SINERGI Vol. 27, No. 3, October 2023: 393-404
http://publikasi.mercubuana.ac.id/index.php/sinergi
http://doi.org/10.22441/sinergi.2023.3.010

The impacts of 5D-Building Information Modeling on construction's Time and cost performance

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Abstract
The construction sector is essential to a country's economic growth and development. This is why the construction of building projects is one of the most pressing concerns for the Indonesian government. The industrial sector has become increasingly dynamic and responsive to the challenges of building projects due to technological advancements. One example is the Building Information Modelling (BIM) 5D, an emerging technology integrating project implementation time and costs into a 3D model. Therefore, this study aims to investigate the success factors of BIM 5D implementation on the time and cost performance of high-rise building construction projects at Campus-II UIN Sunan Ampel Surabaya. This was achieved through a quantitative research method using a questionnaire completed by 62 respondents: the project manager, site manager, engineering head, and site engineer. Moreover, descriptive statistics were utilized to examine the frequency distribution of concentration measures and data distribution on sample characteristics and variables. The findings showed that the factors of tender document, human resources, BIM software, planning process and production process simultaneously positively affected the construction project's cost and time performance.

Keywords:
Building Information Modeling;
Costs performance;
Time performance;

Article History:
Received: February 22, 2023
Revised: April 17, 2023
Accepted: April 29, 2023
Published: October 2, 2023

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INTRODUCTION

The construction sector contributes significantly to the economic growth and development of a country [1][2] in different ways [3]. It is also pertinent to note that building is the key indicator of global economic activity in several countries [4], contributing 5–10% to GDP on average. In Indonesia, the construction sector contributes quite a lot to the national GDP [5], reaching up to 10.12% of IDR 4,175.8 trillion [6]. The 2021 State Budget allocated IDR 417.4 trillion for infrastructural development, and building projects were observed to have the highest focus with 10,706 units. This makes Indonesia continued to lead South East Asia in terms of construction investment, and it was the largest in all of Asia [7].

The construction industry has certain characteristics required to be understood to ensure an effective and efficient working process [8]. This is because numerous variables contribute to construction project delays, such as inaccuracies in work planning, inappropriate construction methods, inadequate timeframe identification, and poorly structured work plans [9]. To that end, being technologically responsive is essential in the dynamic construction industry. This is mainly because the activities usually begin long before the work on site to transform materials and blueprints into entire buildings, structures, and facilities [10]. Moreover, high-quality construction projects always require extensive and planned data processing [11] as well as well-structured information systems throughout the process [12].

Building Information Modelling (BIM) is one of the most promising innovations in the architecture, engineering and construction (AEC) industry [13]. Excellent BIM implementation could cut time 50% faster and save personnel costs by 52.25% compared to those of conventional methods [14][15]. So that, BIM also has the ability to increase the quality, accuracy, and value of project cost management. The concept of modeling in BIM focuses on integrating and collaborating in multiple domains, starting from the building design modeling (3D) to scheduling implementation (4D), and setting construction costs (5D). The virtualization of the building information through the 5D BIM has the capacity to improves the accuracy of project cost estimation [16]. It is pertinent to note that the issues in constructing projects typically arise during the pre-construction stage as indicated by initial inadequacies in design and cost estimation affecting the later phases of development [17].

High-rise buildings are defined as building from 75 to 200 meters in height [18]. High-rise buildings are more complex than low-rise structures because they are required huge number of structural components and elements, as well as the fact that these high-rise buildings demand high structural stability for safety and design requirements [19]. Each stage of construction projects demands effective communication between all the parties involved [20]. Any construction project's success or failure begins with the planning stage [21]. This means poor project planning is expected to cause dissatisfaction among customers [22] and inadequate tender documents can also affect public construction projects negatively [23]. Therefore, there focusing on project planning, coordination among human resources, and control is essential for construction risk management [24]. BIM is an information management system for a to-be-built structure that covers the design and construction phases, as well as the termination of the service and its continuation after implementation [25]. BIM may improve information efficiency and availability by integrating information from all construction activities throughout a project, which benefits stakeholders [26]. Therefore, implementing BIM 5D can minimize service provider complaints [27]. The BIM 5D is majorly established on the elements of an information model that can be implemented throughout the life cycle of a building to present accurate financial data. This is intended to assist the budget manager in determining the quantity of a particular item, adding costs to that amount, and achieving cumulative production costs [28]. The implementation of BIM in the building life cycle is presented in the following Figure 1.

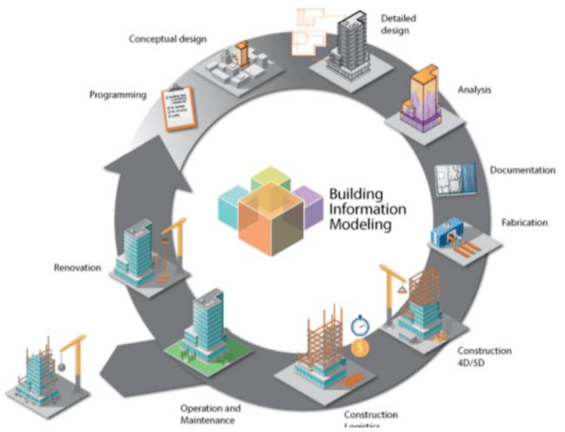


Figure 1. BIM Implementation in the Building Life Cycle Source: [29]

Some of problems often observed during the process of implementing projects are associated with scheduling and they needs to be improved in order to minimize delays in project completion [30]. It is important to note that the success of construction projects largely depends on project scheduling which focuses on ensuring the plans in the contract are appropriate to reduce time, costs, and risk [31]. It has been previously noted that an incorrectly prepared work schedule can lead to an increase in the time needed for the project [32].

Undoubtedly, the planning, implementation, and completion of a construction project is a long activity that requires the cooperation of many different parties. Even experienced human resources require thoroughness in thought and action to achieve the expected excellent standards. Therefore, it does not rule out the possibility of construction project time extensions and inaccurate cost estimates. In the meantime, BIM 5D technology is expected to facilitate and accelerate the lengthy sequence of construction operations. The implementation of a project can become more systematic if the proper method is used to develop a framework system. Thus, it is important to identify the success factors for BIM 5D implementation in construction projects.

According to the background, researchers are interested in identifying the success factors and analyzing the implementation of using BIM 5D in high-rise building construction. The findings are expected to provide insights into the application of BIM 5D to accelerate the construction of high-rise buildings with due consideration for different aspects in order to ensure efficiency in terms of cost, quality, and time for project implementation with the implementation of BIM 5D.

METHOD

This study is a development of [33] study of the cost of concrete and formwork using 5D BIM and [34] discussion of modeling steps from 3D to 5D using the Tekla Structure application. The novelty of this research lies in the research object and method, which is a high-rise building project undertaken by PT XYZ for cost and time analysis using BIM 5D. The study was carried out by simulating the project's implementation time using the S curve and by using 5D BIM. This simulation identifies the critical path of the project by estimating implementation time to avoid job clashes and monitoring material waste in the field to reduce implementation costs.

Proposed Method

This research stages starts with the collection of picture and estimation paperwork data from the parties directly involved in the project, such as the construction management team, consultants, and contractors that won the project tender. After gathering the necessary image data, the next step is to create a BIM-based model.

This research focuses on the building and infrastructure project for Campus II UIN Sunan Ampel Surabaya, which consists of five scopes of work: integrated building for the Faculty of Science and Technology, Faculty of Adab and Humanities, Library and Academic Administration (AEFG Building), building Laboratory of the Faculty of Science and Technology (Building F1), Faculty of Psychology and Health (Building I), and Faculty of Social and Politics (Building II). The project was implemented between January 27, 2020 to August 29, 2022.

A survey method was conducted to obtain primary data, while secondary data is collected through direct observation and relevant journals. The survey aimed to identify the factors that influence the successful implementation of BIM 5D in construction projects. This study's population consisted of all service provider company staff and workers involved in the Campus II UIN Sunan Ampel Surabaya construction project. A purposive sampling technique was performed by distributing questionnaires to 62 respondents, they are the project manager, site manager, engineering head, and site engineer. Purposive sampling is "used to select respondents who are most likely to provide relevant and useful information and is a method for identifying and selecting cases that will make the most efficient use of limited research resources." [35].

This research investigated the factors that influence the cost and time performance of implementing BIM 5D in construction projects by five independent variables: tender documents (X1) by four indicators, human resources (X2) by four indicators, BIM applications (X3) by four indicators, planning process (X4) by three indicators, and production process (X5) by four indicators. Meanwhile, the cost and time performance of the construction project is indicated in the preparation, implementation, and completion stages as the dependent variables. The description of the variables and indicators of this study are explained in more detail in the indicator column of Table 1. SPSS 26 was used to process the data obtained through the questionnaire. The tests conducted include Pearson validity test, Cronbach's alpha reliability test, and the multiple linear regression test. The illustration of the research flowchart can be seen in Figure 2.

Materials

This study's materials are in the form of a master schedule, Bill of Quantity, Detailed Engineering Design, work plans for technical requirements or specifications, and work implementation reports. After all the data has been collected, the BIM application can be used.

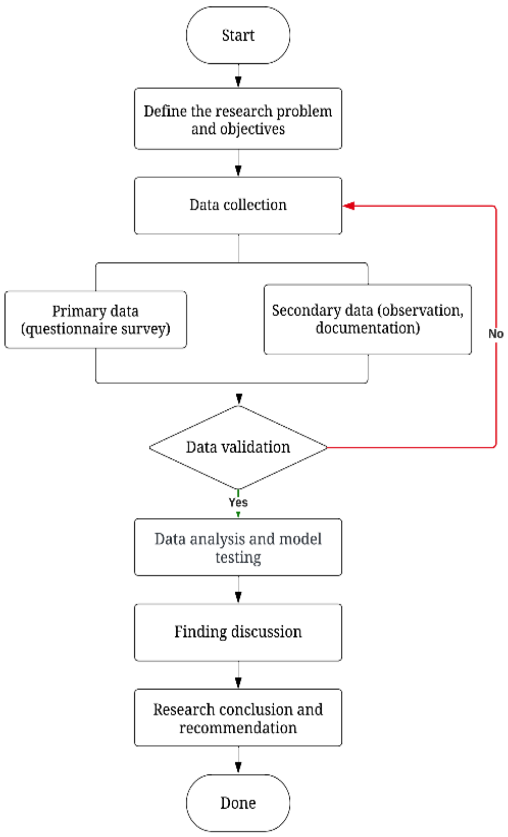


Figure 2. Research flowchart

1. Revit Autodesk application. BIM 3D modelling conducted by inputting structural, architectural and ME working drawings. At this stage, there are issues with project design in terms of the suitability of planning for all parts, including structural, architectural, and mechanical-electrical components.
2. BIM 4D Sequence modelling with component grouping based on project activity sequence (Activity Sequencing).
3. Cubicost application. 5D BIM modelling performed by using structural, architectural, and mechanical electrical working drawings as input. At this stage, the correct overall volume of work is obtained, and a correction is made to the entire initial budget.

RESULTS AND DISCUSSION

The variables used for the building BIM were validated by experts including BIM specialists and building company managers. This led to the selection of the five independent variables containing 20 indicators and two dependent variables with six indicators. It is pertinent to state that the validation process was conducted through agree/disagree statements. Moreover, variable Y represents the evaluation of the application of BIM 5D on time and cost performance using three indicators for each of the project preparation, project implementation, and project completion stages. The variable validation stage was followed by the formulation of the questionnaires.

Validity Test

The personal correlation test was considered valid when the r calculated was greater than the r-table value and the significance value was less than 0.05. It is important to note that r-table was determined through the degree of freedom (df) value using the formula df=n-2, where n is the number of samples. The variable was considered valid when the r-value of each statement item was higher than r-table (0.250) with a significance level of 0.05 [36]. It was discovered that all research variables are valid based on these criteria as indicated in Table 1**.**

Reliability Test

Cronbach's alpha value was used to test for variable reliability based on the criteria that the variable is reliable when the value is > 0.6. The results of the study variable reliability test are shown in Table 2.

Based on the results of the validity and reliability tests, the seven latent variables were declared reliable, and all variable indicators were also valid. This means they can be used for further analysis.

Table 1. Validity Test

Code	Indicator	R_{value}	Sig	Note
X1.1	Complete and clear technical specifications	0.817	0.000	Valid
X1.2	Data conformity between technical specifications and the Bill of Quantities describing the structural, architectural, mechanical, electrical, and landscape work	0.719	0.000	Valid
X1.3	Unobtrusive design	0.583	0.000	Valid
X1.4	Clear implementation schedule	0.649	0.000	Valid
X2.1	Availability of experts	0.683	0.000	Valid
X2.2	Training availability for BIM 5D	0.745	0.000	Valid
X2.3	Personnel has knowledge and experience with BIM software and its designation.	0.854	0.000	Valid
X2.4	Personnel are well-informed of the project's scope.	0.741	0.000	Valid
X3.1	Hardware devices (laptop/computer) support application development	0.714	0.000	Valid
X3.2	Application update	0.835	0.000	Valid
X3.3	The operating system on a laptop/computer supports BIM	0.864	0.000	Valid
X3.4	The ability to transfer data across software	0.550	0.000	Valid
X4.1	Poor design and delays in design details	0.804	0.000	Valid
X4.2	Inadequate planning and scheduling	0.814	0.000	Valid
X4.3	Design and material specifications changes	0.747	0.000	Valid
X5.1	Predictable work plan	0.726	0.000	Valid
X5.2	Eliminate waste in workflows	0.818	0.000	Valid
X5.3	Identify incomplete work execution	0.805	0.000	Valid
X5.4	Conduct a constraint analysis in the production process	0.782	0.000	Valid
Y1.1	The impact of BIM 5D on time in the project preparation stage	0.781	0.000	Valid
Y1.2	The impact of BIM 5D on time in the project implementation stage	0.851	0.000	Valid
Y1.3	The impact of BIM 5D on time in the project completion stage	0.683	0.000	Valid
Y2.1	The impact of BIM 5D on cost in the project preparation stage	0.702	0.000	Valid
Y2.2	The impact of BIM 5D on cost in the project implementation stage	0.832	0.000	Valid
Y2.3	The impact of BIM 5D on cost in the project completion stage	0.766	0.000	Valid

Table 2. Reliability Test

No	Variable	Cronbach's Alfa	Notes
1	X1 Tender document	0.629	Reliable
2	X2 Human resources	0.728	Reliable
3	X3 BIM software	0.731	Reliable
4	X4 Planning process	0.696	Reliable
5	X5 Production process	0.789	Reliable
6	Y1 BIM application to time performance	0.663	Reliable
7	Y2 BIM application to cost performance	0.650	Reliable

Multiple Linear Regression

Multiple linear regression is a model of regression that includes multiple independent variables. This method was applied to determine the relationship between each of independent variables with the dependent variable which is linear.

$$y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + .. b_xX_y \quad (1)$$

Equation (1) is used to determine the relationship between the predictor variable and the response variable. In this study, hypothesis tests were performed to determine the research results.

Hypothesis Testing

This research hypothesis is that the implementation of BIM 5D affects the time performance and cost of high-rise building construction. The implementation of BIM 5D in this study was described by five variables: document tenders (X1), human resources (X2), BIM software (X3), planning process (X4), and production process (X5).

T-test

A partial hypothesis (t-test) was conducted by comparing the t-value to the t-table and the significance value. The criterion is that the independent factors affect the dependent variable when the t-count is higher than the t-table. Moreover, the independent factors significantly affect the dependent variable when the significance values is less than 0.05. The t-table value was determined by calculating the degree of freedom (df) using df = n-k-1, where n is the number of study samples and k is the number of independent variables tested as previously stated. Therefore, df value = 62-5-1 = 56 and this means the t-table is 2.00324 at a significance level of 0.05.

The results of the independent variable t-test for Y1 are presented in Table 3 and this led to the following conclusion

1. The t-value for the variable X1 was found to be 3.314 which is higher than the t-table value of 2.00324 while the significance level was 0.002 and less than 0.05, thereby indicating variable X1 has a significant and positive influence on variable Y1.
2. The t-value for variable X2 was found to be 0.568 which is less than the t-table value of 2.00324 while the significance level value was 0.572 and higher than 0.05, thereby, indicating that variable X2 has no positive effect on variable Y1.
3. The t-value for the variable X3 was found to be 5.175 which is higher than the t-table value of 2.00324 while the significance level was 0.000 and lesser than 0.05, thereby, indicating that variable X3 has a significant and positive influence on variable Y1.
4. The t-count value for the variable X4 was found to be -1.582 which is less than t table 2.00324 while the significance level was 0.119 and higher than 0.05, thereby, indicating a negative and non- statistically significant relationship between variables X4 and Y1.
5. The t-value for the variable X5 was found to be 2.361 which is higher than the t-table value of 2.00324 while the significance level was 0.022 and less than 0.05, thereby, indicating that variable X5 has a positive and statistically significant influence on variable Y1.

Table 3. Independent variables' coefficients to Y1

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	-3.847	2.075		-1.854	.069
	X1	.362	.109	.329	3.314	.002
	X2	.059	.104	.057	.568	.572
	X3	.473	.091	.523	5.175	.000
	X4	-.269	.170	-.199	-1.582	.119
	X5	.256	.108	.256	2.361	.022

a. Dependent Variable: Y1

Table 4. Independent variables' coefficients to Y2

Coefficients

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	-7.345	1.561		-4.705	.000
	X1	.336	.082	.310	4.085	.000
	X2	.044	.078	.043	.560	.578
	X3	.141	.069	.159	2.057	.044
	X4	.447	.128	.335	3.491	.001
	X5	.280	.081	.285	3.442	.001

a. Dependent Variable: Y2

The independent variable t-test results for Y2 presented in Table 4 also led to the following conclusion:

1. The t-value for the variable X1 was 4,085 which is higher than the t table value of 2.00324 while the significance level was 0 and less than 0.05, thereby, indicating a positive and statistically significant relationship between variables X1 and Y2.
2. The t-value for the variable X2 was 0.560 which is less than the t-table value of 2.00324 while the significance level was 0.578 and higher than 0.05, thereby, indicating there is no significant positive relationship between variables X2 and Y2.
3. The t-value for the variable X3 was 2.057 which is higher than the t-table value of 2.00324 while the significance level was 0.044 and less than 0.05, thereby, indicating a positive and statistically significant relationship between variables X3 and Y2.
4. The t-value for the variable X4 was 3.491 which is higher than the t-table of 2.00324 while the significance level was 0.001 and less than 0.05, thereby, indicating a positive and statistically significant relationship between X4 and Y2.
5. The t-value for the variable X5 was 3.442 which is higher than the t-table value of 2.00324 while the significance level was0.001 and less than 0.05, thereby, indicating a positive and statistically significant relationship between variables X5 and Y2.

F-Test

The simultaneous hypothesis (F-test) was conducted by comparing the f-value to the f-table and the significance value based on the criteria that the independent factors have a simultaneous influence on the dependent variable when f-count > f-table and the independent variables significantly influence the dependent variable when the significant value is less than 0.05.

The f-table value was determined through the degree of freedom (df) value using the formula df = (k-1; n-k), where n is the number of samples and k is the number of variables tested. It is important to reiterate that the number of samples used was 62 and the number of variables analyzed per sample was 6. This means the the numerator's df value is 4 while the denominator's df value is 57. Therefore, the f-table value at df=(4:57) and a significance level of 0.05,was found to be 2.53.

It was discovered from Table 5 that the F-value for Y1 is 17,554 and Y2 is 38,016 with a significance value of 0.000. This means these values are greater than the F-table value of 2.53 and the significance value is less than 0.05. Therefore, there is a positive, significant and simultaneous influence of independent variables on the dependent variables Y1 and Y2.

Table 5. F-test

ANNOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	128.320	5	25.664	17.554	.000[b]
	Residual	81.874	56	1.462		
	Total	210.194	61			

a. Dependent Variable: Y1

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	157.339	5	31.468	38.016	.000[b]
	Residual	46.354	56	.828		
	Total	203.694	61			

a. Dependent Variable: Y2

b. Predictors: (Constant), X5, X2, X1, X3, X4

Table 6. Coefficient of determination (R^2)

Coefficient of determination (R^2)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.781[a]	.610	.576	1.209

Dependent Variable: Y1

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.879[a]	.772	.752	.910

Dependent Variable: Y2

a. Predictors: (Constant), X5, X2, X1, X3, X4

The coefficient of determination (R^2) value for Y1 was recorded to be 0.610 or 61% in Table 6 and this means the independent variable have the ability to explain Y1 by 61% while the remaining 39% is associated with the variables not included in this research model. Moreover, the R^2 value for Y2 was found to be 0.772 or 77.2% and this shows the independent variable can explain 0.772, or 77.2% of Y2 while the remaining 22.8% is linked to other variables not included in the model.

Case study of BIM 5D Implementation in Construction Projects

The UIN Sunan Ampel project consisting of of 5 campus buildings with supporting infrastructure and facilities belonging to the Ministry of Religion of the Republic of Indonesia Islamic State of Sunan Ampel Surabaya was used as the case study. The project's general contractor is PT XYZ, one of Indonesia's largest state-owned construction companies. The 3D model developed for the project is presented in Figure 3. The comprehensive modeling based on structural, architectural, and MEP work is indicated in Figure 4. The modeling can be used to identify solutions for potential clashes detected during design review and verification as presented in Figure 5.

Moreover, the submission of designs and approval materials was completed using BIM software as indicated in Figure 6 to allow the owner and consultant to see the design more realistically.

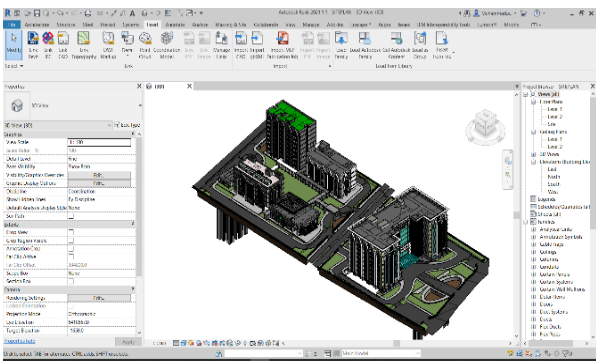


Figure 3. 3D Modelling

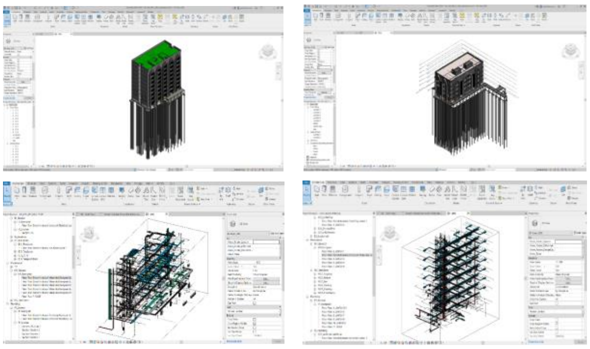


Figure 4. Structural Modeling, Architecture and ME

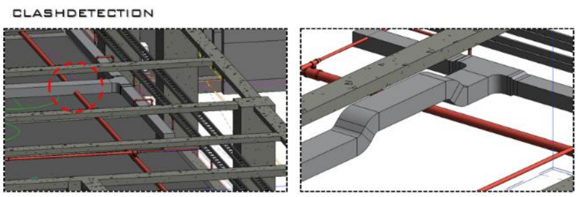


Figure 5. Design review and clash detection

BIM 4D software was used to view the job sequence in Figure 7 in order to identify the tasks that are on the critical path to be completed promptly. It was also used to determine and compare the target for fieldwork based on a budget year or per month and compare to the S Curve approved during the pre-construction stage. BIM 5D was applied to save time, ensure accurate calculation, and simplify result verification.

The TRB (Take-off Reinforcement Bar) modeling was used to calculate the steel cutting lists and iron volume while TAS (Take-off for Architecture and Structure) was applied for structural such as concrete and formwork as well as architectural including walls and plaster, floor and wall tiles, ceilings and partitions, door window frames, and painting calculations as indicated in Figure 8. The BIM 5D modeling was used to produce the quantity summary in Figure 9 and the rebar schedule in Figure 10.

From the above calculations, a volume comparison analysis between BQ and field PO is obtained as indicated in Figure 11. BIM 5D software was able to ensure the optimization of an ideal mix of different waste sizes.

The results showed that the wastes were optimum after rechecking in Figure 12 but one piece of reinforcement has the potential to exceed the minimum length required for the cutting list.

These findings confirm [37]'s research analyzing the application of BIM in the Chinese construction industry, which demonstrates that BIM technology in the construction phase improves construction quality, reduces construction costs, and meets good management standards. Furthermore, according to [38], BIM is one of India's most rapidly adopted technologies. Its ability to autonomously generate documents and material take-offs that provide the precise unit allows construction projects to be completed in less time than without BIM implementation.

Figure 6. Design approval

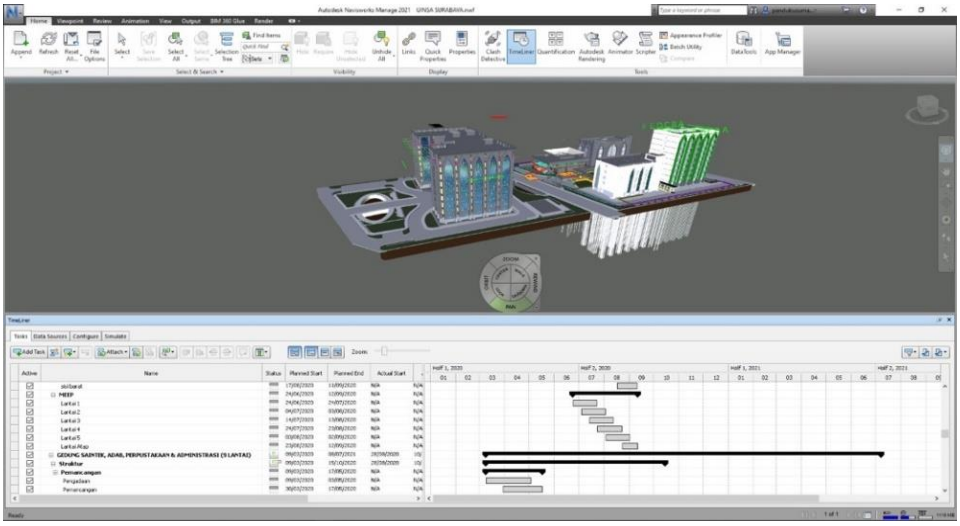


Figure 7. Projected sequence of work with Ms. Project

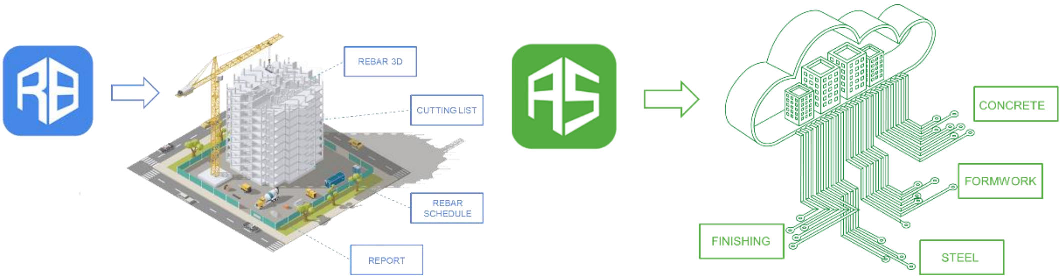


Figure 8. Modeling quantity of TAS & TRB

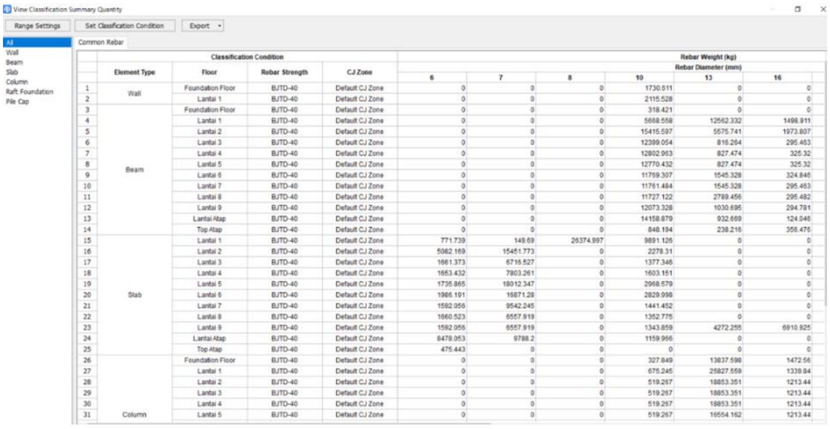


Figure 9. Recap of the quantity cutting list for iron

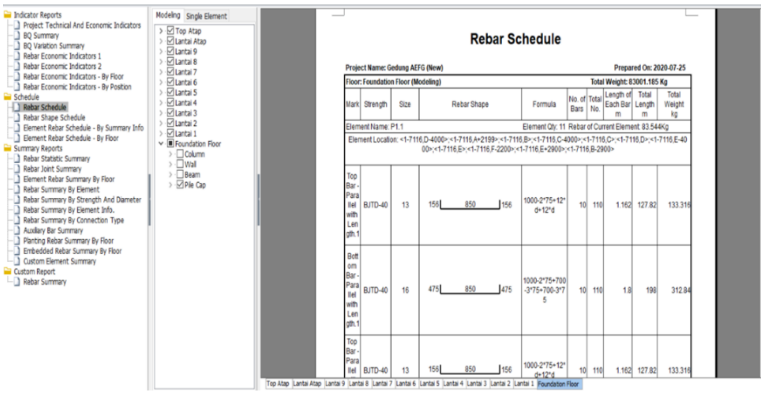
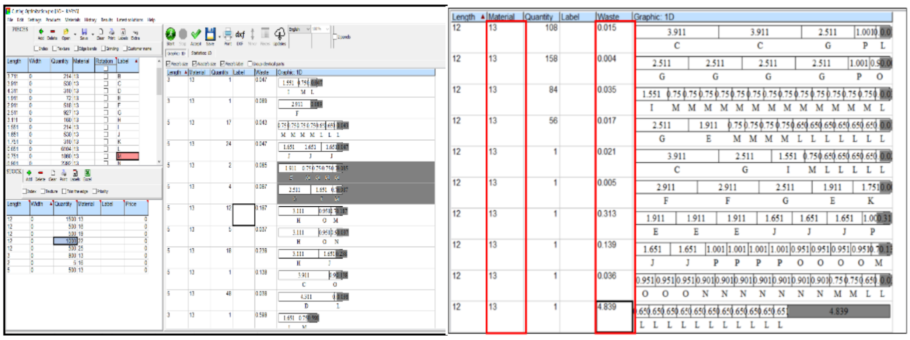


Figure 10. Rebar Schedule

Koef	Diameter / size	Bil Of Quantity		Pre-Order Materials		Deviation		Percentage
		Heavy	sat.	amount	sat.	amount	sat.	%
4.74	ø8	35,881.97	Kg	26,425.50	Kg	9,456.47	Kg	26.35%
7.40	D10	356,835.61	Kg	400,511.98	Kg	(43,676.36)	Kg	-12.24%
12.50	D13	559,335.02	Kg	593,014.70	Kg	(33,679.69)	Kg	-6.02%
18.94	D16	278,645.71	Kg	392,669.83	Kg	(114,024.13)	Kg	-40.92%
26.80	D19	218,122.64	Kg	239,900.47	Kg	(21,777.84)	Kg	-9.98%
35.80	D22	775,642.08	Kg	761,815.20	Kg	13,826.88	Kg	1.78%
46.20	D25	790,367.00	Kg	947,930.47	Kg	(157,563.47)	Kg	-19.94%
75.77	D32	16,930.11	Kg	5,681.70	Kg	11,248.41	Kg	66.44%
	Sub-Total	3,031,760.14	Kg	3,367,949.86	Kg	(336,189.72)	Kg	-11.09%

Figure 11. Comparative analysis of volume calculations



size/diameter	Length min	Cutting List max
13	0.651	8.268
16	2.104	2.96
19	2.854	7.609
22	2.448	7.979
25	5.721	5.721

Figure 12. Crosscheck the results of the waste calculation.

CONCLUSION

The research findings and the case studies showed that the factors supporting the implementation of BIM in the UIN Sunan Ampel Surabaya Campus building construction project are pretty good. This was demonstrated by the existence of precise and comprehensive standard operating procedures in the BIM Execution Plan (BEP). Moreover, the amount of equipment used was reasonably good based on the ideal criteria for BIM implementation in addition to the application of legally licensed software. This study indicates that there is a positive, significant and simultaneous influence between independent variables (tender documents, human resources, BIM software, planning process, and production process) on the dependent variable (cost and time performance) of a construction project with the application of BIM 5D. The survey findings showed that all government and state-owned construction projects had utilized BIM 5D, which was discovered to be advantageous in terms of time and cost. This research confirmed that the most perceived benefit of implementing BIM 5D at the UIN Sunan Ampel Surabaya Campus building construction project is that monitoring project implementation can be carried out more effectively than manual calculations, allowing for better use of time and costs when implementing construction projects. This was observed from the waste analysis results for ironing in the field. This is in line with the findings of [39][40] that the application of BIM to construction projects could reduce waste and increase the productivity of construction work.

The authors recommend that state-owned construction companies pay more attention to the process of project budget monitoring using implementing BIM in order to adjust project time and costs more precisely. The author realizes that this research has limitations. This research is a case study of one project limited to state-owned companies, so the conclusions cannot be generalized. Therefore, the authors suggest that further research be carried out by private national contractors, planning consultants, and other construction management professionals. In addition, testing the success factors in implementing BIM can be explored to increase knowledge, especially regarding applying BIM to construction projects.

ACKNOWLEDGMENT

The authors acknowledge the colleagues of Campus II UIN Sunan Ampel Surabaya and all informants for providing insight and expertise that greatly assisted the research, although they may not agree with all the interpretations/conclusions of this paper.

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