

Cost Overrun Factors in Construction Projects: A BIM and SEM Analysis

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Received: 12 September 2025 | Revised: 12 October 2025, 23 November 2025, and 11 December 2025 | Accepted: 13 December 2025

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ABSTRACT

This research addresses the phenomenon of cost overruns with the following objectives: (i) identifying cost overrun factors using a Building Information Modeling (BIM) application approach, (ii) analyzing the causality model of these factors, and (iii) applying the BIM method to manage cost overruns. Data collection was conducted through relevant research, followed by determining the variables, indicators, and respondent criteria. Expert validation of the variables was then carried out. Finally, a perception survey was conducted using a questionnaire, and the data were processed using the Structural Equation Modeling (SEM) method with SmartPLS software. According to the results, two variables had a significant effect, namely implementation and working relationships ($X1 = 0.325$) and natural environment ($X9 = 0.271$). Meanwhile, the other eight variables showed a minor effect on cost estimates, such as finance ($X6 = 0.118$), economic feasibility ($X8 = 0.041$), labor ($X5 = 0.027$), equipment ($X4 = 0.025$), materials ($X3 = 0.021$), unexpected aspects ($X10 = 0.018$), project documentation aspects ($X2 = 0.006$), and implementation time, which showed a zero effect ($X7 = 0.00$). The novelty of this research lies in the integration of BIM and SEM to quantitatively analyze cost overrun factors in Indonesian building projects, providing insights into minimizing cost overruns in construction projects.

Keywords-cost overrun; BIM; SEM

I. INTRODUCTION

Infrastructure development is the driving force behind a country's growth [1]. The former is an integral part of economic institutional development through productivity improvement. The construction industry, therefore, has a major impact on a country's economy [2]. In developing countries, the construction industry is growing rapidly in terms of both quantity and quality. The Indonesian government is focusing on increasing investment, both public and private, in order to boost Indonesia's economic growth [3]. Infrastructure development is one of the factors contributing to the increasing role of the construction sector in the Indonesian economy [4]. In 2023, the budget allocated for infrastructure increased by 12.5%, that is, from IDR 373.1 trillion in 2022 to IDR 391.7 trillion in 2023 [5]. Moreover, the construction sector's contribution to the Gross Domestic Product (GDP) reached 9.45% in the third quarter of 2022 [6].

The construction industry, however, faces various challenges, such as low productivity, cost overruns, and client dissatisfaction [7]. The larger the construction activity, the more complex the mechanism, which means more problems will be encountered. Every construction activity has limitations and objectives that require more integrated management and control system. The two main problems to be solved are project delays and cost overruns [8].

Infrastructure projects, regardless of their geopolitical location and function, experienced an average final cost of 60% more than the previously approved budget. More specifically, construction projects in developed countries, such as the United States, Australia, the Netherlands, and South Korea, experienced cost overruns of 16-95%; other infrastructure projects in Europe experienced cost overruns of 200%; while in developing countries, such as Saudi Arabia, Qatar, and Jordan, the cost overrun range was between 70-200% [9].

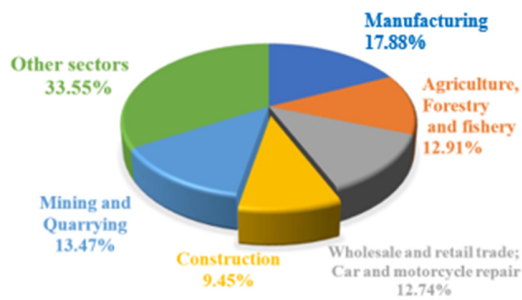


Fig. 1. Distribution of Indonesia's GDP at current prices for the third quarter of 2022.

A promising approach to mitigate cost overruns is BIM, which has improved various issues in the construction project life cycle [10]. BIM is a digital representation of the physical and functional characteristics of a project, where information is stored, managed, and shared in a digital database [11]. It can be a helpful tool for project managers due to its capabilities in information management and field work coordination. For this reason, many practitioners believe that this technology is worth considering in modern project management approaches, as it has helped its users reduce uncertainty and achieve successful project completion. Some benefits of BIM are better scheduling, improved drawings, a single detailed model, and control over time and costs. This technology facilitates collision detection, evaluates constructability, performs analysis, and compiles time and cost estimates using a 4D and 5D approach. Therefore, it can be applied at all stages of the construction process, from planning to operation and maintenance.

Addressing cost overruns requires an in-depth analysis of their factors and the role of BIM in mitigating them. Minimizing cost overruns can benefit the construction industry and have a positive impact on the country's economy. Most studies focus on descriptive analyses rather than causal modeling, and mainly within developed-country contexts. Several studies demonstrate progress in understanding BIM's role in cost control, yet little empirical evidence exists for developing countries such as Indonesia, where its adoption remains limited and project-cost performance issues persist. Therefore, this study addresses a significant research gap by integrating BIM and SEM to quantitatively analyze the interrelationships among BIM implementation, project characteristics, and environmental factors influencing cost overruns in Indonesian building-construction projects.

II. MATERIALS AND METHODS

A. Cost Overrun

Cost overruns basically occur when project implementation costs exceed the budget set during the planning stage. This situation often places a significant financial burden on contractors because the actual costs are much higher than initially estimated. Cost overrun factors can be internal or external and can be divided into three parts depending on the phase in which they occur, namely at the initial stage of the construction project, during the construction process, or after construction. The difference between the planned budget and

actual costs is often due to the complexity of construction projects, which results in delays and unexpected expenses [12]. It is important to understand the root causes of cost overruns, given their significant financial impact, to develop effective mitigation strategies.

B. Building Information Modeling

BIM is capable of simulating all information of a construction project into a 3D model that serves as a means for planning, designing, implementing construction, and maintaining the building and its infrastructure for all parties involved in the project, such as consultants, owners, and contractors [13]. BIM changes the traditional construction process, where conflicts and misunderstandings often arise between relevant stakeholders due to unclear and poorly recorded information flows, which lead to rework and subsequent delays in the execution of work, since implementation problems are only discovered after the project is underway. These delays automatically increase the cost. Additionally, the use of various conventional software for a single project may produce inaccuracies in material and work calculations, which will systematically result in poor work quality [14].

C. Research Methodology

In order to identify cost overrun factors and explore the ways in which BIM can help mitigate them, the current research addresses three questions, which are summarized in Table I, along with the research strategy for each of them.

TABLE I. RESEARCH QUESTIONS AND STRATEGY

No	Formulation of the problem	Question	Research strategy
RQ1	What are the factors that cause cost overruns in building construction projects?	What	Archival survey and analysis
RQ2	How is BIM applied to building construction projects?	How	Archival survey and analysis
RQ3	How can BIM be integrated to mitigate cost overruns in building construction projects?	How	Case study

The research process for RQ1 and RQ2 can be broken down into more specific steps, as illustrated in Figures 2 and 3, respectively. Two types of variables were used, independent variables (X) and dependent variables (Y). These variables were defined based on literature review and validated through expert judgement to ensure their relevance. Different research instruments were developed for RQ1, RQ2, and RQ3 to collect reliable data.

1) Research Instrument RQ1

To answer RQ1, an literature analysis was conducted to identify variables and indicators. These were then compiled into a questionnaire to be filled out by respondents which were implementing parties/contractors involved in building construction projects to provide expert validation.

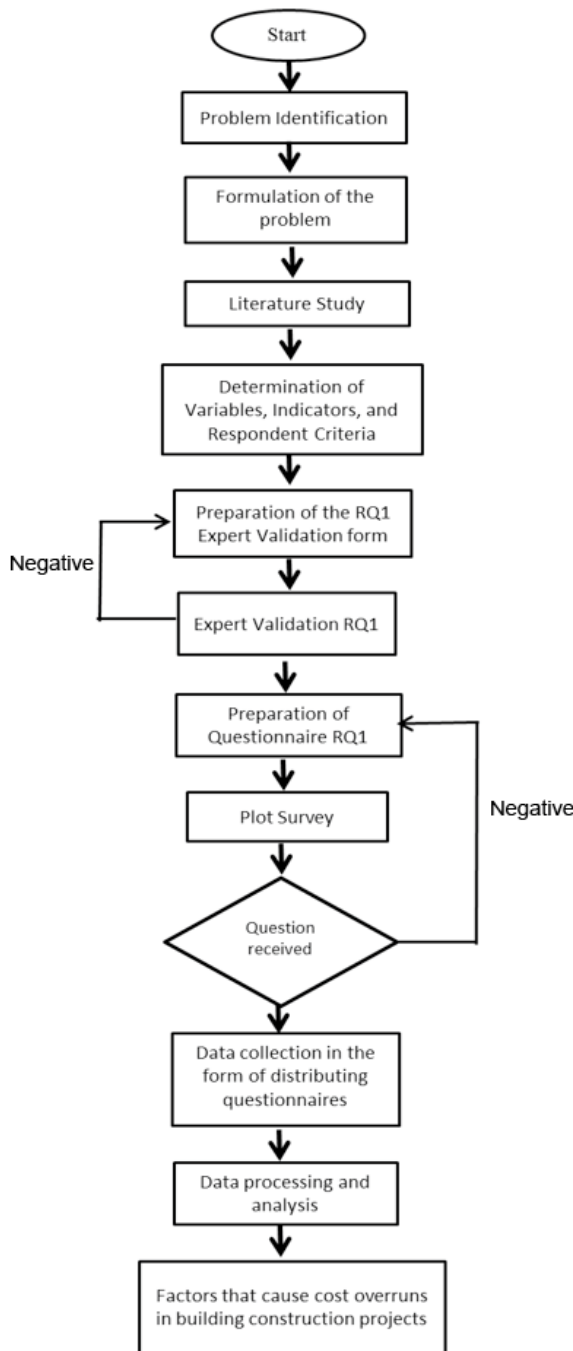


Fig. 2. RQ1 research process flow diagram.

2) Research Instrument RQ2

RQ2 was addressed with a second-stage questionnaire, as a pilot survey. It was distributed again to the implementing parties/contractors. The pilot survey aims to ensure that the questionnaire created by the researcher is easily understood by respondents. After the pilot survey, the final questionnaire was distributed to measure the influence of each interrelated variable, concerning BIM application in building construction projects. The collected data were analyzed using the Partial

Least Square (PLS) method with SmartPLS software. Based on the results of the model, a final expert validation questionnaire was created.

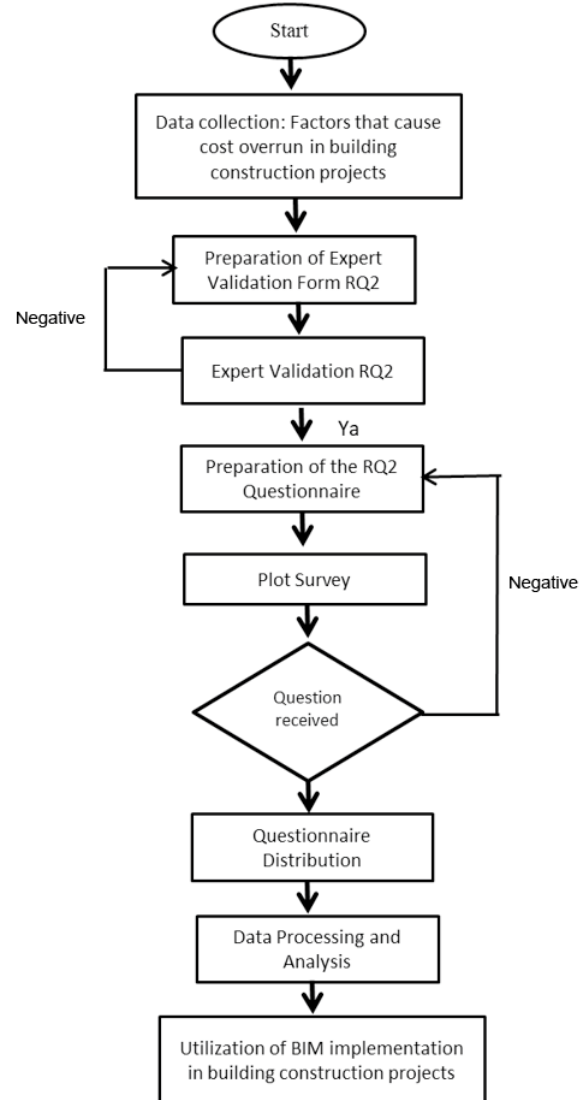


Fig. 3. RQ2 research process flow diagram

3) Research Instrument RQ3

After distributing the finalized questionnaire, the data were collected and processed using the fuzzy method to answer RQ3. Then, the results were analyzed and validated by experts in the fields of construction and BIM to determine the contribution of BIM in mitigating cost overruns in building construction projects.

The final step was to compile a research report covering the methodology, analysis results, and main findings. The report explains how BIM contributes to cost overrun mitigation in building construction projects, and provides conclusions and practical recommendations for construction professionals.

III. RESULTS AND DISCUSSION

A. Results of RQ1 Data Analysis

Table II presents the study variables that were identified through archival analysis.

TABLE II. VARIABLES OF FACTORS CAUSING COST OVERRUNS IN BUILDING CONSTRUCTION PROJECTS

Variable	Sub variable	Reference
X.1 Implementation and working relations	X.1.1 Poor project management	[15]
	X.1.2 Improper construction methods	[15]
	X.1.3 Incompetent subcontractors	[15]
	X.1.4 Project scope changes	[15]
	X.1.5 Lack of consultant experience	[15]
	X.1.6 Subcontractor work delays	[15]
	X.1.7 Lack of coordination between owner, contractor, and consultant	[16]
	X.1.8 Inadequate contractor's leadership skills and expertise	[16]
	X.1.9 Lack of project monitoring and supervision from the contractor	[17]
	X.1.10 Slow decision making	[17]
	X.1.11 Poor communication between all parties	[17]
	X.1.12 Disputes between parties involved in the project	[17]
X.2 Project document aspects	X.2.1 Frequent design changes	[15]
	X.2.2 Complex project design.	[15]
	X.2.3 Frequent contractual claims	[15]
	X.2.4 Wrong planning	[16]
	X.2.5 Delays in job approvals	[17]
	X.2.6 Absence of construction cost data	[17]
	X.2.7 Ineffective project planning and scheduling by contractors	[17]
	X.2.8 Errors or discrepancies in documents or specifications issued by the consultant	[17]
	X.2.9 Material selection and changes in type and specifications during construction	[18]
	X.2.10 Change of orders during construction	[18]
	X.2.11 Incomplete project data and information	[18]
	X.2.12 Incomplete contract documents	[19]
	X.2.13 Delays in drawing creation and approval	[20]
X.3 Materials	X.3.1 Changes in the scope of work or changes in material specifications by the client	[15]
	X.3.2 Fluctuations in raw material prices	[15]
	X.3.3 Fuel shortage	[17]
	X.3.3 Poor material procurement	[17]
	X.3.5 Poor material quality	[17]
	X.3.6 Errors in managing material storage	[18]
	X.3.7 Increase in the price of materials (ingredients)	[18]
	X.3.8 Limited availability of materials on the market	[20]
	X.3.9 Damage to materials (ingredients) in storage	[21]
X.4 Equipment	X.4.1 Inadequate or frequent breakdowns of construction equipment and plant	[15]
	X.4.2 Shortage of factory spare parts and equipment	[17]
	X.4.3 Poor equipment maintenance	[17]
	X.4.4 Lack of equipment availability	[18]
	X.4.4 High equipment costs	[18]
	X.4.6 High equipment prices/rental	[22]
	X.4.7 High equipment mobilization/demobilization costs	[20]
	X.4.8 Inappropriate selection of heavy equipment	[20]
X.5 Labor	X.5.1 Work errors during construction	
	X.5.2 Labor strike	[15]

X.5	X.5.3 Lack of skilled/experienced labor	[16]	
	X.5.4 Labor shortage	[17]	
	X.5.5 Unqualified workforce/team	[17]	
	X.5.5 Lack of workforce presence	[18]	
	X.5.7 Fluctuation in labor wages	[22]	
	X.5.8 Labor productivity	[20]	
	X.5.9 Inappropriate placement of project personnel in the organizational structure	[20]	
	X.6 Finance	X.6.1 Provision of insufficient funds by the owner	[15]
		X.6.2 Late payment by the owner	[15]
X.6.3 Financial difficulties experienced by contractors		[15]	
X.6.4 Financial difficulties faced by clients		[15]	
X.6.5 Complicated payment mechanism		[17]	
X.6.6 High transportation costs		[18]	
X.6.6 High cost of skilled and experienced labor		[18]	
X.6.8 Additional costs due to overtime work		[22]	
X.6.9 Rework costs		[22]	
X.6.10 Lack of sub-contractor capabilities in terms of funding/finance		[20]	
X.7 Execution time	X.7.1 Additional work	[15]	
	X.7.2 Work delays by suppliers/subcontractors	[16]	
	X.7.3 Acceleration required by the owner	[17]	
	X.7.4 Inadequate contract duration	[22]	
	X.7.5 Other construction activities taking place at the same time	[22]	
	X.7.6 Schedule delay due to weather conditions	[20]	
X.8 Economic feasibility	X.8.1 Inappropriate government policies	[17]	
	X.8.2 Project complexity	[17]	
	X.8.3 Inadequate site investigation or unexpected site conditions	[17]	
	X.8.4 Exchange rate fluctuations	[17]	
	X.8.5 Interest rate charged by bankers to finance a project	[22]	
	X.8.6 Global economic impact	[22]	
	X.8.7 High insurance premium costs and other social burdens on the workforce	[22]	
	X.8.8 High land prices	[22]	
X.9 Natural environment	X.9.1 Bad weather	[20]	
	X.9.2 Environmental impact on the feasibility of project development	[22]	
	X.9.3 Natural disasters	[15]	
	X.9.4 High land prices		
X.10 Unexpected aspects	X.9.5 Project locations that are far from city centers or equipment and material distribution centers		
	X.10.1 Accidents at the scene		
	X.10.2 Project locations that are far from city centers or equipment and material distribution centers		
	X.10.3 Riot/damage around the project site		
	X.10.4 Changes in laws and regulations		
	X.10.5 High land prices		
	X.10.6 Theft of materials		
Y.1 Estimated costs	Y.1.1 Fluctuations in raw material prices	[15]	
	Y.1.2 Project cost estimates are inaccurate	[16]	
	Y.1.3 Production costs are unstable	[17]	
	Y.1.4 Increase in labor wages	[17]	
	Y.1.5 Poor project management	[18]	
	Y.1.6 High maintenance costs for work equipment	[17]	
	Y.1.7 Contingencies not taken into account	[18]	
	Y.1.8 Effects of inflation and escalation not taken into account	[20]	
	Y.1.9 Insufficient allocation of funds	[21]	

B. Results of RQ2 Data Analysis

1) Respondent Overview

The results of the questionnaire survey, used in this study, were obtained from respondents who met the predetermined research respondent requirements. They consisted of building construction service providers, namely contractors, consultants, and government agencies. Data about the agency (Table III), position (Table IV), education level (Table V), and work experience (Table VI) of the respondents were collected and should be considered as additional information for the interpretation of the research results.

TABLE III. RESPONDENT AGENCY

Agency	Number
BUMN contractor	1
Private contractor	18
BUMN consultant	1
Private consultant	19
Entrepreneur	1
Tomokaka Group	1
Unifa	1
Creative Works Center	1
Academics	1
University	1
Employee	1
Civil servants	2
PU honorer	1
Business owner	1
Public servant	1
KOMINFOSIP Ministry Mamuju Regency	1
PUPR Ministry	1

TABLE IV. RESPONDENT POSITION

Position	Number
Project manager	8
Site manager	7
HSE	1
Quality control	5
Quantity surveyor	1
Engineering staff	12
Lecturer	2
Director	2
Staff	2
Expert	1
Team leader	1
Planning department	1
Teaching staff	1
Technical staff	1
Project owner	1
Chief executive officer	1
Acting head	1
Civil servant	1
Individual consultant	1
Department staff	1
Owner	2

TABLE V. RESPONDENT EDUCATION LEVEL

Last education	Number
Senior high school	2
Advanced diploma	1
Bachelor's degree	23
Master's degree	22
Doctoral degree	5

TABLE VI. RESPONDENT WORK EXPERIENCE

Work experience	Number
3-5 years	14
5-10 years	16
10-15 years	7
>15 years	16

2) Data Analysis

a) Convergent Validity

Convergent Validity can be evaluated using: the loading factor value or the Average Variance Extracted (AVE) value. In this research, it was evaluated using the AVE value, and the results are presented in Table VII.

TABLE VII. RESULTS OF THE AVE CONVERGENT VALIDITY TEST

Variable	AVE	Status
Estimated costs (Y)	0.604	Valid
X1	0.735	0.857
X2	0.732	Valid
X3	0.776	Valid
X4	0.756	Valid
X5	0.773	Valid
X6	0.707	Valid
X7	0.653	Valid
X8	0.712	Valid
X9	0.710	Valid
X10	0.733	Valid

a. Source: SmartPLS Data Processing (2025)

All variables in this study showed AVE values above the minimum threshold of 0.50, which means that each indicator was able to adequately explain the variance of its construct. The dependent variable Cost Estimate (Y) has an AVE value of 0.604, indicating good convergent validity. All independent variables from X2 to X10 also meet the validity criteria, with AVE values ranging from 0.653 to 0.776.

b) Discriminant Validity

Discriminant validity is used to ensure that the constructs or variables in a measurement model truly measure different things and do not overlap with one another. Discriminant validity can be measured using Cross Loading, Fornell-Larcker Criterion, and latent variable correlation.

• Cross Loading

An indicator/statement is considered valid if the relationship between the indicator/statement and its construct/variable (cross-loading value) is higher than its relationship with other constructs. The cross-loading results were obtained using SmartPLS version 4. Overall, all variables meet the validity criteria, with several indicators (such as X1.11, X2.8, X3.9, and X5.6) achieving values > 0.9, indicating high reliability. However, indicators with values below 0.6 (e.g., X9.4 = 0.406) need to be reevaluated or removed to improve construct quality.

In addition, the square root of AVE (\sqrt{AVE}) or vAVE for all indicators is above 0.7, with the highest value being 0.881 (X3) and the lowest being 0.777 (Cost Estimate), suggesting

that each construct is more strongly correlated with its own indicators than with other constructs (Table VIII). Thus, all indicators in this model have met the requirements for convergent and discriminant validity and are declared valid for use in further analysis.

TABLE VIII. LATENT VARIABLE VALUE OF CORRELATION ROOT, AVE VALUE, AND SQUARE ROOT OF AVE

Variable	AVE	√AVE	Status
Estimated costs (Y)	0.604	0.777	Valid
X1	0.735	0.857	Valid
X2	0.732	0.856	Valid
X3	0.776	0.881	Valid
X4	0.756	0.869	Valid
X5	0.773	0.879	Valid
X6	0.707	0.841	Valid
X7	0.653	0.808	Valid
X8	0.712	0.844	Valid
X9	0.710	0.843	Valid
X10	0.733	0.856	Valid

a. Source: SmartPLS Data Processing (2025)

• Fornell-Larcker

The Fornell-Larcker test evaluates discriminant validity in PLS models by comparing the square root of each construct's AVE to its correlations with other constructs. Discriminant validity is established when the AVE square root is greater than

the correlations. Thus, this test ensures that each construct is unique and can be empirically distinguished from other constructs in the study.

Based on the results of the Fornell-Larcker test (Table IX), discriminant validity can be confirmed by comparing the vAVE values (found on the diagonal of Table IX, such as 0.777 for Cost estimates, 0.857 for X1, 0.855 for X2, and up to 0.856 for X10) to the correlations between constructs (values outside the diagonal). The results show that each vAVE value is greater than the correlations between other constructs in the same row and column. Thus, all constructs are declared discriminantly valid, because each construct represents itself more than other constructs, meeting the Fornell-Larcker criteria.

a) Internal Consistency

Based on the reliability test results using Cronbach's Alpha, all variable indicators showed values above the minimum threshold of 0.70, which means that each construct was declared reliable (Table X). The highest value was observed for variable X2 at 0.969, followed by X1 (0.967) and X3 (0.964), which indicates very high internal consistency between items in the construct. Meanwhile, the variables with the lowest values are still relatively high, namely X7 (0.893) and X9 (0.897), and meet the reliability criteria. Thus, all constructs in this study can be said to have excellent reliability, indicating that they are able to measure the same concept consistently.

TABLE IX. FORNELL-LARCKER TEST RESULTS

Variable	Estimated cost	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	Status
Estimated cost	0.777											Valid
X1	0.841	0.857										Valid
X2	0.823	0.873	0.855								0.801	Valid
X3	0.75	0.841	0.858	0.881							0.789	Valid
X4	0.765	0.804	0.842	0.937	0.869						0.821	Valid
X5	0.819	0.91	0.922	0.88	0.872	0.879					0.822	Valid
X6	0.746	0.891	0.842	0.916	0.91	0.874	0.841				0.826	Valid
X7	0.779	0.823	0.807	0.801	0.843	0.818	0.883	0.808			0.819	Valid
X8	0.82	0.802	0.778	0.693	0.769	0.816	0.77	0.768	0.844		0.704	Valid
X9	0.811	0.687	0.771	0.654	0.718	0.756	0.697	0.826	0.789	0.842	0.758	Valid
X10	0.702	0.77									0.856	Valid

TABLE X. CRONBACH'S ALPHA VALUE

Variable	Cronbach's alpha	Status
X1	0.967	Reliable
X2	0.969	Reliable
X3	0.964	Reliable
X4	0.954	Reliable
X5	0.963	Reliable
X6	0.953	Reliable
X7	0.893	Reliable
X8	0.942	Reliable
X9	0.897	Reliable
X10	0.909	Reliable

a. Source: SmartPLS Data Processing (2025)

TABLE XI. CR VALUE

Variable	CR	Status
X1	0.971	Reliable
X2	0.972	Reliable
X3	0.969	Reliable
X4	0.961	Reliable
X5	0.968	Reliable
X6	0.960	Reliable
X7	0.918	Reliable
X8	0.952	Reliable
X9	0.924	Reliable
X10	0.932	Reliable

a. Source: SmartPLS Data Processing (2025)

b) Composite Reability (CR)

Based on the CR test results, all variables in this research model obtained values above the proposed threshold of 0.70. Therefore, all variables were declared reliable, as displayed in Table XI.

c) Model Fit Test

Model fit testing was conducted by evaluating the output of SmartPLS 4.0 using standard Goodness of Fit (GoF) criteria. The results were compared with reference values to determine whether the research model met the fit requirements, and are

presented in Table XII. The results of the overall model fit test indicate a Standardized Root Mean Square Residual (SRMR) value of 0.087 and a squared euclidean distance (d_{ULS}) of 32.015, both of which meet the rule of thumb criteria and suggest that the model is fit. However, other parameters, such as Chi-Square (χ^2), showed a value of ∞ , while Normed Fit Index (NFI) and geodesic distance (d_G) were not available (n/a). Thus, these three parameters were categorized as unfit. Nevertheless, the GoF value of 0.729 suggests that the model is in the moderate fit category (close to strong). In addition, the Q^2 Predictive Relevance value of 0.706 indicates a strong predictive ability of the model. Overall, even though several indicators are not fit, the model is still considered acceptable because it has a good level of fit and predictive power.

The hypothesis testing results (Table XIII) indicated that only three out of ten paths of independent variables on cost estimation had a significant and acceptable effect, namely X1, X6, and X9, with T-statistic values of 3.143, 1.754, and 1.913, and p-values of 0.001, 0.040, and 0.028, respectively (all < 0.05). This confirms that these three variables have a significant effect on cost estimation.

TABLE XII. MODEL FIT TEST

Parameter	Rule of thumb	Parameter values	Status
SRMR	< 0.10	0.087	Fit
d_{ULS}	> 0.05	32.015	Fit
d_G	> 0.05	n/a	Not fit
χ^2	χ^2 statistic $\leq \chi^2$ table	∞	Not fit
NFI	Approaching 1 (≥ 0.90 ideal)	n/a	Not fit
GoF	0.1 (small), 0.25 (moderate), 0.36 (strong)	0,729	Moderate fit
Q^2 Predictive Relevance	$Q^2 > 0$ (0.02=weak, 0.15=moderate, 0.35=strong)	0.706	Strong fit

a. Source: SmartPLS Data Processing (2025)

TABLE XIII. PATH COEFFICIENT RESULTS AND SIGNIFICANCE TEST WITH THE BOOTSTRAPPING METHOD

Hypothesis	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T-statistic ((O/STDEV))	P value	Status
X1→Y	0.712	0.76	0.227	3.143	0.001	A
X2→Y	0.088	0.042	0.232	0.378	0.353	R
X3→Y	0.214	0.203	0.296	0.721	0.236	R
X4→Y	0.233	0.301	0.332	0.702	0.241	R
X5→Y	-0.228	-0.292	0.267	0.853	0.197	R
X6→Y	-0.498	-0.526	0.284	1.754	0.040	A
X7→Y	-0.012	-0.022	0.279	0.042	0.483	R
X8→Y	0.179	0.182	0.226	0.791	0.215	R
X9→Y	0.418	0.401	0.219	1.913	0.028	A
X10→Y	-0.111	-0.048	0.158	0.699	0.242	R

a. A: Accepted, R: Rejected.

Based on the results of the effect size analysis on cost estimates, only two variables have a significant effect, namely X1 with a value of 0.325 and X9 with a value of 0.217, as illustrated in Table XIV. Meanwhile, the other eight variables show a minor effect on cost estimates, such as X6 with a value

of 0.118, X8 with a value of 0.041, X5 with a value of 0.027, X4 with a value of 0.025, X3 with a value of 0.021, X10 with a value of 0.018, X2 with a value of 0.006, and X7 even showing a zero effect (0.00). This indicates that in this model, the largest contribution to the increase in cost estimates comes from variables X1 and X9, while the other variables make an insignificant contribution. The results of data analysis using the SEM method are illustrated in Figure 4.

TABLE XIV. THE RESULT OF EFFECT SIZE TEST (F^2)

Variable	Estimated costs	Status
X1	0.325	Big effect
X2	0.006	Small effect
X3	0.021	Small effect I
X4	0.025	Small effect
X5	0.027	Small effect
X6	0.118	Small effect
X7	0.00	Small effect
X8	0.041	Small effect
X9	0.217	Big effect
X10	0.018	Small effect

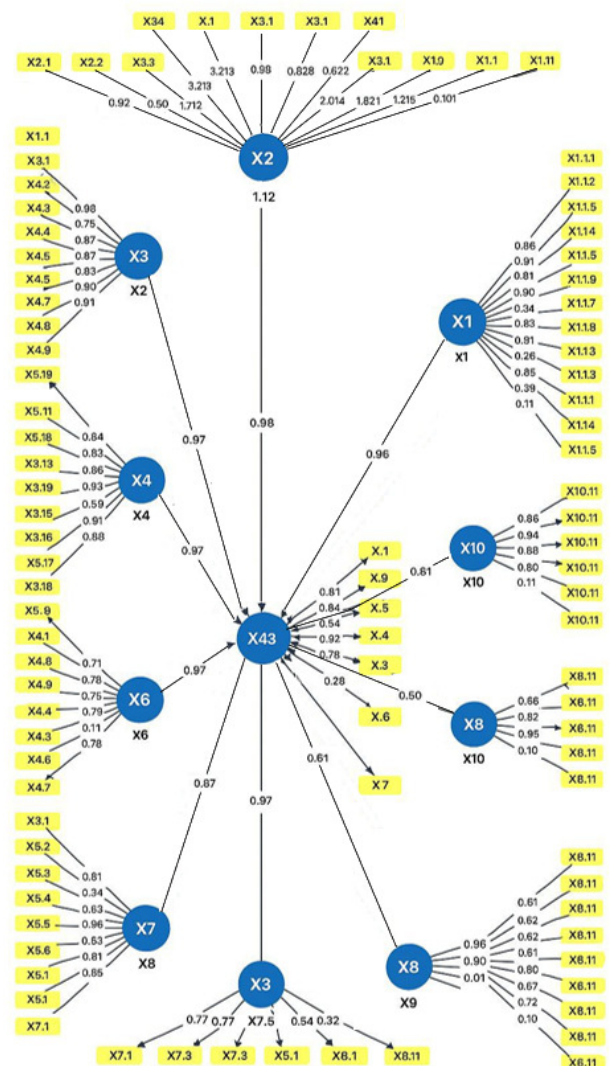


Fig. 4. Results of data analysis using the SEM method.

The benefits of BIM implementation in mitigating cost overrun are listed by category in Table XV.

TABLE XV. IMPLEMENTATION OF BIM IN HANDLING FACTORS CAUSING COST OVERRUN

Sub-variable	Handling	Ref.
X.1 Damage to materials (materials) on site	X.1.1 Visualization and planning of material storage	[23]
	X.1.2 Real-time material monitoring and tracking	[24]
	X.1.3 Inter-stakeholder coordination and digital documentation	[25]
	X.1.4 Damage documentation and rapid decision making	[26]
X.2 Errors or discrepancies in documents or specifications issued by the consultant	X.2.1 Clash detection	[26]
	X.2.2 Integrated multidisciplinary coordination	[27]
	X.2.3 3D visualization and construction simulation	[25]
	X.2.4 Digital audit of design documents	[23]
	X.2.5 Integration with quantity take-off and cost estimation (5D BIM)	[28]
X.3 Poor communication between all parties	X.3.1 Visualization of design and project progress in 3D/4D/5D	[25]
	X.3.2 Real-time collaboration through an integrated platform	[27]
	X.3.3 Cross-disciplinary coordination in an integrated model	[29]
X.4 Poor material procurement	X.4.1 Accurate automatic material quantification	[28]
	X.4.2 5D BIM integration for procurement cost and schedule estimation	[26]
	X.4.3 Increased transparency and coordination between teams	[27]
	X.4.4 Simulation of material delivery and placement	[26]
X.5 work errors during construction	X.5.1 Detailed and accurate 3D visualization	[27]
	X.5.2 Integration of schedule with model (4D BIM)	[30]
	X.5.3 Real-time progress and quality monitoring	[31]
	X.5.4 Clear documentation and revision trail	[29]
X.6 High equipment costs	X.6.1 Integration of equipment data with schedule and cost (6D BIM)	[26]
	X.6.2 Visualization of equipment usage in the project	[29]
	X.6.3 BIM-based preventative maintenance planning	[32]
	X.6.4 Real-time efficiency and cost analysis	[27]
X.7 Lack of workforce presence	X.7.1 4D BIM (Integration of schedule with model)	[27]
	X.7.2 BIM-based project progress monitoring	[33]
X.8 Poor material quality	X.8.1 Integration of material specifications into BIM (5D) models	[27]
	X.8.2 Material tracking and logistics through BIM	[34]
	X.8.3 Integration of BIM and quality management systems	[29]
X.9 Absence of construction cost data	X.9.1 5D BIM for model integration and cost estimation	[28]
	X.9.2 Creating a project cost database in a BIM system	[27]

	X.9.3 Simulation of design changes to costs directly	[35]
X.10 There is an increase in the price of materials (ingredients)	X.10.1 5D BIM for price increase impact analysis	[28]
	X.10.2 BIM integration with real-time market price data	[27]
	X.10.3 Alternative material modeling	[29]
X.11 Inappropriate placement of project personnel in the organizational structure	X.11.1 BIM-based project organization and collaboration platforms	[26]
	X.11.2 Role-based access in BIM	[29]
	X.11.3 Visualization of tasks in a 4D BIM timeline	
X.12 High insurance premium costs and other social burdens on the workforce	X.12.1 BIM 4D for labor efficiency simulation	[36]
	X.12.2 BIM integration with human resource management system	[27]
	X.12.3 Simulation of alternative scheduling schemes	
X.13 High equipment prices/rental	X.13.1 Equipment scheduling simulation with 4D BIM	[36]
	X.13.2 Equipment cost estimation with 5D BIM	[28]
	X.13.3 Selection of alternative tools via BIM library	[27]
X.14 Errors in managing material storage	X.14.1 BIM 4D for synchronization of material arrival and storage times	[36]
	X.14.2 Mapping storage locations with BIM site layout	[37]
	X.14.3 BIM integration with inventory management systems	
X.15 Environmental impact on the feasibility of project development	X.15.1 Site condition and drainage simulation with BIM with Geographic Information System (GIS)	[38]
	X.15.2 Green BIM for energy and emission impact evaluation	[39]
	X.15.3 Topographic and drainage modeling	[27]
X.16 Inadequate or frequent breakdowns of construction equipment and plant	X.16.1 4D BIM for scheduling equipment usage and maintenance	[36]
	X.16.2 BIM and asset management for factory equipment	[23]
	X.16.3 BIM 5D for equipment maintenance and repair cost estimation	[27]
X.17 Labor shortage	X.17.1 4D BIM for job schedule and labor requirement simulation	[27]
	X.17.2 Using BIM and resource management tools	[40]
	X.17.3 Analysis of workload and labor productivity	
X.18 Late payment by owner	X.18.1 5D BIM: Integration of models, time, and cost	[27]
	X.18.2 Using BIM and cost management tools	[40]
	X.18.3 Digital audit of work progress	
X.19 High transportation costs	X.19.1 Using BIM and 4D for material delivery simulation	[36]
	X.19.2 Using BIM and GIS	[41]
	X.19.3 5D BIM for transportation cost estimation	

IV. CONCLUSION

Based on a literature study accompanied by expert validation, the factors that cause cost overruns in building construction projects include implementation and working relationships, project documentation, materials, equipment,

labor, finance, implementation time, economic feasibility, natural environment, unexpected aspects, and cost estimates.

The results of SmartPLS processing indicate that only two variables have a significant effect: implementation and working relations ($X1 = 0.325$), and the natural environment ($X9 = 0.217$), while the other eight variables have a minor effect on cost estimation.

The novelty of this study lies in integrating Building Information Modeling (BIM) and Structural Equation Modeling (SEM) to quantitatively analyze cost overrun factors within the context of Indonesian building projects. This research contributes theoretically by extending BIM-based cost management models through the integration of SEM to uncover the causal relationships among project variables. In practice, it provides a validated analytical framework that helps project stakeholders identify and control the most influential cost drivers, supporting more effective cost management strategies in developing countries.

Future research could focus on expanding this study by including more diverse construction project types or regions to validate and generalize the current findings. This direction is important because project environments and management practices may vary significantly across locations, potentially affecting BIM adoption and cost performance outcomes. It is also proposed to explore additional variables influencing project cost behavior and to integrate qualitative approaches for deeper insights into the practical challenges of BIM implementation in developing countries.

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