing collaboration among diverse stakeholders within the Architecture, Engineering, and Construction (AEC) industries [11, 12]. However, the extent of BIM adoption varies significantly across regions. In India, a rapidly developing nation with a burgeoning construction sector pivotal to its economy, the adoption rate of BIM is alarmingly low, estimated to be between 10 and 18%. This starkly contrasts with the United States, where BIM adoption is approximately 71% [13, 14]. This discrepancy can be attributed to various factors, including economic development, technological infrastructure, and varying levels of industry awareness [15]. Despite its established potential, the limited adoption of BIM in India highlights the urgent need for a comprehensive understanding of its implications and benefits in the local context [14, 16] (Gupta and Singh 2021). As BIM continues to gain traction globally, this research aims to evaluate its impact on project cost and time efficiency through a robust decision-making framework. Specifically, the study will identify key factors influencing construction project costs and timelines, formulate a framework for these factors, and validate their interconnections through case studies.

The introduction of BIM into the AEC sector over the past decade has yielded notable benefits across various project phases [17, 18] (Tatum and Zohdi 2018). However, one of the major challenges to widespread BIM implementation remains the lack of quantifiable benefits that substantiate its value. This paper seeks to address this gap by quantifying the benefits of BIM integration in construction projects and utilizing this data to develop a comprehensive decision-making framework. By doing so, this research contributes to a deeper understanding of how BIM can enhance project efficiency and effectiveness, thereby promoting its adoption in regions where it remains underutilized [19].

This study enhances existing BIM research by using real-world case studies to provide practical, actionable insights into BIM's impact on project time and cost, moving beyond theoretical models. It delivers detailed, context-specific findings across various building types and geographical locations, offering a nuanced understanding of BIM's effectiveness. The study incorporates longitudinal data, capturing BIM's influence throughout a project's lifecycle, and includes perspectives from multiple stakeholders, revealing the organizational dynamics involved. By comparing diverse projects, it identifies common trends and outliers, distilling best practices and potential pitfalls. Additionally, the research offers practical implementation strategies and contributes to the development of industry standards. This comprehensive, evidence-based approach provides valuable guidance for practitioners, researchers, and policymakers, enhancing the understanding and application of BIM in building projects.

2 Literature review

Building Information Modeling (BIM) has emerged as a transformative technology in the construction industry, integrating processes and software to enhance the value of building projects [20]. More than just a tool, BIM represents a comprehensive approach to information management that spans the entire lifecycle of a construction project, from initial design through construction and into facilities management [21]. This holistic integration allows for improved project delivery, enhanced collaboration, and greater efficiency in resource utilization. Despite the numerous advantages associated with BIM, its implementation is not without challenges. A study by [22] highlights various risk factors in the application of BIM, emphasizing that effective management of these risks is crucial to avoid unnecessary cost losses. Additionally, [23] identifies the need for further research into the risks and challenges of BIM implementation, while also demonstrating the significant benefits that this hybrid integration can bring to the Architecture, Engineering, Construction, and Operations (AECO) industry. However [24], notes that little is known about the specific implementation processes and the challenges faced by practitioners, indicating a gap in the existing literature.

While a plethora of studies on BIM have emerged over the last decade [25], points out that previous research has not adequately collated or prioritized the benefits, risks, and challenges of BIM based on comprehensive literature reviews and input from subject matter experts (SMEs). This gap underscores the need for a structured examination of BIM's multifaceted applications and its pivotal role in modern construction practices. BIM serves as a dynamic repository of information, facilitating seamless communication and collaboration among project stakeholders [26]. It provides a shared platform where architects, engineers, contractors, and other professionals can access and exchange data, laying a solid foundation for informed decision-making throughout a project's lifecycle [27]. One of BIM's standout features is its ability to create detailed 3D models that closely resemble the actual building [11]. The degree of detail in these models significantly impacts a structure's performance, making them invaluable tools for architects and engineers. These models aid in visualization and serve as the basis for various critical functions, including fabrication, code compliance, and cost estimation [28, 29].

In construction, BIM's applications extend to streamlining the creation of fabrication and shop drawings, simplifying complex processes such as sheet metal ductwork production. Additionally, it enhances construction sequencing by coordinating building component ordering, fabrication, and delivery timelines [30]. BIM also excels in conflict detection, identifying interferences and collisions between various systems, which enhances construction safety and efficiency. Beyond the construction phase, BIM proves valuable in facilities management, supporting renovations, space planning, and maintenance operations [31].

2.1 BIM in project life-cycle

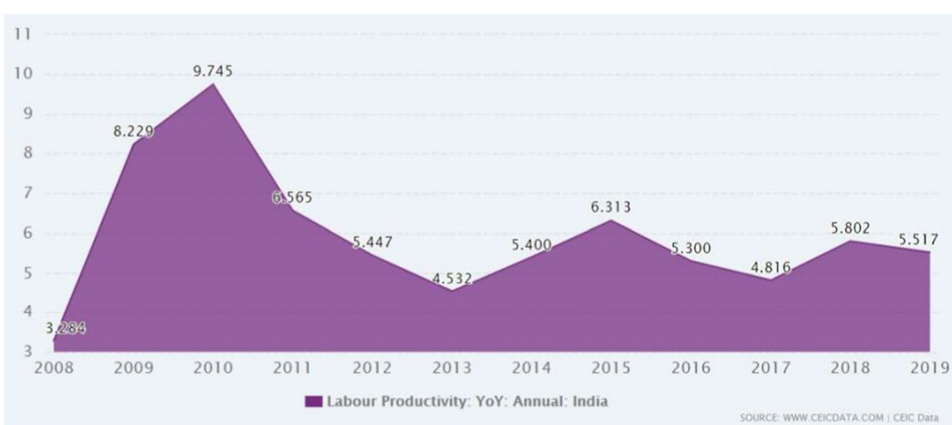
As per the Centre for the Study of Education in an International Context (CEIC), in the construction sector in India, labor productivity is declining and is expected to be in the same declining position for some time, Fig. 1, taken from CEIC source. As per the planning commission, India is an underdeveloped country, continuing to grow in terms of construction output. The construction sector indirectly contributes to the Gross domestic product (GDP) of the nation.

India stands amongst the lowest, with just 10–18% being its BIM adoption rate as compared to 71% of users of BIM in the United States alone [32]. With the increasing use of BIM in the construction sector, benefits can be analyzed with a low labor productivity rate.

The graph (Fig. 2), taken from G.M. Jagadeesh (2019) [33] shows the usage of BIM in project stages- Concept and schematic design, Design Development, Procurement and tendering, Construction and Facility operation. The maximized users are using it for design development, followed by construction and conceptual design.

The graph (Fig. 3), taken from Eastman (2011) [34] represents the relationship of the level of influence on cost with Project time duration. The timeline of the project is divided into different phases based on the project life-cycle steps, including the conceptual stage, design and engineering stage, procurement and structure stage, followed by the operation and maintenance stage at the end. The two curves on the graph represent the ability to influence the cost and the

Fig. 1 Labour productivity growth in construction sector



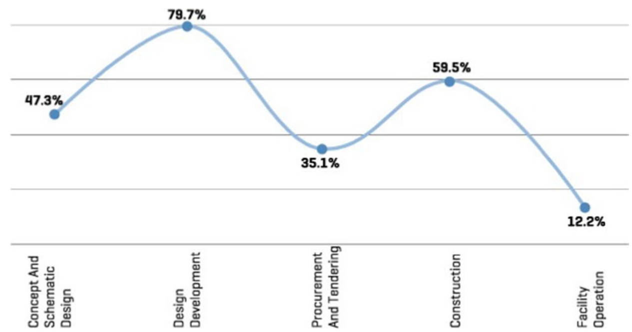


Fig. 2 BIM usage in various project

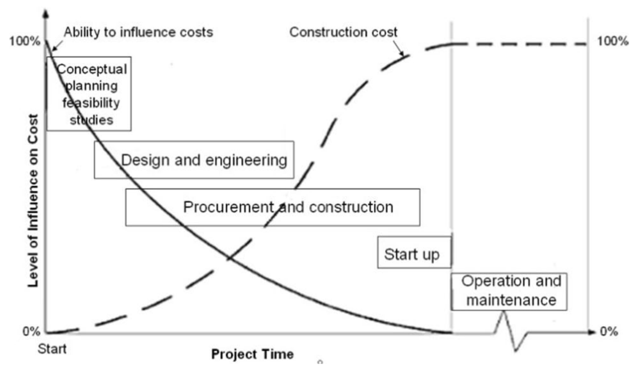


Fig. 3 Project life cycle: ability to influence cost

construction cost of the project. As we are leading towards the last step of the project life cycle, it can be noted that the ability to influence cost is becoming negligible as a major part of the construction cost is already being spent.

As per [1], use of BIM during the conceptual and design phase can maximize the effect on construction cost, i.e., reduction of the overall cost estimated. The team can creatively come up with ideas and provide solutions to issues before problems become high-cost impacts to the project.

2.2 Benefits OF BIM

The primary benefit of Building Information Modeling (BIM) lies in its capacity to provide an accurate and detailed representation of a building's components within an integrated data environment. This accuracy fosters various advantages, including accelerated and more efficient processes through enhanced information sharing and reuse of data (CRC Construction Innovation, 2007). Such an integrated approach enables better design outcomes by facilitating rigorous analysis, rapid simulations, and performance benchmarking, ultimately leading to more innovative and effective solutions [1]. BIM also plays a crucial role in controlling whole-life costs and understanding environmental data, resulting in more predictable environmental performance and improved lifecycle cost management. By capturing detailed information about materials, systems, and operations, BIM allows for a comprehensive assessment of potential cost implications throughout a building's lifespan [35]. Additionally, the flexibility of documentation outputs and automation capabilities inherent in BIM enhance production quality and efficiency. This digital product data can be leveraged for downstream processes, such as manufacturing and structural system assembly, further streamlining the construction workflow [1]. The study reviews methodologies for clash detection in BIM, highlighting its role in reducing rework and project delays [36]. Another paper shows how effective clash detection improves project performance by minimizing errors and enhancing coordination [37]. Additionally, the study investigates the impact of 4D BIM on project time management, aiding in planning and monitoring construction activities [38]. This meta-analysis assesses BIM functionalities like clash detection and scheduling, demonstrating their effects on project cost and time efficiency [31].

A literature review on BIM highlights its multifaceted benefits, which can be observed immediately upon implementation, Table 1. While the initial investment in BIM technology can be substantial, the long-term financial benefits are noteworthy, suggesting that organizations can significantly enhance their operational efficiency and cost-effectiveness through its use [35]. Notably, the applicability of BIM extends beyond the initial model formation; its benefits can be realized across multiple phases of the project lifecycle, enhancing overall project outcomes [20]. However, it is crucial to

Table 1 Benefits of BIM in different stages of a project

Stages	Benefits of BIM
Design Phase	Evaluate the impact of design alternatives Less time required to spend on documentation Lower risks and better predict outcomes (errors and conflict reduction) Enables automation of documentation (better accuracy and automatic changes) Enable faster reviews
Construction phase	Reduce RFIs, change orders, claims and conflicts Reduce construction and production cost Reduces project delivery time Reduces on-site wastage
Both design and construction phase	Increases client engagement Clear understating of the scope of the project Increases productivity and efficiency Encourages sustainable methods of usage
All project phases	Improves collaboration and communication Increases project profitability Allows for long-term data assessment

note that BIM is primarily utilized during the planning and design stages of a project, with somewhat limited application during the construction and operational phases. Research by [20] has identified and categorized the main and secondary functions of BIM throughout various project phases, illustrating its importance not only in design but also in construction management and facilities operation [39].

2.3 Investment cost of BIM

According to Autodesk's research, businesses are aware of the costs associated with BIM adoption. However, there is a lot of diversity across companies when it comes to assessing or tracking BIM expenditure as a separate expense from overall business operations. Because the costs of BIM typically go beyond hardware changes, the following areas should be considered when evaluating the cost to the firm [40].

2.3.1 Direct labour cost

Direct personnel expenditures associated with BIM start-up are required to ensure that technology installation is effective. These expenses include the apparent necessity for initial and ongoing employee training, but it's also crucial to consider the financial implications of a less efficient workforce throughout the BIM transition phase [13].

2.3.2 Cost of BIM managers and experts

To enable their new BIM capabilities, several companies have had to recruit an extra BIM manager or more IT support. The amount of skill—and hence the price of that competence—should be proportionate to technological advancements [41]. The study explores the challenges of BIM implementation in the UK construction industry, highlighting issues such as high costs and the steep learning curve for professionals [42]. A systematic review categorizes barriers to BIM adoption in construction projects, including cost, technical challenges, and resistance to change [43].

2.3.3 Long term cost

There are also long-term expenses associated with BIM, such as how the BIM workflow affects your company's internal procedures. These are based on BIM best practices including introducing data and information into the model early in the design development process or modeling during the preconstruction phase. These expenses are difficult to measure, but they are required for a thorough investment analysis [35]. The study examines the challenges small and medium-sized enterprises face in adopting BIM, including costs, lack of skilled personnel, and the steep learning curve [42]. Another

Table 2 Challenges in BIM

Factors	Challenge	Sources
Cost	Cost of software, hardware and updates	[10, 45]
	Cost of hiring experienced staff	[10, 46]
	Lack of substantial quantifiable benefits	[10]
	Fast-paced and small-sized projects do not justify the investment cost of BIM	[45, 46]
Demand	Not enough demand in the market from the owner's side	[45]
BIM professionals	Lack of expertise and need for training	[10, 45]
	Unclear responsibilities, roles, and deliverables	[10]
	Lack of accountability for the errors caused	[10]
BIM process	Disruption in workflow	[45]
	Security and vulnerability of file sharing	[10, 46]
	Complexity of BIM	[10]
	Lack of software interoperability	[10, 45]
	Lack of regulations about BIM usage	[10, 45]
	Legal liabilities of the BIM process	[45]
	Copyright protection for ownership of data	[10, 46]
	Cultural resistance in the company prevents adoption of BIM	[45]

paper discusses barriers to BIM adoption, such as software, training, and implementation costs, as well as the learning curve for employees [44].

2.4 Challenges of BIM

After carrying out an extensive literature study, the following challenges of BIM were identified, shown in Table 2:

Researchers Andrew Criminale [10] and Amjed N. Hasan [45] identified several obstacles to the adoption and application of BIM, which are highlighted in the table. These issues are related to demand, costs, BIM specialists, and the BIM process itself, among other important areas. The biggest flaws in BIM design are inherent in three building process stages: (1) the preparation of a building investment project, and the analysis of the existing situation; (2) the preparation of the building execution technology project; (3) the existing standard processing and information collection in building exploitation period [47]. One of the issues associated with costs is the initial and continuous expenditure on hardware, software, and updates. The cost of employing and retaining a team with BIM expertise increases this financial burden. It is also mentioned that the benefits of BIM are not always seen to be significant or measurable, which can discourage investment, especially in settings with small-scale, fast-paced projects where the return on investment might not seem justified. It is believed that there is not enough demand for BIM, especially among owners. This could indicate a lag in market-driven requirements and slow down the adoption rate. BIM professionals are particularly concerned about the severe shortage of knowledge in the current workforce, which calls for a large investment in training. In addition, there is a lack of clarity on the roles and duties associated with BIM, which can cause uncertainty over deliverables and accountability and ultimately lead to unsolved problems during projects. The literature review demonstrates that BIM technologies enhance efficiency in project scheduling and budgeting, indicating a strong link to reduced time and costs [48, 49] report that current practices show BIM adoption is associated with lower project costs and shorter timelines, highlighting the need for on-going research into best implementation practices.

Disruptions to current workflow patterns, security threats associated with file sharing, and the intrinsic complexity of BIM technology is examples of operational challenges encountered in the BIM process. The lack of legislative frameworks controlling BIM usage and software interoperability problems is also highlighted in the chart, which makes it more difficult to integrate BIM into standard procedures. Adoption of BIM is further hampered by legal worries about data ownership and liability in the BIM process, as well as cultural opposition to altering conventional practices in the workplace. In conclusion, while BIM technology has great potential for advancements in building engineering, architecture, and construction, there are a number of obstacles standing in the way of its general adoption and efficient application. The complicated landscape of BIM implementation is influenced by a number of factors, including high initial costs, hazy advantages, and market demand; additionally, there are gaps in professional training, problems with process integration, legal barriers, and cultural barriers. BIM is introduced in AEC sector in last decade. Through this time, it has been applied in different of phases of project and its implementation has gained a significant benefit to the projects. It affirmatively impacts the project efficiency. As per Moreno C. [45], one of the obstacles in implementation of BIM is lack of substantial quantifiable benefits. This research works in direction of the same and tries to compute the percentage benefit of BIM, which can further be used for formation of decision-making framework. The review paper analyzes the challenges in BIM implementation, including financial, technical, and organizational barriers that hinder widespread adoption [34].

The primary objectives of this research are proposed as under:

To evaluate how the adoption of BIM affects the time performance of building projects: Previous studies [50] suggest that BIM enhances the coordination and collaboration of stakeholders, thereby reducing rework, scheduling conflicts, and delays. This research aims to explore this observation through case studies and provide insights into time savings achieved by adopting BIM workflows. To assess the impact of BIM on cost management: A key benefit of BIM highlighted by [12] is its ability to improve cost estimation accuracy and control, which in turn minimizes cost overruns. This research will investigate how BIM's real-time data integration and model-based cost estimation influence the overall project budget.

This study explores additional dimensions such as project quality, sustainability, and stakeholder satisfaction, demonstrating BIM's holistic benefits beyond time and cost savings. It highlights improvements in construction quality and sustainability, emphasizing BIM's role in reducing errors and waste. The research also examines enhanced stakeholder satisfaction due to better communication and collaboration facilitated by BIM. However, the study identifies significant challenges in implementing BIM, including high initial costs, the need for extensive training, and technology gaps. These obstacles can hinder adoption, particularly for smaller firms with limited resources. By addressing these challenges, the study provides a balanced view of BIM's impact, offering practical solutions and recommendations to overcome these barriers. This comprehensive approach ensures a deeper understanding of BIM's multifaceted benefits and challenges, guiding stakeholders in effectively leveraging BIM for improved project outcomes.

3 Research methodology

This research employs a qualitative case study methodology to explore the impact of Building Information Modeling (BIM) on project time and cost within the construction industry. The case study approach is particularly effective for examining complex phenomena in real-world contexts, allowing for an in-depth understanding of the specific factors that contribute to the benefits of BIM implementation [51].

3.1 Case selection

The research will focus on multiple case studies from various construction projects that have successfully integrated BIM into their workflows. The selection criteria for these case studies will include:

Diversity of Project Types: Projects will be selected from different sectors, such as residential and commercial to ensure a comprehensive analysis of BIM's impact across various contexts [10].

Geographical Representation: The study will encompass projects from diverse geographical locations to account for regional differences in BIM adoption and implementation [15].

Project Size and Complexity: Both small and large-scale projects will be analyzed to understand how BIM affects project time and cost across different levels of complexity [2].

3.2 Data collection

Data will be collected through a combination of qualitative methods, including:

Interviews: Semi-structured interviews will be conducted with key stakeholders involved in each case study project, including project managers, architects, engineers, and contractors. These interviews will aim to gather insights into their experiences with BIM, perceived benefits, challenges faced, and changes in project delivery time and cost [52]. A purposive sampling method was employed to select participants who have relevant expertise in BIM integration and project management. The sample size for the survey consists of 54 professionals, following the methodology of previous studies that examined similar

BIM-related issues. The sample includes: 50% BIM managers, 40% architects and 10% other consultants (e.g., project managers, engineers). All randomly selected participants were having a minimum of five years of experience with BIM, ensuring the collection of reliable and informed responses. The survey was administered online to enhance accessibility and efficiency in data collection. The structure of the survey was designed to gather insights into key factors that influence project time and cost, with specific questions addressing:

a) The impact of BIM on project timelines
b) The ability of BIM to reduce design errors and rework
c) BIM's contribution to accurate cost estimation and budget control
d) Challenges faced during BIM implementation

Document Analysis: Relevant project documentation, such as project plans, schedules, cost estimates, and BIM models, will be analyzed to quantify the impact of BIM on project outcomes. This analysis will provide empirical data to support the findings from the interviews [53].

Observation: Where feasible, site visits will be conducted to observe the practical application of BIM during project execution. This will help in understanding how BIM tools are utilized in real-time and their effects on project workflows [52].

3.3 Data analysis

The data collected from interviews, document analysis, and observations will be analyzed using thematic analysis postulating the new hypothesis as mentioned below. This method involves identifying, analyzing, and reporting patterns (themes) within the data, providing a rich and detailed account of the participants' perspectives and the impact of BIM on project time and cost [54].

Hypothesis

In case of the introduction of a new project,

Project cost = Direct cost + Indirect cost

= Construction cost + (Investment cost + Extra cost)

Where,

Investment cost: initial phase conceptualization and design development cost.

Construction cost: cost to build the structure.

Extra cost: cost induced due to errors and changes in project.

Assumption: The Construction cost of the structure is fixed, i.e., do not vary with the project interface.

For the hypothesis functionality and ease of understanding, direct cost includes the construction cost and for indirect cost, the investment and extra cost induced due to factors like design errors, change in scope, etc. would be taken into account.

Figure 4 shows the types of Projects A. The analysis will focus on key themes such as:

Time Efficiency: How BIM contributes to reducing project timelines through improved planning and coordination.

Cost Management: The role of BIM in enhancing cost estimation accuracy and controlling expenditures throughout the project lifecycle.

Stakeholder Collaboration: The impact of BIM on communication and collaboration among project participants.

3.4 Validation of findings

To ensure the credibility and reliability of the findings, member checking will be employed. This involves returning to the participants with the findings to validate the interpretations and conclusions drawn from the data [55]. Additionally, triangulation will be used by comparing data from different sources (interviews, documents, observations) to verify the consistency of the findings and enhance the robustness of the conclusions [56].

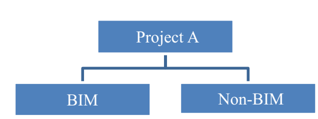


Fig. 4 Two types of Projects A

3.5 Ethical considerations

Ethical considerations will be paramount throughout the research process. Informed consent will be obtained from all participants prior to data collection, and confidentiality will be maintained by anonymizing participant identities and project details in the reporting of findings [52].

The study employs a mixed-methods approach to derive quantitative results, incorporating detailed data collection from real-world case studies. Methods include pre- and post-BIM implementation comparisons of project timelines and budgets, along with surveys and interviews with key stakeholders to gather quantitative data on time and cost metrics. Statistical analysis ensures accuracy and reliability, with results cross-verified through triangulation. Transparency is upheld by documenting data sources, analytical techniques, and assumptions, ensuring robust and reproducible findings. This approach provides a clear, evidence-based understanding of BIM's impact on building projects.

The present research offers significant improvements and complements earlier methodologies. Previous studies often focused narrowly on either quantitative or qualitative metrics, limiting the comprehensiveness of their findings. This research bridges that gap by integrating both types of metrics, providing a more holistic view of BIM's impact. Additionally, earlier studies might have examined isolated phases of BIM implementation, whereas this research evaluates BIM across all project phases, from design to construction. The inclusion of diverse case studies, spanning different project scales and complexities, enhances the generalizability of the results. By addressing sub-factors like resource allocation, technology adoption challenges, and stakeholder collaboration, this study provides a deeper understanding of BIM's multifaceted benefits. Moreover, the proposed approach highlights the importance of regional context and adaptability, offering valuable insights for regions with varying levels of BIM adoption.

4 Analysis & discussion

The research presented in The Impact of BIM on Building Project's Time and Cost (Through Case Studies) makes several notable contributions to the existing body of knowledge on Building Information Modeling (BIM) and its influence on construction project efficiency. The key contributions of this research are as follows:

4.1 Quantification of BIM benefits

Previous studies have qualitatively acknowledged the potential of BIM in improving project performance, but this research provides empirical evidence by quantifying the specific reductions in time and cost resulting from BIM implementation. The study goes beyond theoretical assertions by offering data-driven insights, demonstrating that BIM can reduce design errors by 50–60%, clashes by 40%, and rework costs by 40–50%, while also providing significant

Table 3 Relative importance as per survey

S.N	Factors	Impact of BIM (%) Reduction by:	Rating	Relative importance (%)
1	Design errors	50–60	6	13
2	Construction waste	4.3–15.2	2	4
3	Rework cost	40–50	5	10
4	Design modification	40–50	5	10
5	Clashes	40	4	8
6	Cost estimation time	80	6	13
7	Co-ordination RFI	80	6	13
8	Unbudgeted changes	37–62	5	10
9	Change orders	32	4	8
10	Labour and work schedule	50	5	10
			47	

improvements in coordination, cost estimation, and labor scheduling, Table 3. The empirical results align with prior studies [11, 50] but add value by specifying the magnitude of these benefits.

As per the literature, the factors can be rated as:

The Table 3 outlines the impact of BIM on various factors in construction projects. BIM significantly reduces design errors by 50–60%, construction waste by 4.3–15.2%, and rework costs by 40–50%. It also decreases design modifications by 40–50% and clashes by 40%. BIM enhances cost estimation time and coordination RFIs by 80%, and cuts down unbudgeted changes by 37–62% and change orders by 32%. Furthermore, it improves labor and work schedules by 50%. The relative importance ratings indicate that cost estimation time, coordination RFIs, and design errors are the most crucial, each with a 13% importance.

4.2 Identification of key influencing factors

This research systematically identifies and prioritizes factors that contribute to project cost and time. By focusing on critical elements such as design errors, unbudgeted changes, cost estimation, coordination requests for information (RFI), and labor/work schedule, the study provides a structured approach to understanding how each of these variables is influenced by BIM. The ranking of these factors and the assignment of relative importance (e.g., design errors contributing to 16% of cost/time impacts) provide a nuanced understanding of where BIM yields the most significant improvements, building on frameworks like those proposed by [13, 29]. As per the results of the first questionnaire, the total number of responses was 54 and the weightage gain by individuals is in the following form:

The Table 4 highlights major factors impacting cost and time in construction projects, along with their relative importance. Design errors significantly affect both cost and time, with a relative importance of 16%. Construction waste, rework costs, and coordination RFIs each have a 9% importance. Design modifications and change orders impact cost and time less, with 7% importance each. Unbudgeted changes and cost estimation each have a 10% importance, while clashes have a 12% importance. Labor and work schedule issues affect cost and time, with an 11% importance. Overall, the data emphasizes design errors and clashes as critical factors. In view of the results from Table 4, the top five factors considered for the second survey, includes:

- Design errors
- Unbudgeted changes
- Cost estimate
- Co-ordination RFI
- Labour and work schedule

Table 4 Relative importance as per survey

S.No	Factors	Major factors impacting on cost / (%) No. of respondent	Major factors impacting on time/ (%) No. of respondent	Relative importance (%)
1	Design Errors	36	25	16
2	Construction Waste	20	15	9
3	Rework cost	15	20	9
4	Design Modification	13	14	7
5	Unbudgeted changes	18	18	10
6	Cost estimation	13	26	10
7	Clashes	20	24	12
8	Co-ordination RFI	17	16	9
9	Change order	12	13	7
10	Labour and work schedule	21	20	11
	Total	185	191	

Table 5 Distribution of BIM and non-BIM projects

		Frequency	Percent
Valid	BIM	24	44.4
	Non-BIM	30	55.6
	Total	54	100.0

Table 6 Comparison of BIM implementation and benefits across three case studies

	Case study 1	Case study 2	Case study 3
Area (sqft)	484000	315000	16500
Project cost	₹ 4,60,00,000	₹ 3,80,00,000	₹ 6,87,71,285
Project time (years)	2	1	4
Project Interface	BIM in all phases	BIM in design development	Non-BIM
Investment cost	₹ 1,38,000	₹ 57,000	₹ 68,771
Benefits analyzed			
Schedule benefit	1143 h saved	1300 h saved	+ 30%
Total cost benefit	801565	0	+ 38%
BIM cost benefit	200392		
Assumption	75% error could be rectified through conventional approach as well	60% error could be rectified through conventional approach as well	

Questionnaire-2 to determine the impact. The Questionnaire 2 is divided into four sections:

1. **General information:** Basic project detail as: type of project, project interface
2. **Investment Cost:** the total amount invested in the project, division of the amount mentioned.
3. **Impact on factors in BIM project:** usage phases of BIM, percentage of benefits analyzed, impact of factors on project cost and time
4. **Impact on factors in non-BIM project:** impact of factors on project cost and time this questionnaire is filled out while conducting live interviews and primary case studies.

Questionnaire-2 results

Table 5 shows the frequency and percentage distribution of projects utilizing BIM and those without BIM, indicating that 44.4% of the projects implemented BIM, while 55.6% did not. As per the results of the second questionnaire (N = 54).

Project interface

4.3 Reliable data validation using statistical tools

The methodology includes rigorous reliability checks through Cronbach's Alpha tests (values > 0.7), ensuring the robustness of the survey data. This enhances the credibility of the findings, contributing to the methodological rigor in BIM research. The statistical validation process adds to the existing literature by ensuring that results are both reliable and replicable [57].

4.4 Comparative analysis of BIM and Non-BIM projects

The research advances knowledge by providing a direct comparison between BIM and non-BIM project interfaces, showcasing a 38% and 35% reduction in cost and time, respectively, when BIM is used across all project phases. This clear, data-supported comparison of BIM and traditional methods allows stakeholders to make informed decisions regarding the financial and temporal trade-offs of BIM adoption. The study addresses a gap in the literature, where few empirical studies have provided such a direct comparison across different project phases [20].

For all the data received through surveys, primary case studies and interviews, the impact of factors on project cost and time is assigned in the options marked in the survey. The results are further analyzed for their reliability and it is being found that the variance of values is lower than 1 and is between 0.1 and 0.6. Hence, the results are reliable.

Case studies

The above table (Table 6) compares three case studies on BIM usage in construction projects. Case study 1 utilized BIM in all phases, resulting in 1,143 h saved and a total cost benefit of ₹8,01,565, with BIM contributing ₹2,00,392. Case study 2 used BIM only in design development, saving 1,300 h but showing no total cost benefit. Case study 3 did not use BIM and had a 30% schedule increase and 38% total cost benefit. Assumptions indicate conventional approaches could rectify 60–75% of errors.

For all the data received through surveys, primary case studies and interviews, the impact of factors on project cost and time is assigned in the options marked in the survey. The total number of responses was 42 more impact on project cost and time when BIM is used in all phases of construction. When it is used for the concept and design stage, benefits of 31% and 26% are analyzed in terms of cost and time. The authors in a research reports that the adoption of BIM not only enhances project delivery speed but also contributes to significant cost savings throughout the project lifecycle [58].

As per the rating, the average of the values is assigned as the score of each aspect.

Table 7 compares the investment costs and the impacts on cost and time for projects using BIM in the design phase, BIM in all phases, and non-BIM projects, yielding the following outcomes.

Investment Costs: BIM in the design phase has the highest software cost (3.5), followed by BIM in all phases (3) and non-BIM (2.96). Hardware and updates are most expensive for non-BIM projects (3.26), while BIM in all phases incurs the lowest costs (2.13). Direct labor costs are highest in non-BIM (2.74) and lowest in BIM during the design phase (1.88).

Impact on Cost: BIM in all phases reduces design errors and RFIs most effectively (3.88 and 3, respectively), whereas non-BIM projects show higher costs for unbudgeted changes (2.96).

Impact on Time: BIM in all phases shows the greatest reduction in design errors (3.63) and RFI resolution time (1.88). Non-BIM projects perform better in cost estimation-related time (3.48), while BIM in all phases offers better labor and schedule management (3.38).

Overall, BIM in all phases is more effective in cost and time savings, despite higher initial investment. The results are further analyzed for their reliability and it is found that the variance of values is lower than 1 and are in between 0.1 and 0.6. Effective implementation of BIM practices leads to improved project timelines and cost efficiency, underscoring the necessity for widespread adoption in the construction sector [33, 59–61]. Research on seismic retrofitting and material

Table 7 Comparison of investment costs, cost impacts, and time impacts across BIM implementation phases and non-BIM projects

S. No	Variable	BIM in design phase	BIM in all phases	Non-BIM
A	Investment Cost (scale: 1: 1–10%, 2: 10–20%, 3: 20–30%, 4: 30–40%)			
1	Software cost	3.5	3	2.96
2	Hardware and updates	2.7	2.13	3.26
3	Direct labour cost	2	1.88	2.74
4	Managers and experts	1.6	2.5	1.87
5	IT support team	2.3	1.38	1.35
B	Impact of factors on cost (scale: 1: 1–5%, 2: 5–10%, 3: 10–15%, 4: 15–20%, 5: 20–25%)			
		−ve	−ve	+ve
1	Design error	2.7	3.88	2.87
2	RFI	2.6	3.0	1.83
3	Unbudgeted changes	2.2	2.38	2.96
4	Cost estimate	2.3	2.63	2.22
5	Labour and work schedule		2.38	2.43
C	Impact of factors on time (scale: 1: 1–5%, 2: 5–10%, 3: 10–15%, 4: 15–20%, 5: 20–25%)			
		−ve	−ve	+ve
1	Design error	2.3	3.63	3.22
2	RFI	2.1	1.88	3.26
3	Unbudgeted changes	2.3	2.13	2.78
4	Cost estimate	1.7	2.5	3.48
5	Labour and work schedule		3.38	2.7

Table 8 Comparison of investment cost, cost-impact factors, and time-impact factors for BIM in the design phase, BIM in all phases, and non-BIM projects

S.No	Variable	BIM in design phase (%)	BIM in all phases (%)	Non-BIM (%)
A	Investment Cost	0.1–0.18% of project budget	0.25%-0.5% of project budget	0.05–0.1% of project budget
1	Software cost	29	27	26
2	Hardware and updates	23	18	27
3	Direct labour cost	19	15	22
4	Managers and experts	15	22	15
5	IT support team	14	18	10
		100	100	100
B		Impact of factors on cost		
		−ve	−ve	+ve
1	Design error	14	19	14
2	RFI	13	15	9
3	Unbudgeted changes	11	12	15
4	Cost estimate	12	13	11
5	Labour and work schedule	0	12	12
		49	71	62
C		Impact of factors on time		
		−ve	−ve	+ve
1	Design error	12	18	16
2	RFI	11	9	16
3	Unbudgeted changes	12	11	14
4	Cost estimate	9	13	17
5	Labour and work schedule	0	17	14
		42	68	77

management has highlighted cost-effective solutions for structural resilience. Khursheed et al. (2022, 2024) [62–65] assessed retrofitting costs for load-bearing and RCC hospital buildings, while their studies on material management identified key factors causing delays and budget overruns. Paul et al. (2020) [66] analyzed MMFX bars' economic feasibility in Indian construction. These studies provide crucial insights into cost-efficient retrofitting and construction practices.

Table 8 compares the investment costs and the impacts on cost and time for projects using BIM in the design phase, BIM in all phases, and non-BIM projects.

Investment Costs: BIM in the design phase accounts for 0.1–0.18% of the project budget, with software costs making up 29%, hardware and updates 23%, and direct labor costs 19%. In contrast, BIM in all phases costs 0.25%-0.5% of the budget, with software costs at 27%, hardware at 18%, and labor costs at 15%. Non-BIM projects incur the lowest investment cost (0.05–0.1%), with hardware costs the highest (27%).

Impact on Cost: BIM in all phases shows the highest impact on cost, with 71% of cost factors being negative, primarily from design errors (19%) and RFIs (15%). Non-BIM projects have a 62% negative impact on costs, with unbudgeted changes (15%) and labor schedule issues (12%) being significant contributors.

Impact on Time: BIM in all phases results in 68% negative impacts on time, with design errors (18%) and labor schedule issues (17%) having the highest effect. Non-BIM projects experience the highest positive impact on time (77%), primarily due to cost estimates (17%) and labor schedules (14%). It can be noted that the percentage output is on the higher side. The study highlights that BIM applications can lead to a reduction in both construction time and project costs by facilitating better resource management and communication [67].

4.5 Holistic assessment of BIM across project phases

While many studies focus on the benefits of BIM during specific stages like design or planning, this research evaluates BIM's impact throughout the entire project lifecycle, from design to construction and operation. The findings underscore that the use of BIM in all phases results in greater benefits (e.g., 38% cost and 35%-time reduction) than limiting its application to the design phase alone. This expands upon earlier research, which often limited its scope to isolated project phases [35]. This research reveals a positive correlation between BIM usage and improved time and cost performance in various construction projects, validating its effectiveness as a project management tool [68].

5 Conclusion

The present research provides substantial evidence of Building Information Modeling (BIM) as a transformative tool for enhancing project efficiency. The findings clearly show that BIM significantly reduces project costs and timelines by addressing key inefficiencies inherent in traditional construction practices, particularly design errors, unbudgeted changes, coordination issues, and cost estimation delays. The integration of BIM in construction projects has been shown to significantly reduce project duration and costs while enhancing collaboration among stakeholders [59].

Through an extensive literature review and surveys, the research identified ten critical factors influencing project cost and time, with the top five—design errors, unbudgeted changes, Requests for Information (RFI), labor and work schedules, and cost estimates—being most impactful [36]. Traditional project methods, while requiring lower upfront investment costs (0.1% of the project budget), often lead to an increase of up to 43% in project costs and 55% in project time due to these inefficiencies. In contrast, BIM, despite requiring a slightly higher initial investment (0.2–0.5% of the project budget), can reduce overall costs by 60% and project time by 50%, showcasing its cost-effectiveness and time-saving capabilities [1].

The case studies in this research reinforce these conclusions. Projects using BIM throughout all phases of construction demonstrated substantial benefits, including a 38% reduction in project costs and a 35% reduction in time (Case Study 1). Conversely, non-BIM projects experienced higher costs and longer durations due to frequent design changes and lack of coordination. These findings indicate that BIM's comprehensive application offers significant improvements over traditional methods, supporting its use as an integrated project management tool rather than just a design technology [29].

Table 9 effectively summarizes the findings from previous research alongside the results of the current study highlighting the consistency and contributions of your research in the context of existing literature.

Overall, the table highlights the alignment of current research findings with existing literature, collectively underscoring BIM's significant impact on improving construction project efficiency. It illustrates a robust consensus on BIM's benefits, emphasizing the need for continued exploration of best practices to maximize its potential in the construction industry. This comparative analysis not only strengthens the credibility of the present research but also positions it as a valuable addition to the ongoing discourse on BIM's role in modern construction management. Furthermore, the research emphasizes that as project scale increases, BIM's ability to mitigate risks and optimize resource allocation becomes even more evident. This scalability makes BIM particularly beneficial for larger, more complex projects, where errors and delays have more pronounced impacts.

In conclusion, this study strongly advocates for the adoption of BIM to optimize construction project performance. BIM's ability to streamline processes, reduce risks, and ensure more accurate cost and time management proves invaluable for the construction industry. Future research should explore BIM's potential in enhancing other project dimensions, such as quality, sustainability, and stakeholder collaboration, to fully realize its impact on construction management.

6 Limitations and future scope

This research primarily focused on the impact of BIM on time and cost in construction projects, analyzing five key factors. However, sub-factors such as resource allocation, technology adoption challenges, and stakeholder collaboration were not explored in depth. The study has several limitations, including its reliance on case studies from large-scale

Table 9 Comparison of the findings of the present study with earlier studies

S. No	Study	Key findings from previous research	Key findings from present research
1	[62]	BIM integration reduces project duration and costs, enhancing stakeholder collaboration	Confirmed significant reductions in project duration and costs
2	[59]	Effective BIM implementation leads to improved timelines and cost efficiency in construction projects	Found that effective BIM practices improved project timelines
3	[67]	BIM applications result in better resource management and communication, leading to time and cost savings	Highlighted enhanced resource management through BIM
4	[58]	Adoption of BIM enhances project delivery speed and contributes to significant cost savings	Observed similar trends in project delivery speed and cost efficiency
5	[68]	Positive correlation between BIM usage and improved time and cost performance in construction projects	Found a strong correlation between BIM usage and project performance metrics
6	[48]	BIM technologies enhance efficiency in project scheduling and budgeting, leading to reduced time and costs	Confirmed that BIM improved scheduling efficiency and budget control
7	[49]	BIM adoption is associated with lower project costs and shorter timelines, indicating a need for best practices	Identified key best practices for BIM implementation that led to time and cost reductions

projects, which may limit the applicability of the findings to smaller projects. Assumptions like uniform labor efficiency may oversimplify real-world conditions, and the results may not be fully applicable to regions with low BIM adoption. Additionally, the emphasis on quantitative metrics like time and cost overlooks qualitative aspects such as collaboration, communication, and stakeholder satisfaction. Future research can address these limitations by expanding the scope to include additional factors such as project quality, sustainability, safety, and stakeholder integration. Exploring these dimensions will provide a more comprehensive understanding of BIM's full potential and benefits. A broader analysis that includes smaller projects and different regional contexts will also enhance the generalizability of the findings. Incorporating both quantitative and qualitative metrics will offer a more holistic view of BIM's impact on construction projects.

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Declarations

Ethics approval and consent to participate The need for ethical approval for this questionnaire study was waived by the Ethics Committee of the School of Planning and Architecture, New Delhi, India, due to the nature of the study, which involved minimal risk to participants. All participants provided informed consent prior to their inclusion in the study. Authors state that the research was conducted according to ethical standards.

Informed consent Not applicable.

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