ANALYSIS THE POTENTIAL OF BUILDING INFORMATION MODELING (BIM) AND LEAN CONSTRUCTION IN REDUCING CONSTRUCTION WASTE THROUGH MODELING: A CASE STUDY OF SMP NEGERI 6 SURAKARTA

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Abstract

The construction industry has a significant contribution to the generation of construction waste which has the potential to increase costs and cause environment impacts if not managed optimally. This study aims to analyze the effect of the application of Building Information Modeling (BIM) and Lean Construction principles in reducing construction waste in the construction project of SMP Negeri 6 Surakarta. The methods used in this research include the utilization of BIM for waste estimation and calculation and the Delphi method to identify the main factors causing waste generation. The results showed that BIM-based planning using Autodesk Revit contributed positively to the reduction of construction waste, with a decrease in the percentage of reinforcement steel waste by 4.83% and concrete waste by 8.55%. The main factors contributing to waste generation include initial design that does not consider aspects of material efficiency, material waste due to overuse, inefficiency in the implementation process, repetition of work, and lack of control over ready mix concrete and site mix. In addition, material damage at the procurement stage is also one of the significant causes of construction waste generation. These findings indicate that the application of BIM and Lean Construction can be an effective strategy for reducing construction waste and improving resource efficiency in development projects.

Keywords: BIM, Lean Construction, Waste

1. INTRODUCTION

The construction industry contributes greatly to infrastructure development, but it also contributes negative impacts to the environment, especially through construction waste that causes waste of resources and increased project costs (Hartono et al., 2016). One form of ongoing development is the SMP Negeri 6 Surakarta building project, which is part of an effort to equalize educational facilities in Surakarta City (Haris, 2023).

Unfortunately, construction waste management is often overlooked, and many parties still consider it as ordinary waste. Poorly managed waste can adversely affect the environment and increase project costs. One of the factors causing construction waste is the suboptimal use of materials and the lack of proper waste management planning (Zulkibli et al., 2017 ;Widhiawati et al., 2019).

Research conducted by Akinade et al., (2018) shows that construction waste can be minimized through the use of Building Information Modelling (BIM). BIM facilitates project visualization, automatic retrieval of material quantities, and more efficient organization of the construction process. In addition, Lean Construction can also be used to reduce waste and improve project efficiency by optimizing workflow.

Lean construction is a production process approach adapted by the construction industry. The application of Lean methods is expected to be used as an effort in mapping construction waste (Zulaida and Yuwono, 2019). The full potential of BIM can be realized with lean construction principles (Aziz et al., 2024).

This research aims to analyze the effect of BIM on the reduction of construction waste and identify the causes and types of waste in the construction project of SMP Negeri 6 Surakarta. Currently, the contractor and planning consultant have not implemented BIM and waste management methods optimally, so this research is expected to provide insight into the potential application of both methods in improving project efficiency.

2. METHOD

2.1. Data Collection

The data used in this research consists of primary data obtained through interviews with panelist. This data is used to determine the causes of waste in construction projects. Initially, a list of interview questions was prepared in advance based on previous research with Lean Construction principles. Next is secondary data in the form of work volume from RAB, work volume from MC, working drawings, and RKS from the project. This data is useful for analyzing the volume of waste generated by conventional methods and using BIM.

2.2. Data Analysis

This research was conducted on the SMP N 6 Surakarta building construction project, precisely on one of the buildings. The work analyzed in the calculation of waste is structural work in the form of concrete work and reinforcement. This research analyzes the waste of pile cap foundation structure work, columns, beams, and floor plates.

2.2.1. Building Information and Modeling (BIM)

BIM is a digital tool used in the construction industry for collecting, modeling, and archiving information in the form of 3D models of buildings at scale. BIM has advanced dimensions of 4D and 5D. 4D is related to scheduling. Whereas 5D relates to costs extracted from volumes extracted from modeling (Kjartansdóttir et al., 2017).

This research uses Autodesk Revit as a BIM tool. By utilizing Quantity Take Off from Revit, the volume of each job can be calculated. So that the calculation of waste can be done by calculating the difference between the BIM volume and the implementation volume. This is done simultaneously with the manual calculation of waste. So that it can be seen how much the percentage of waste reduction is.

2.2.2. Delphi Method

The Delphi method is a method used to seek consistency in the opinions of interviewees. It is generally conducted in two to three rounds (Gossler et al., 2019) The Delphi method can be used as a tool to structure an overall effective group communication process to address complex issues (Linstone et al., 2002).

The classic Delphi method in qualitative research begins with the first round, which uses open-ended questions to collect respondents' opinions. Next, the process of identification and analysis is carried out until it reaches a level of agreement and consistency that is in accordance with the research objectives. This research uses delphi method to measure the consistency of answers during the interview.

2.3. Research Instrument

2.3.1. Respondent

The selection of respondents was carried out based on the delphi method. Research using the delphi method has weaknesses when conducted with too many respondents. (Hsu and Sandford, 2007). In this study using three respondents. This is also in line with field conditions that have limited resources. 3 respondents were selected with the same background, namely in terms of work that is directly related to the issues discussed (Sugiyono, 2022).

2.3.2. Tools

There are several tools used in this research such as Autodesk revit, Naviswork, and Microsoft Excel.

2.4. Research Stage

The initial stage of this research began with the process of problem identification and literature study to collect data related to the study conducted. Then data collection was carried out by interview to be processed by the delphi method. In addition, data collection in the form of secondary data of working drawings will be continued in Revit modeling. After modeling, Clash checking will be carried out until quantity take off. Furthermore, data analysis is carried out both waste calculations and interview data using the delphi method. Then the final determination is made as the final result and discussion. The stages of the research can be seen in the flow chart in Figure 1 below.

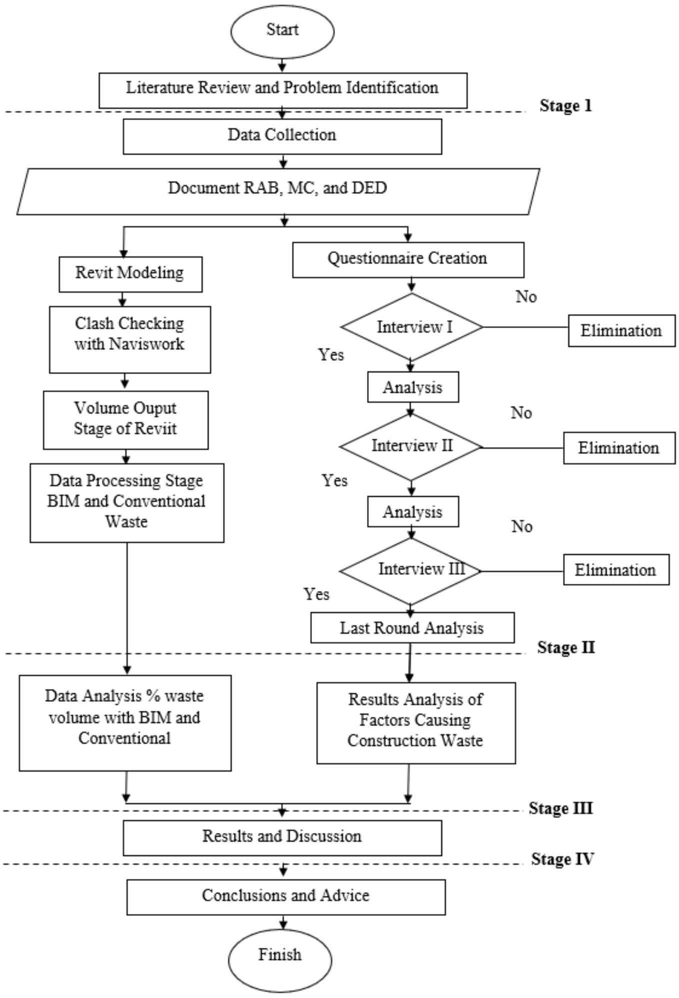

Figure 1. Flow chart.

3. RESULT AND DISCUSSION

3.1. Result of Waste Calculation with BIM

This research was conducted by calculating conventional waste and BIM waste. The BIM volume output is obtained after completing all the required BIM modeling. The appearance of BIM modeling with Autodesk Revit can be seen in Figure 2 below.

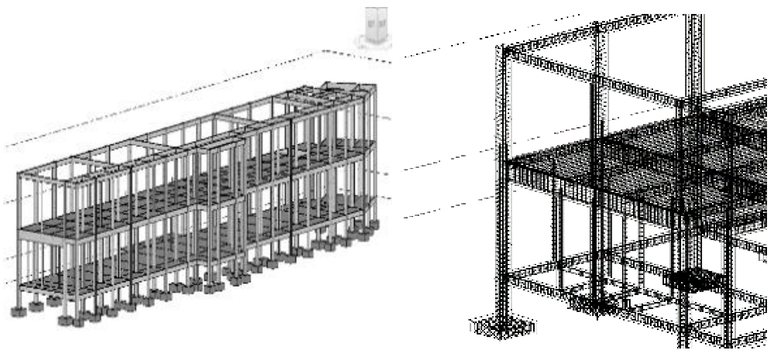

Figure 2. BIM modeling result (result of data analysis).

The conventional waste calculation process is carried out by calculating the difference between the volume of MC and RAB. While the calculation of waste with BIM is done by calculating the difference between the MC volume and the BIM output volume. The modeling process until the quantity take off stage is complete, followed by a recapitulation and calculation of waste volume. Recapitulation and calculation of reinforcement steel waste can be seen in Table 1.

Table 1. Recapitulation of reinforcement steel volume and waste

WORK ITEM	MC	RAB	BIM	CONVEN. WASTE	BIM WASTE
(A)	(B)	(C)	(D)	(E = C-B)	(F = D-B)
PILE CAP					
PS 2	3906	3970	3917	64	11
PS 3	1856	1977	1892	121	36
SLOOF					
SL1	3354	3485	3407	132	53
SL2	274	278	274	4	0
COL					
K2	4448	5028	4830	581	383
K4	351	431	430	80	79
K4 LT 2	242	257	253	16	11
KS2 lt 1	2013	2228	2222	214	209
KS2 lt 2	981	1330	1270	349	289
K3	1208	1317	1278	110	71
KS3	494	499	495	5	1
KP 1	343	530	499	187	157
KP 2	146	247	237	101	91
BEAM					
BL1	4353	5049	4357	696	4
BL2	782	864	824	82	42
BL3	4245	4603	4260	358	14
RB1	1951	2056	1996	105	45
RB2	382	394	391	12	9
RB3	68	71	69	3	2
BA 1	359	374	366	15	7
SLAB I					
LV 2 (12CM)	9292	9562	9301	270	9
TOTAL	41046	44550	42568	3504	1522

*Result of Data Analysis

Based on the calculation results presented in Table 1, there was a reduction, from the conventional 3,504.474 kg to with BIM 1,521.975 kg. The percentage of difference of waste to toal material occurred from 8.54% to 3.71% Furthermore, the calculation of the percentage of reinforcement steel waste reduction shows a result of 4.83%. These results are in line with previous research conducted by Zain et al., (2022) which states that there is a difference in quantity between calculations between BIM and conventional, where calculations using BIM are more efficient than calculations in conventional ways.

With the same process as reinforcement steel waste, the next is the calculation of concrete waste with conventional and BIM methods presented in Table 2.

Table 2. Recapitulation of Concrete Volume and Waste

WORK ITEM	MC	RAB	BIM	CONVEN. WASTE	BIM WASTE
(A)	(B)	(C)	(D)	(E = C-B)	(F = D-B)
PILE CAP					
PS 2	38	38	38	0	0
PS 3	16	16	16	0	0
SLOOF					
SL1	25	28	25	3	0
SL2	2	2	2	0	0
COL					
K2	28	31	31	3	3
K4	4	5	5	0	0
KS2	15	20	19	5	4
K3	11	11	11	0	0
KS3	4	4	4	0	0
KP	3	3	3	0	0

WORK ITEM (A)	MC (B)	RAB (C)	BIM (D)	CONVEN. WASTE (E = C-B)	BIM WASTE (F = D-B)
BEAM					
BL1	23	29	28	5	5
BL2	4	5	5	1	1
BL3	19	31	26	12	7
RB1	14	17	15	2	0
RB2	3	3	3	0	0
RB3	0	0	0	0	0
BA1	2	2	2	0	0
SLAB I					
LT 2 12CM	70	85	72	16	2
LT 1 7 CM	49	52	50	4	1
TOTAL	331	383	355	52	24

*Result of Data Analysis

From the calculation results presented in Table 2, there was a reduction in concrete waste. The percentage difference of waste to toal material decrease from 15.83% to 7.28%. Furthermore, the calculation of the percentage of reinforcement steel waste reduction shows a result of 8.55%. This is in line with the results of research conducted by Fauziyah and Christian, (2023) which says that the application of BIM can have a good impact on efforts to reduce construction waste.. The following diagrams show the comparison of the two types of waste calculations with the BIM and conventional methods shown in Figures 3 and 4.

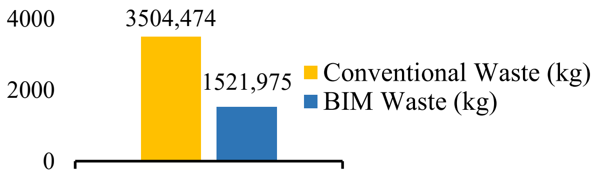

Figure 3. Bar Chart of reinforcement steel waste (result of data analysis).

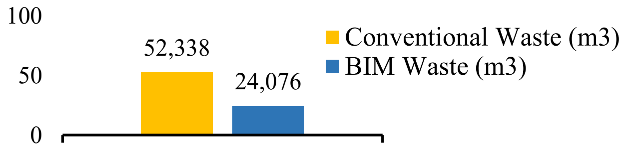

Figure 4. Bar Chart of concrete waste (result of data analysis).

Based on two calculations previously presented, the calculation of reinforcement steel waste and concrete waste using the BIM method is proven to have a positive impact on reducing construction waste. These results are in line with previous research where calculations using BIM are more efficient than calculations in conventional ways. So it can be said that the results of the above analysis support the formulation of the problem. There is a positive effect on reducing the quantity of waste when using the BIM method.

3.2. Factors that Cause Waste

Then after the interview, data processing is carried out including the calculation of the average answer from the interviewee using a Likert scale. Then calculate the standard deviation, calculate the inter-quartile range (IR) of each respondents answer. After that, the data that has been obtained is considered to meet the consistent criteria if the standard deviation is less than 1.5 (SD<1.5) and the inter quartile range (IR) is less than 2.5 (IR<2.5). Then the next requirement is an average of more than four. The data is shown in the Table 3 below.

Lean construction principles are used as a tool to collect data on the causes of construction waste from procurement, implementation, to design derived from lean construction principles (Mudzakir et al., 2017). It was found that there are 13 factors that cause waste which will be asked to respondents during the interview.

Table 3. Recapitulation of round I interview results

INS	RESP			AVR	RESULT			
	1	2	3		SD		IR	
X1	1	4	2	2.3	1.2	✓	3	×
X2	1	2	4	2.3	1.2	✓	3	×
X3	5	5	4	4.7	0.5	✓	1	✓
X4	1	4	2	2.3	1.2	✓	3	×
X5	5	5	5	5.0	0.0	✓	0	✓
X6	1	5	2	2.7	1.7	×	4	×
X7	3	5	4	4.0	0.8	✓	2	✓
X8	5	4	4	4.3	0.5	✓	1	✓
X9	5	5	5	5.0	0.0	✓	0	✓
X10	5	4	4	4.3	0.5	✓	1	✓
X11	5	5	5	5.0	0.0	✓	0	✓
X12	5	5	3	4.3	0.9	✓	2	✓
X13	5	5	5	5.0	0.0	✓	0	✓

* Result of Data Analysis

In the first round there were several questions that did not meet the Delphi criteria or were inconsistent. These results showed that 4 of the questions, namely X1, X2, X4, and X6, did not show any relationship with the project situation or in other words, not consistency. Then, a second round of interviews was needed after eliminating and adding the variables proposed by the respondents. Some of these instruments had to be eliminated if they did not meet the requirements (Mayburry et al., 2011).

After the second round of interviews was conducted, the results were processed in the same way as the first round. So as to get results that meet the criteria. The results of the second round interview recapitulation are shown in Table 4 below.

Table 4. Recapitulation of round II interview results

INS	RESP			AVR	RESULT			
	1	2	3		SD		IR	
X3	5	5	5	5.0	0.0	✓	0	✓
X5	5	5	4	4.7	0.5	✓	1	✓
X7	3	5	4	4.0	0.8	✓	2	✓
X8	5	5	4	4.7	0.5	✓	1	✓
X9	5	5	3	4.3	0.9	✓	2	✓
X10	5	4	4	4.3	0.5	✓	1	✓
X11	5	5	5	5.0	0.0	✓	0	✓
X12	5	5	3	4.3	0.9	✓	2	✓
X13	5	5	5	5.0	0.0	✓	0	✓

*Result of Data Analysis

Data processing was carried out until consistent results were obtained. This shows that the respondents' answers have a uniform pattern. This consistency indicates that the interview instrument used in the second round has successfully identified the main factors contributing to the generation of construction waste in the project.

4. CONCLUSION

Based on the results of the discussion that has been presented, it can be concluded that the application of Building Information Modeling (BIM) contributes significantly to reducing construction waste, especially in reinforcement steel and concrete materials. This waste reduction is influenced by various factors that occur at each stage of the construction project. At the design stage, one of the main causes is the initial design that does not consider the potential waste generation. During the implementation stage, excessive use of materials, repetitive work due to process ineffectiveness, waste in mixing materials in the field, and lack of control over ready-to-use materials are the dominant factors that contribute to waste generation. In addition, the procurement aspect of the materials also influences the amount of waste generated, especially due to damage incurred during the distribution and storage process.

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