Analysis of Material Waste Percentage Using Building Information Modeling

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Abstract

The construction industry generates significant material waste, which has a major impact on project costs and environmental sustainability. This study analyzes the percentage of steel reinforcement waste in building projects in Jakarta, using Building Information Modeling (BIM) with Autodesk Revit for accurate volume measurements. The analysis shows a waste percentage of 39% for diameter D22, 23% for D19, 18% for D13, 16% for D10, 4% for D16, and 0.02% for D8. These results highlight that larger diameter steel bars contribute the most to material waste, influenced by design complexity and low cutting efficiency. Comparison with the project's Cost Estimate Plan data shows that the BIM model produces a slightly lower rebar volume, with an average deviation of 5.07%, validating its accuracy in material estimation. The study shows that integrating BIM technology improves material usage efficiency, supports waste reduction initiatives, contributing to cost savings and sustainable construction management.

Keywords: Waste Material, BIM, Quantity Take-Off, Revit, Construction Waste.

1. INTRODUCTION

The construction industry contributes significantly to global material waste, which has significant environmental impacts and increases project costs. Nearly half of the 100 billion tons of raw materials extracted worldwide each year are consumed by construction activities, making material efficiency crucial for sustainable development. Excessive material waste, often resulting from inaccurate planning, inefficient cutting, and a lack of integrated management, poses challenges to both cost control and environmental sustainability (Miller, 2022; Atullah, 2023).

Traditional construction methods lack accurate material requirement estimates, resulting in large amounts of scrap that cannot be effectively reused. These inefficiencies underscore the need for advanced digital tools to improve material planning and minimize waste. Building Information Modeling (BIM) has emerged as a transformative technology in this context. BIM enables detailed 3D modeling and accurate quantity capture, facilitating better project visualization, coordination, and material tracking throughout the project lifecycle (Eastman et al., 2008; Putera, 2022). Autodesk Revit, a leading BIM software program, provides comprehensive capabilities for structural modeling and quantity estimation, supporting better decision-making in construction projects.

This study analyzes the percentage of material waste, particularly steel reinforcement, in the building project in Jakarta using a BIM workflow. This study aims to quantify material waste by comparing volumes obtained from BIM models and those obtained using conventional methods. Ultimately, the goal is to demonstrate how BIM technology can improve material efficiency, reduce waste, and contribute to cost savings and environmental sustainability in the construction sector.

Research Question

1. How does the volume of reinforcement work compare between conventional methods and Building Information Modeling (BIM) in building construction projects?

2. How does the percentage of waste material vary between reinforcement diameters in construction projects?

2. METHOD

This study uses quantitative methods to analyze material waste in building projects. The research focuses specifically on the main structural materials of buildings: reinforcing steel for columns, beams, and floor slabs. The core of this analysis involves a comparison between two sets of data:

1) Conventional Volume: The planned volume of materials is obtained from the official Project Cost Estimate, which is calculated using traditional methods.

2) BIM Volume: Material volume is calculated by creating a detailed 3D structural model of the building using Autodesk Revit software, based on the project's Detailed Engineering Design (DED) documents. An automatic Quantity Take-Off (QTO) is then generated from this model.

To achieve the research objectives, the following steps were taken to complete and analyze the data:

1) Calculation of Distribution Length and Passage Connections
   The calculation of distribution length and passage connections must be carried out as a preliminary step before modeling in Autodesk Revit software. This was carried out in the following stages:
   (1) Calculating standard hooks.
   (2) Calculating Sengkang hooks, Sengkang ties, and Sengkang restraints.
   (3) Calculating the length of distribution and bypass connections.
2) 3D Modeling in Autodesk Revit
3) Waste Percentage Calculation
   The waste percentage between QTO output and RAB data is calculated using the following formula:

$$\text{Waste Percentage} = \frac{\text{Weight Waste}}{\text{Total Weight of Waste}} \times 100\% \quad (2.1)$$

   This approach allows for a direct measurement of how BIM can improve the accuracy of material estimation and subsequently reduce waste.

3. Results and Discussion

The analysis revealed a consistent discrepancy between the material quantities calculated using conventional methods and the more precise volumes generated from the BIM model. The BIM-based Quantity Take-Off (QTO) produced lower material volumes for all analyzed structural elements, indicating that the conventional methods resulted in material overestimation.

3.1 Reinforcement Volume Recapitulation

3.1.1 Revit Output Reinforcement Volume

Calculating the volume of structural work with BIM using Revit software produces data that is automatically calculated based on 3D modeling. The volume obtained includes concrete and reinforcement work on the main structural elements, namely slabs, beams, and columns. In principle, Revit calculates concrete volume using the following 3D geometry formula:

$$\text{Concrete Volume} = \text{Length} \times \text{Width} \times \text{Height} \quad (3.1)$$

Table 1: Revit Slab Reinforcement Volume Output on Each Floor

No.	Floor	Slab Reinforcement Volume (kg)
1	1	11.818,82
2	2	15.497,39
3	3	15.589,67
4	4	14.733,34
5	5	14.768,51
6	6	14.768,51
7	7	14.827,00
8	8	15.115,23
9	9	10.457,15
10	10	10.405,58
11	Roof	2.211,84
Total		140.193,04

Table 2: Revit Beam Reinforcement Volume Output on Each Floor

No.	Floor	Beam Reinforcement Volume (kg)
1	2	27.918,46
2	3	26.363,10
3	4	27.175,40
4	5	27.061,63
5	6	25.263,91
6	7	24.382,33
7	8	32.362,66
8	9	18.718,91
9	10	21.574,50
10	Roof	9.135,56
Total		239.956,46

Table 3: Revit Column Reinforcement Volume Output on Each Floor

No.	Floor	Column Reinforcement Volume (kg)
1	1	49.743,24
2	2	18.351,29
3	3	19.522,69
4	4	19.450,39
5	5	26.002,25
6	6	12.553,37
7	7	17.346,19
8	8	10.787,44
9	9	12.365,08
10	10	9.822,07
Total		195.944,01

Based on the Revit reinforcement volume output shown in Table 1 to Table 3, the total volume is as follows:

- Slabs: reinforcement volume of 140,193.04 kg.
- Beams: reinforcement volume of 239,956.46 kg.
- Columns: reinforcement volume of 195,944.01 kg.

The following is a summary of the reinforcement volume output from Revit in Table 4.

Table 4: Summary Of The Reinforcement Volume Output From Revit

Structural Elements	Reinforcement Volume (kg)
Slabs	140.193,04
Beams	239.956,46
Columns	195.944,01
Total	576.093,51

3.1.2 Reinforcement Volume in the Cost Estimate Plan

The calculation of the volume of structural work in the RAB is based on the design drawings and manual calculation methods in accordance with the geometric rules of each structural element. The results of these volume calculations are then used as the basis for preparing the costs in the project Cost Estimate Plan.

The following are the concrete volumes and reinforcement weights in the Cost Estimate Plan in Tables 5 to 7.

Table 5: Slab Reinforcement Volume on Each Floor in the Cost Estimate Plan

No.	Floor	Slab Reinforcement Volume (kg)
1	1	18.513,08
2	2	14.500,06
3	3	14.801,52
4	4	14.152,37
5	5	14.107,78
6	6	14.169,39
7	7	14.151,92
8	8	14.001,35
9	9	10.037,52
10	10	11.173,61
11	Roof	2.290,53
Total		141.899,13

Table 6: Beam Reinforcement Volume on Each Floor in the Cost Estimate Plan

No.	Floor	Beam Reinforcement Volume (kg)
1	2	30.159,45
2	3	29.732,80
3	4	28.120,20
4	5	28.354,13
5	6	28.277,08
6	7	26.258,00
7	8	28.088,48
8	9	19.850,98
9	10	23.270,70
10	Roof	7.774,48
Total		249.886,30

Table 7: Column Reinforcement Volume on Each Floor in the Cost Estimate Plan

No.	Floor	Column Reinforcement Volume (kg)
1	1	56.210,91
2	2	23.161,69
3	3	21.865,37
4	4	20.637,12
5	5	20.264,13
6	6	18.943,79
7	7	17.198,51
8	8	13.752,38
9	9	12.447,55
10	10	10.593,56
Total		215.075,01

Based on the concrete and reinforcement volumes shown in Tables 5 to 7, the total volumes are as follows:
- Slabs: reinforcement volume of 141,899.13 kg.
- Beams: reinforcement volume of 249,886.30 kg.
- Columns: reinforcement volume of 215,075.01 kg.

For a recapitulation of the total volume of concrete and reinforcement in the RAB, see in Table 8.

Table 8: Summary Of The Reinforcement Volume in the Cost Estimate Plan

Structural Elements	Reinforcement Volume (kg)
Slabs	141.899,13
Beams	249.886,30
Columns	215.075,01
Total	606.860,44

3.2 Comparison of Reinforcement Volume

The percentage difference between the two methods uses a formula sourced from the journal Simatupang, F. J. et al. (2024) as follows:

$$\text{Difference Percentage} = \frac{\text{Volume in Cost Estimate Plan} - \text{Volume Revit}}{\text{Volume in Cost Estimate Plan}} x\ 100\% \quad (3.2)$$

Table 9: Comparison of Revit Reinforcement Volume and Cost Estimate Plan Reinforcement Volume

Structural Elements	Volume Revit (kg)	Volume in Cost Estimate Plan (kg)	Volume Difference (kg)	% Difference
Slabs	140,193.04	141,899.13	1706.09	1.20%
Beams	239,956.46	249,886.30	9929.84	3.97%
Columns	195,944.01	215,075.01	19131	8.90%
Total Reinforcement	576,093.51	606,860.44	30,766.93	5.07%

The comparison of reinforcement volume between Autodesk Revit BIM and conventional methods reveals a consistent trend of lower volumes reported by the Revit model. Specifically, the slab reinforcement volume shows a relatively small difference of 1.20%. This minimal discrepancy can be attributed to the slab's simple geometry—flat surfaces and uniform reinforcement patterns—and Revit's approach to calculating clean geometry without excess allowances, resulting in slightly reduced volume estimations.

In contrast, beam reinforcement volumes exhibit a moderate difference of 3.97%. This is due to the beams' more complex reinforcement configurations with varied diameters and lengths, which are captured more precisely by Revit's 3D modeling capabilities. Meanwhile, conventional methods rely on 2D drawings and practical experience, which may increase approximation errors and overestimation.

The largest volume difference appears in columns, reaching 8.90%. This notable disparity arises from multiple lap splice requirements in columns, given their multi-story construction. Conventional BoQ calculations tend to overestimate length by assuming splices extend beyond the actual storey height, whereas Revit models apply splice lengths strictly based on realistic bar lengths approaching the standard 12-meter lengths.

Overall, the 5.07% volume difference across all reinforcement elements indicates that Revit's volume takeoffs offer sufficiently accurate estimates for material planning and cost control. The variances observed are reasonable considering the inherent differences between advanced 3D modeling and manual 2D-based methods supplemented by field judgment. These differences highlight Revit BIM's significant potential to improve precision in material estimation, directly impacting waste reduction and project cost efficiency in construction management.

3.3 Calculation of Reinforcement Waste Percentage

Based on field data and QTO, the waste percentage for the main materials is calculated using formula (2.1).

$$\text{Waste Percentage} = \frac{\text{Weight Waste}}{\text{Total Weight of Waste}} \times 100\% \quad (2.1)$$

Example of D10 calculation:

Weight in each meter of D10 = 0,617 kg/m (SNI 2052:2017)
Waste length = 39401 m
Weight of waste = Weight in each meter × Waste length = 24429 kg
Total weight of waste = 152648,24 kg

$$\text{Waste Percentage} = \frac{\text{Weight Waste}}{\text{Total Weight of Waste}} \times 100\%$$
$$= \frac{24429}{152648{,}24} \times 100\%$$
$$= 16\%$$

The same calculation was performed for the other reinforcement diameters, resulting in the waste percentage for each reinforcement diameter as shown in Table 10 below.

Table 10: Percentage of Reinforcement Waste

Bar Diameter	Waste Length (m)	Weight of Waste (kg)	% Waste
D22	20080	59838	39%
D19	15574	34731	23%
D13	26939	28016	18%
D10	39401	24429	16%
D16	3543	5598	4%
D8	93	37	0,02%
Total	105630	152648,24	

The study finds varying reinforcement waste percentages across different bar diameters in the construction project. The largest waste occurs in D22 bars at 39% and D19 bars at 23%, primarily used in main columns and beams with long cut lengths near 12 meters, leaving small unusable remnants. D13 bars, often applied in stirrups and secondary beams, generate 18% waste due to frequent short cuts and numerous pieces. D10 bars contribute 16% waste, mainly from slab reinforcement with a high quantity of short bars spaced at 200 mm, leading to significant cumulative waste despite a relatively lower percentage. Waste from D16 and D8 bars is minimal, at 4% and 0.02% respectively, due to limited usage in secondary structures and small quantities.

These findings highlight that larger diameter bars and frequent short cuts are the main contributors to material waste, suggesting a need for targeted optimization strategies in cutting and material usage to reduce waste and improve construction efficiency.

4. Conclusions

The implementation of Building Information Modeling in the Presisi 3 Building project successfully quantified the percentage of material waste resulting from conventional estimation methods. The key conclusions are as follows:

1. For reinforcing steel, the conventional methods resulted in a 5.07% greater volume compared to the BIM calculation, amounting to a surplus of 30,766.93 kg.
2. This study reveals significant variations in material waste percentages across different reinforcement diameters in the construction project, with D22 showing the highest waste percentage at 39%, followed by D19 at 23%, D13 at 18%, D10 at 16%, D16 at 4%, and D8 at a minimal 0.02%.

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