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RESEARCH ARTICLE

Exploring Sustainable Construction: The Impact of Building Information Modeling (BIM) on Design Changes to Reduce Costs and Enhance Productivity

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ABSTRACT

The objective of this study is to evaluate the factors contributing to design changes and the impact of Building Information Modeling (BIM) on these changes during construction, which can affect project cost savings. The participants in the study included project personnel, comprising a total of 60 respondents from three project sites on the island of Java, Indonesia. Data was collected through questionnaires and project data analysis. The sequence of design changes during construction is primarily influenced by design modifications, followed by requests for additional work, owner-initiated design changes during implementation, the presence of supplementary project tasks, coordination issues due to discrepancies in drawings, alterations in work specifications, conflicts with adjacent structures, incomplete drawings, sudden schedule adjustments by the owner, and errors in execution. The effects of design changes on project costs include schedule delays, disruptions in work sequences, cost overruns, rework, and diminished work quality. The Influence of BIM to design changes include increased productivity, the ease of using BIM, reduced work repetition, cost reductions, shortened work durations (schedule). The analysis reviewed shop drawing procedures and determined that the use of BIM in creating working drawings can reduce time and project costs by 22%.

INTRODUCTION

The objective of this research is to examine issues in projects related to cost overruns during construction. The problem is attributed to design changes. The implementation of the BIM system addresses these issues by analyzing the factors contributing to project cost savings.

The research problems are: 1) What is the effect of design changes during construction on project costs; 2) What is the impact of implementing the BIM system on design changes during project execution for cost savings; 3) How can the BIM system mitigate schedule delays during project execution; 4) How can the BIM system optimize costs during project implementation.

Within the ASEAN Economic Community (AEC), the architecture, engineering, and construction (AEC) industry witnesses significant advancements with BIM technology. An accurate virtual model of a building can be digitally constructed using BIM technology. Once the model is finalized, it will have precise geometric accuracy. Utilizing BIM in construction planning sessions can substantially reduce costs.

The reasons for the critical importance of using BIM in projects include frequent errors, repetitive work, frequent addendums, misinterpretation of composite working drawings, project schedule delays, insufficient human resources, excessive project expenditures, and frequent design changes during the project (BIM Consulting Service, 2022). The primary BIM application used is Revit, which offers an extensive array of features that enable designers to assess and optimize building performance, including cost efficiency. BIM enhances cost savings by identifying design errors and construction issues early in the design phase, minimizing rework, reducing material waste, and saving labor costs. During construction, BIM monitors project costs in real time, providing valuable insights for optimizing resources and minimizing waste. As the project progresses, BIM helps detect potential problems and inefficiencies and highlights areas that require improvement.

Building Information Modelling

BIM can lead to significant economic development. Building Information Modeling can substantially enhance productivity, primarily by fostering communication and coordination, identifying errors, and reducing costs. Another critical aspect is cost efficiency.

The detailed calculations and 3D visualizations generated by BIM make it easier and more cost-effective for teams to plan structures that remain secure and operational for many years. The first BIM system was introduced in 1992, with new software emerging in 2003 as a result of academic research, which has now become standard practice in the construction industry (A. Bormann et al, 1018). Numerous AEC (Architecture, Engineering & Construction) firms have utilized BIM for cost control (P. Mesaros et al, 2020). Additionally, BIM can minimize delays in construction timelines (S.S. Martin et al, 2020).

Concept of Building Information Modeling

The BIM concept involves a 3-dimensional representation of a building, incorporating elements that streamline the development of construction methods. It then expands into a 4-dimensional model to define the start time of implementation, material delivery schedules, and project completion dates. BIM further evolves into 5-dimensions for accurate cost estimation, 6-dimensions to evaluate construction sustainability, 7-dimensions for management applications, 8-dimensions to assess workplace safety, 9-dimensions for lean construction principles, and 10-dimensions to understand the industrialization process in construction (Biblus, 2018).

Benefits of Building Information Modeling

When implemented correctly, the BIM system offers several benefits, including more precise project visualization, enhanced coordination, early clash detection (S. Azhar et al., 2008), reduced risk of delays and cost overruns (C. Eastman & P. Teicholz, 2011), and improved scheduling through efficient information management (C.A. Berlian et al., 2016).

Previous research indicates that design changes stem from internal factors, such as the organizations involved in project execution, and external factors, including political, economic, environmental, and technological advancements, as well as third-party providers (A.A Yana, 2017). Design changes play a significant role in contributing to project delays and cost increases (J. Yap et al., 2017). BIM enhances decision-making processes (F. Jalaei, A. Jrade, 2015). Factors limiting BIM adoption can be grouped into four categories: individuals, organizations, government, and BIM software vendors. The driving factors include external influences, technology, communication, and organizational structure (F.R. Utomo, 2021).

Exploring advanced construction technologies and techniques improves project accuracy, cost efficiency, and value. BIM has become a cornerstone in modern construction. It plays a pivotal role in mitigating project delays and cost overruns (Martins et al., 2020). Almost all construction projects experience various levels of design changes throughout their lifecycle. In most cases, these changes are unavoidable to refine or modify the original design or project scope (Alnuaimi et al., 2010). Design changes substantially increase both cost and time due to production and redesign efforts (Chang et al., 2011). Scope creep is a major risk factor that drives design cost overruns in construction projects (Knight, K et al., 2002).

This study also aims to determine how rework resulting from design changes negatively impacts project performance and to propose recommendations for mitigating this issue through project learning and effective communication in building construction (Jeffrey Boon et al., 2017). Change management is a critical aspect of project management in construction, as changes are a primary cause of delays and disruptions. Both owners and contractors widely acknowledge that the effects of changes are difficult to quantify and often lead to disputes (Motawa et al., 2007).

Addressing the identified causes effectively would significantly reduce delays and cost overruns in construction projects, thereby contributing to the country's economic growth and development (Muhammad Tahir et al., 2018). Understanding the causes of time and cost overruns in freeform buildings, as identified in this study, can help clients make informed decisions about these projects, while assisting consultants and contractors in minimizing the risks of such overruns (Andrew Kavuma et al., 2019).

Construction projects are inherently prone to changes or errors during execution for various reasons, making cost and time overruns, as well as change orders, inevitable (Alnuaimi et al., 2010), which severely impact project performance (Durdyev et al., 2018). As an innovative solution, Integrated Project Delivery (IPD), which promotes collaborative decision-making among key stakeholders in the earliest stages of project design (Durdyev et al., 2019), has been recommended to prevent or reduce design changes during construction (Malin, N, 2015), thus improving project scheduling (Kibert, C.J, 2016) and maintaining the project budget (Malin, N, 2015). Additionally, efficient communication among stakeholders using Building Information Modeling (BIM) is another effective strategy for avoiding design problems (Serdar Durdyev, 2020).

Many researchers have analyzed the causes of design changes based on construction phases, such as pre-planning, planning, design, and execution (Hanif et al., 2016; Arain et al., 2007; Sha'ar, K.Z. et al., 2016), while a few have categorized the sources of design changes from the perspectives of clients, consultants, and contractors (Yap et al., 2017; Faridi et al., 2006 ; Chang et al., 2011).

METHOD

Research was conducted to identify the differences between BIM and conventional systems in evaluating the effectiveness of time, cost, and labor across three sites on the island of Java. The BIM dimensions utilized in this study extended to 5D, encompassing shop drawings and work methods.

The projects involved include the Nestle Batik Spark Project in Batang, Pekalongan, Central Java, Indonesia, and the IKEA-2 JGC Project in Cikarang, West Java, Indonesia, where BIM was implemented during the initial construction phase, starting with the tender process. In contrast, BIM was applied to the Cargill Bromo and Quantum Leap Projects in Gresik, East Java, Indonesia, during design development by consultants, allowing BIM modeling to continue into the construction phase. The research locations are as follows.

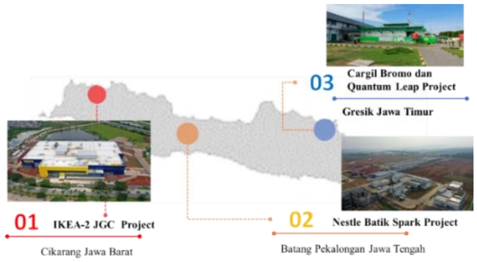

Figure 1. Research Sites

The research employed a quantitative methodology, utilizing a questionnaire completed by 60 respondents, including project managers, BIM managers, engineers, drafters, and quantity surveyors from the three locations. Secondary data in this study comprised documentation such as work drawings, work plans, cost breakdowns for each work item, and photographs taken during data collection. The study variables were categorized into three main variables, further divided into several sub-variables, each with its own numerical code. Factors influencing design changes (X1) consist of 11 sub-variables, including alterations in work specifications, requests for additional work, incomplete drawings, design modifications, execution errors, coordination issues due to discrepancies in drawings, conflicts with adjacent structures, owner-initiated design changes during implementation, sudden schedule changes by the owner, and adjustments in work scope. The impacts of design changes (X2) consist of five sub-variables: rework, delays in work schedules, cost overruns, disrupted work sequences, and diminished work quality. The application of BIM to design changes (X3) consists of five sub-variables: the ease of using BIM, cost reductions/savings in workflow, increased productivity, shortened work durations (schedule), and reduced work repetition.

Data processing was conducted using SPSS software to calculate the average value of each indicator. Key indicators were identified by ranking the averages, with the initial objective of determining the priority of each indicator. The analysis technique employed by the researcher was the Exploratory Factor Analysis (EFA) method using SPSS. EFA is an exploratory method that does not rely on a predetermined hypothesis, allowing for the discovery of new patterns and relationships in previously unexamined data. It is a powerful tool for data exploration, aimed at identifying underlying factor structures without any prior assumptions. The study involved data from 60 respondents, and factor analysis was used to ensure that the questionnaire items accurately reflected the studied variables. This method simplifies complex relationships among the research variables, identifying a relatively small number of factors that explain many interrelated variables.

The core steps in the factor analysis process include:

a. Determine which variable or factor is being analyzed.

b. The variables are tested using MSA (Measure of Sampling Adequacy) tests. All correlation matrices (correlations between variables), measured by the Measure of Sampling Adequacy (MSA) test, must be tested. This test requires a significant correlation between at least some variables.

c. At this stage, several variables are examined to identify those that meet the analysis requirements. To assess the correlation, the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy Test can be consulted, an index that evaluates the suitability of factor analysis. A value between 0.5 and 1.0 indicates that factor analysis is appropriate, while a value below 0.5 suggests it is not.

d. The factoring process is carried out by extracting a set of existing variables into one or more factors. This process produces a general table that shows the number of factors or variances of a variable that can be explained by the identified factors. The value of similarity ranges from 0.0 (where the variable does not correlate with other variables) to 1.0 (where the variable variation is entirely due to common factors). The higher the eigenvalue of each factor, the more reliably it represents the group of variables.

RESULT AND DISCUSSION

This data will be analyzed using SPSS software. Variables in this research are X1 (factors influencing design change), X2 (influence of design change), and X3 (influence of BIM on design changes).

Table 1. Ranking of Factors of Influence Design Changes (X1).

No.	Code	Sub variable	
1	X1.4	Design Modification	
2	X1.2	Request for additional work	
3	X1.9	Owner-initiated design changes during implementation	
4	X1.11	Adjustments in work scope	
5	X1.7	Coordination issues due to discrepancies in drawings	
6	X1.1	Alterations in work specifications	
7	X1.8	Conflicts with adjacent structures	
8	X1.3	Incomplete drawings	
9	X1.10	Sudden schedule adjustments by the owner	
10	X1.6	Execution errors	

Table 1 shows the ranking of factors influencing design changes, starting with design modifications, request for additional work, owner-initiated design changes during implementation, adjustments in work scope, coordination issues due to discrepancies in drawings, alterations in work specifications, conflicts with adjacent structures, incomplete drawings, sudden schedule adjustments by the owner, and execution errors.

Table 2. Ranking of Impact of Design Changes (X2).

No.	Code	Sub variable	
1	X2.2	Delays in work schedules	
2	X2.4	Disrupted work sequences	
3	X2.3	Cost overruns	
4	X2.1	Reworks	
5	X2.5	Diminished work quality	

The ranking of the impact of design changes is presented in Table 2, which starts with delays in the work schedule, disruption of the work sequence, cost overruns, reworks, and Diminished work quality.

Table 3. Ranking of Influence of BIM to Design Changes (X3).

No.	Code	Sub variable	
1	X3.3	Increased productivity	
2	X3.1	The ease of using BIM	
3	X3.5	Reduced work repetition	
4	X3.2	Cost reductions	
5	X3.4	Shortened work durations (schedule)	
6	X3.6	Expensive cost of BIM application	

The ranking of BIM's influence on design changes is shown in Table 3. Increased productivity is the top-ranking influence, followed by the ease of using BIM, reduced work repetition, cost reductions, shortened work durations (schedule), and the expensive cost of BIM application.

The data results were analyzed by the Bartlett test of sphericity and Kaiser-Meyer-Olkin (KMO) in two rounds. The KMO and Bartlett test evaluate all available data together. KMO value over 0.5. Variable collinearity indicates how strongly a single variable is correlated with other variables.

This table shows two tests that indicate the suitability of data for structure detection from SPSS software. The Kaiser-Meyer-Olkin Measure of Sampling Adequacy is a statistic that indicates the proportion of variance in variables that might be caused by underlying factors. High values (close to 1.0) generally indicate that a factor analysis may be useful with data. If the value is less than 0.50, the results of the factor analysis probably won't be very useful. The result of Kaiser Meyer Olkin Measure of Sampling Adequency is 0,826. The result from SPSS software MSA value > 0.5 (accepted) and below 0.5 (not accepted).

Table 4. Ranking of Influence of BIM to Design Changes (X3).

No.	Code	Value of MSA	Description
1	X1.1	0.803	MSA > 0,5 (accepted)
2	X1.2	0.715	MSA > 0,5 (accepted)
3	X1.3	0.797	MSA > 0,5 (accepted)
4	X1.4	0.825	MSA > 0,5 (accepted)
5	X1.6	0.822	MSA > 0,5 (accepted)
6	X1.8	0.870	MSA > 0,5 (accepted)
7	X1.9	0.937	MSA > 0,5 (accepted)
8	X1.11	0.574	MSA > 0,5 (accepted)
9	X2.1	0.900	MSA > 0,5 (accepted)
10	X2.2	0.827	MSA > 0,5 (accepted)
11	X2.3	0.926	MSA > 0,5 (accepted)
12	X2.4	0.890	MSA > 0,5 (accepted)
13	X2.5	0.736	MSA > 0,5 (accepted)
14	X3.2	0.811	MSA > 0,5 (accepted)
15	X3.3	0.729	MSA > 0,5 (accepted)
16	X3.4	0.643	MSA > 0,5 (accepted)
17	X3.5	0.801	MSA > 0,5 (accepted)

This component matrix shows the correlation value or relationship between each variable and the component factors that are formed through eigenvalue analysis. In this research, there are five factor components: work schedule factor (1); design factors (2); human resource factors (3); specification factors (4); and additional work factors (5). Through the Rotated Component Matrix, each sub-variable can be seen to be influenced by one of the component factors.

Table 5. Result - Rotated Component Matrix.

Code	Extraction	Component Factors				
		1	2	3	4	5
X1.1	Alterations in work specifications				0.681	
X1.2	Request for additional work				0.767	
X1.3	Incomplete drawings		0.766			
X1.4	Design Modification		0.549			
X1.6	Execution errors		0.581			
X1.8	Conflicts with adjacent structures		0.767			
X1.9	Owner initiated design changes during implementation		0.744			
X1.11	Adjustments in work scope					0.847
X2.1	Reworks	0.777				
X2.2	Delays in work schedules	0.781				
X2.3	Cost overruns	0.803				
X2.4	Disrupted work sequences	0.837				
X2.5	Diminished work quality	0.782				
X3.2	Cost reductions		0.552			
X3.3	Increased productivity			0.738		
X3.4	Shortened work durations (schedule)			0.826		
X3.5	Reduced work repetition			0.755		

Sub variables included in work schedule factors (1) are rework (X2.1), delays in work schedules (X2.2), cost overruns (X2.3), disrupted work sequences (X2.4), and diminished work quality (X2.5). Design factors consist of sub variables such as incomplete drawings (X1.3), design modification (X1.4), execution errors (X1.6), conflicts with adjacent structures (X1.8), Owner initiated design changes during implementation (X1.9), and Cost reductions (X3.2). Increased productivity (X3.3), shortened work durations (schedule) (X3.4), and reduced work repetition (X3.5) are included in human resource factors. Alterations in work specifications (X1.1) and requests for additional work (X1.2) are included in the specification factors. The sub variable of the additional work factor is adjustments in work scope (X1.11).

Documentation from projects includes secondary data such as time schedules, salaries, and equipment. In the initial IKEA project, it was calculated that the project would be completed on time. However, during construction, design changes caused alterations in the work schedule. Conclusions from construction projects state that design discrepancies and frequent design changes are the most important factors resulting in cost overruns, ultimately leading to the complete failure of projects in Saudi Arabia. In another study (Cheng Ying-Mei, 2014), the use of conventional applications took 31 days, while with BIM, it took 24 days.

Table 6. Result - Rotated Component Matrix.

No	Activity	Days									
		1	4	8	12	16	20	24	28	32	36
1	Drawing using conventional										
2	Drawing using BIM										

In terms of engineering, the results mentioned above show that the duration of conventional engineering work takes one week longer than when using BIM. The cost difference between using traditional applications and using BIM was one of the causes of delays in the IKEA project. To compare the total cost difference between traditional applications and BIM, there was a reduction of 22%. The large cost difference between BIM and traditional applications is due to:

a. Number of experts: Fewer experts are required to use BIM compared to traditional applications.

b. Time needed for planning: Using BIM takes only 31 days, while conventional planning takes 24 days.

Table 7. Cost comparison, based on time, human resources and facilities required on the IKEA project.

NO	Description	Conventional cost	BIM cost
1	Time	Rp. 9,138,514,924	Rp. 7,074,979,296
2	Resources	Rp. 334,894,023	Rp. 249,329,424
3	Facilities	Rp. 19,560,788	Rp. 17,335,068
Total		Rp. 9,492,969,734	Rp. 7,341,643,788
Balance		Rp. 2,151,325,946	

From the data above, it can be concluded that the BIM application provides greater efficiency in running IKEA projects in terms of time, resources, and facilities by providing a 22% increase in efficiency.

In the Nestlé Project, one item had the most impact on the increase in the duration of the work schedule. The largest increase in work schedule duration (from the receipt of design drawings to making shop drawings to implementation) was 25 days using BIM. If BIM was not used, the increase would have been 32 days.

Table 8. Work Schedule for Design Drawing Changes Nestle.

No	Activity	Days									
		1	4	8	12	16	20	24	28	32	36
1	Drawing using conventional										
2	Drawing using BIM										

The cost difference between using traditional applications and BIM in the Nestlé project showed a reduction of 22%.

Table 9. Cost comparison, based on time, human resources and facilities required on the Nestle project.

NO	Description	Conventional cost	BIM cost
1	Time	Rp. 845,498,495	Rp. 654,579,480
2	Resources	Rp. 87,860,820	Rp. 68,021,280
3	Facilities	Rp. 19,560,788	Rp. 17,335,068
Total		Rp. 952,920,103	Rp. 739,935,828
Balance		Rp. 212,984,274	

From this, it can be concluded that BIM applications provide greater efficiency in running Nestlé projects in terms of time, resources, and required facilities, also offering a 22% increase in efficiency.

CONCLUSION

The most significant impact of design changes during construction on project costs is the delay in work schedules. Implementing BIM systems in design changes during construction can result in substantial cost savings by increasing productivity, enhancing ease of use, reducing work repetition, shortening project duration, and mitigating the high costs of BIM implementation. The BIM system can decrease schedule delays by 22% during project execution by addressing work schedule factors, design-related issues, and resource management. Additionally, BIM can reduce project costs by considering specification factors and additional work requirements. By utilizing BIM to manage design changes, overall project costs can be reduced by 22%.

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