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Implementation of BIM Methodology in Calculating Column and Beam Structures for the Main Lecture Building of P4T Empat Lawang Regency

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Abstract

Reliable volume estimation and BOQ are indispensable for streamlined construction planning. Errors and omissions in manual calculations and communication result in cost overruns, delays, and ultimately lead to conflicts and disputes among the parties involved in the project. This process is time-consuming and prone to human error. One way to improve efficiency is to implement Building Information Modeling (BIM) in volume estimation and BOQ calculations to enhance work effectiveness. Autodesk Revit is one software that can assist in 3D modeling and accurate volume calculations. This research discusses how BIM can aid in the process of calculating the volume of structural columns and beams for the Main Lecture Hall in the Integrated Agricultural Research and Development Center (P4T). Compared to conventional methods, the research results indicate that the implementation of BIM in this project has provided significant benefits in terms of efficiency, improved calculation accuracy, material usage, and cost savings. With the optimization of concrete usage in structural columns and beams by approximately 23,216% and reinforcement volume by approximately 13.55%, BIM has proven to provide significant added value to the project.

Keywords: BIM, Structure, Volume, Column, Beam

INTRODUCTION

One common challenge encountered in the construction industry is a fragmented delivery process that heavily relies on paper-based documentation and communication. (Januar & Anton, 2021). Errors and omissions in manual calculations and communication lead to cost overruns, delays, and ultimately conflicts and disputes among the project stakeholders. To address this issue, a robust integration system is required to coordinate and collaborate among stakeholders (owner, design consultant, design consultant, contractor, and supervisor) in executing a construction project.

When carrying out a construction project planning, stakeholders must consider the appropriate project control process, which is a vital part in ensuring the smooth running of a project (Duke, 2021). Therefore, a construction project management system is needed that can accelerate work in each construction phase and eliminate the potential for errors during the execution (Fachri, et al. 2019).

Volume calculation is required in project planning. The purpose of calculating the volume of work is to obtain the value of the required cost to carry out the existing work. To produce accurate volume calculations, an estimator must understand and comprehend the definitive design drawings. These drawings include construction plans, construction sections, and details, all of which complement each other (BPSDM, 2016). For a more accurate analysis of the calculation of the volume of work at the initial stage of project planning, it is necessary to consider all the factors that affect the calculation (PUPR, 2016).

Building Information Modeling (BIM) represents a new paradigm for construction industry practitioners, which can foster integration among project stakeholders. This integration has the potential to provide better alignment and efficiency among construction actors (Azhar, 2011). BIM is a technology in the construction, architecture, and engineering fields that is used as a tool to create 3D digital models that encompass planning, design, construction, and maintenance of buildings and infrastructure (Maghfirona A., et al. 2023). BIM is a system that provides comprehensive and accurate information about construction projects, thereby supporting better decision-making throughout the building lifecycle (Smith & Edgar, 2008). Comprehensively, BIM can narrate the life cycle of an asset, which involves the creation and processing of digital information about the asset being worked on.

BIM is a unified entity that serves as a global reference. This digital information includes both graphic and non-graphic information in a common repository, Common Data Environment (CDE) (Putera, 2022). BIM can make the construction process more effective because it can provide a visualization of the object being worked on by presenting all the information of the object before implementation on site. As a result, all disagreements related to the construction process can be discussed and resolved beforehand (Franz & Messner, 2019).

BIM software is classified into six sub-groups. These sub-groups are architecture, structure, construction, MEP, sustainability, and facilities management. Each software sub-group serves a specific discipline (Kalfa, 2018). The BIM software sub-groups are shown in Picture 1.

Figure 1. Sub-Groups Of BIM Software
(Kalfa, 2018)

The use of BIM results in 3D modeling with elements of length, width, and height based on parametric modeling objects. The addition of a time element for scheduling transforms BIM into 4D. Furthermore, BIM is developed into 5D with the addition of a cost element for estimation purposes (PUPR, 2018). Subsequently, BIM can be utilized by building performance designers for energy analysis and environmental impact considerations, referred to as 6D. Once the information elements contained in BIM are complete, owners can use it for facility management, such as maintenance and operations, which is called 7D (Czmoch, I. & Pekala, A. 2014).

The primary objective of implementing BIM is to enhance efficiency, reduce errors, and optimize the use of budgets, as emphasized by PUPR (2018). Prior to the widespread use of BIM, architects often dominated the conceptual design phase, while engineers and draftsmen dominated the detailed design phase. Efficient structural design phases are highly dependent on collaboration and data exchange among project participants (Nielsen & Madsen, 2010). BIM can detect clashes, thereby saving material usage and shortening on-site work time. BIM-based software also has plugins that facilitate users to directly import data between applications, making it easier to communicate and collaborate among all sub-works in a project (Yudi & Apriani, 2020).

There are many benefits to conducting BIM-based educational research, including helping participants quickly understand the core aspects of the work, allowing them to better utilize what they have learned (Rossignac, 2004). The use of BIM methods in structural volume calculations offers numerous advantages compared to conventional methods, as BIM can provide highly accurate calculations, reducing human error and optimizing the use of materials and resources in the field (Usman Haidar et al., 2020).

This research discusses how BIM methods can aid in calculating the design volume of structural columns and beams in a construction project when compared to conventional methods. The research object will be the Main Lecture Hall Building in the Integrated Agricultural Research and Development Center (P4T) of Empat Lawang Regency.

RESEARCH METHODS

General Building Data

The project is located in the Integrated Agricultural Research and Development Center (P4T) in Tebing Tinggi District, Empat Lawang Regency. This research focuses on one of the main buildings in the P4T complex, the Main Lecture Hall, which is a two-story building with a total built-up area of approximately 1,032 square meters.

The following is general data from the construction of the buildings reviewed..

Name	: Main Lecture Hall Building in the Integrated Agricultural Research and Development Center (P4T) Area
Location	: Empat Lawang Regency Integrated Agricultural Research and Development Center area
Function	: Main Lecture Hall Building
Structure Type	: Reinforced Concrete Structures
Number of Floors (Building)	: two floors (not including roof floor)
Ground floor area	: 43 x 13 m
Second floor area	: 43 x 11 m

Research Prosedures

This research focuses on a comparative analysis of volume calculations and Bill of Quantity (BOQ) for structural columns and beams in a building between conventional methods and those using Building Information Modeling (BIM) in a construction project. Through this concept, an analysis can be conducted to determine the optimal total planned cost of a structural building project when examined using both methods. The primary objective of this research is to calculate the volume using 3D modeling quickly, accurately, efficiently, and error-free using Autodesk Revit 2024 software, and finally, to conduct a comparative study between manual estimation and BIM-based estimation. The research object will be the Main Lecture Hall Building within the Integrated Agricultural Research and Development Center (P4T).

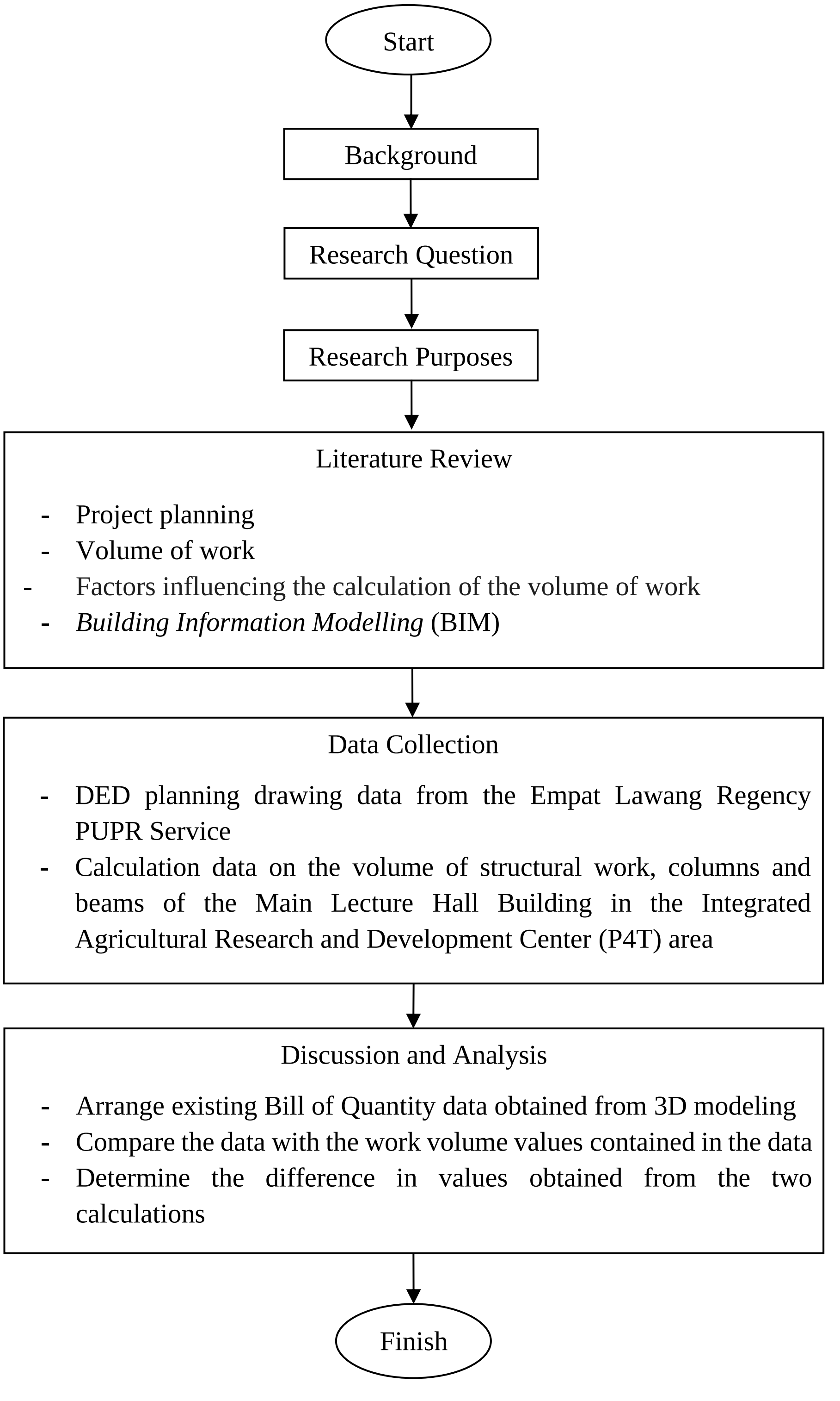

Figure 2. Research Methodology Flow Chart

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RESULTS AND DISCUSSION

Building Modeling

The initial design phase involved creating a detailed 3D model of the building. The modeling was performed using BIM-based software, Autodesk Revit 2024. This software allowed us to visualize the design from various angles and make necessary modifications efficiently.

1. Creating a grid system.
   Grid serves as the primary reference for placing building elements such as walls, columns, and beams. To create a grid, click on the "Architecture" menu and select "Grid". Then, define the starting and ending points of the grid, adjust the grid spacing, and set other properties as needed.

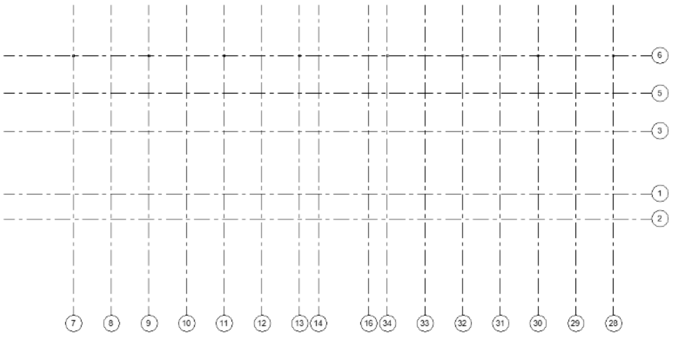

Figure 3. Grid view

2. Create a building structure level.
   Levels function as reference planes for positioning architectural elements like floors, walls, and roofs. The Architecture tab's Level feature enables users to set the elevation, name, and other parameters for each level. This facilitates the creation of a clear and coherent spatial hierarchy within the building model.

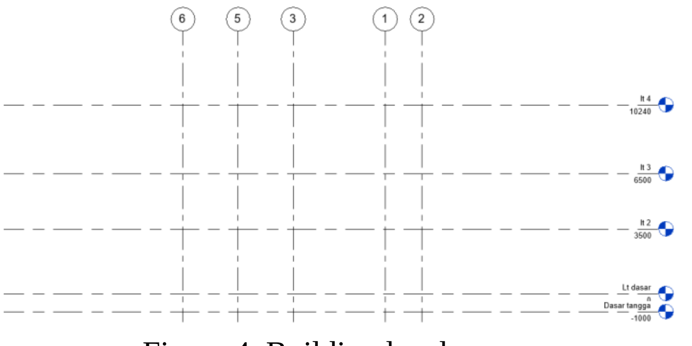

Figure 4. Building level

3. Column modelling.
   The column feature in the Architecture tab enables users to accurately specify the dimensions, material, and placement of columns. Revit's parameterization feature allows for flexible modification of column models and the creation of integrated documentation, leading to improved efficiency in the design and construction process.

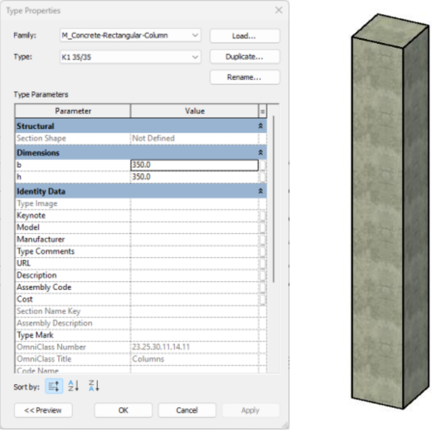

Figure 4. Column modelling

4. Beam modelling.
Using the beam tool in the Architecture tab, users can precisely define the dimensions, material, and location of beams. Revit's parameterization capabilities allow for easy modification of beam models and the generation of integrated documentation, enhancing efficiency in the design and construction phases.

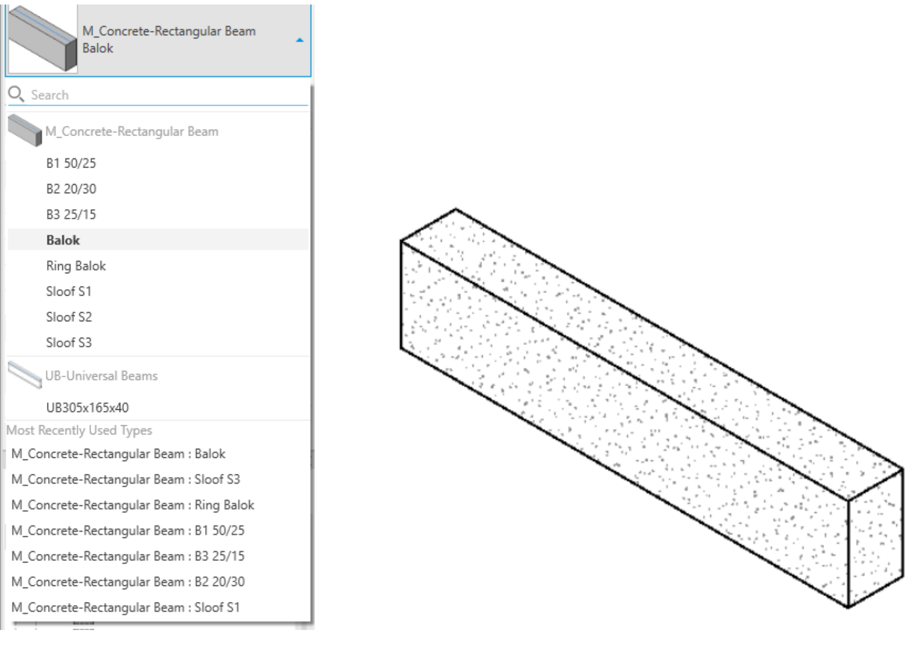

Figure 5. Beam modelling

5. Results of column and beam modeling structures.

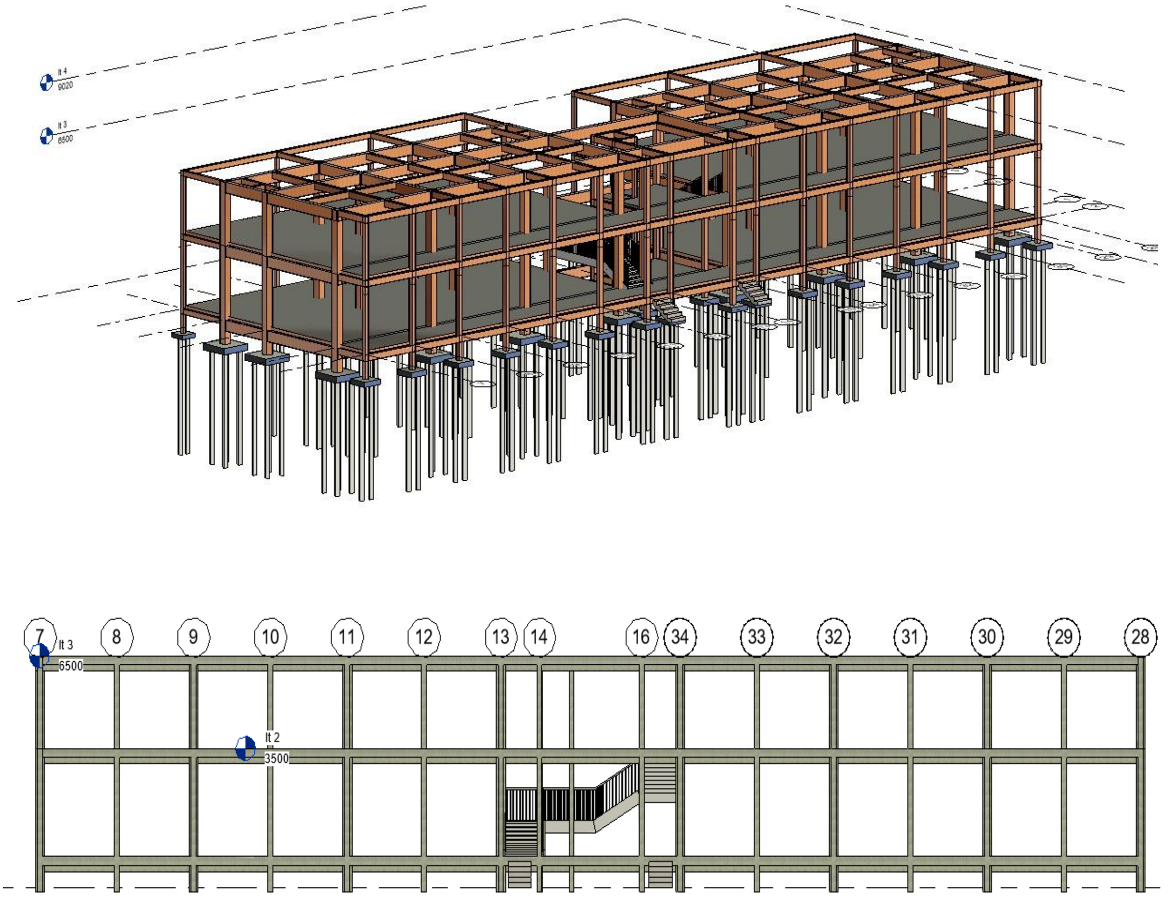

Figure 6. Results of modeling of beam and column structures

Calculation of Volume and Reinforcement of Column and Beam Structures

This table shows the calculated volume of the columns and beams in the main lecture hall building at the P4T area. These calculations were done using Autodesk Revit 2024 software.

Table 1. Volume calculation of structural modeling for sloof, beam, and column

Type	Amount	Volume Sample Structure	Gross Volume of Structure	Reinforcement Volume Sample	Total Reinforcement Volume	Net Structural Volume	Unit
B1 50/25	12	0,33	3,996	0,00595412	0,0714494	3,925	m^3
B1 50/25	12	0,58	6,96	0,00595412	0,0714494	6,889	m^3
B1 50/25	3	0,91	2,73	0,00595412	0,0178624	2,712	m^3
B1 50/25	1	0,92	0,92	0,00595412	0,0059541	0,914	m^3
B1 50/25	4	2,12	8,48	0,00595412	0,0238165	8,456	m^3
B1 50/25	1	5,03	5,03	0,00595412	0,0059541	5,024	m^3
B1 50/25	3	5,07	15,201	0,00595412	0,0178624	15,183	m^3
Total Volume of Beam B1			**43,317**			**43,10265**	**m^3**
B2 20/30	15	0,10	1,5	0,0022033	0,0330495	1,467	m^3
B2 20/30	17	0,11	1,785	0,0022033	0,0374561	1,748	m^3
B2 20/30	12	0,17	2,04	0,0022033	0,0264396	2,014	m^3

B2 20/30	2	0,19	0,38	0,0022033	0,0044066	0,376	m^3
B2 20/30	2	0,20	0,4	0,0022033	0,0044066	0,396	m^3
B2 20/30	1	0,22	0,22	0,0022033	0,0022033	0,218	m^3
B2 20/30	1	0,23	0,23	0,0022033	0,0022033	0,228	m^3
B2 20/30	12	0,29	3,426	0,0022033	0,0264396	3,400	m^3
B2 20/30	4	1,00	4	0,0022033	0,0088132	3,991	m^3
B2 20/30	2	2,40	4,8	0,0022033	0,0044066	4,796	m^3
Total Volume of Beam B2			**18,781**			**18,631**	m^3
B3 25/15	1	0,004	0,004	0,00175367	0,0017537	0,002	m^3
B3 25/15	4	0,03	0,1332	0,00175367	0,0070147	0,126	m^3
B3 25/15	2	0,04	0,089	0,00175367	0,0035073	0,085	m^3
B3 25/15	1	0,05	0,05	0,00175367	0,0017537	0,048	m^3
B3 25/15	20	0,10	2	0,00175367	0,0350734	1,965	m^3
B3 25/15	6	0,11	0,66	0,00175367	0,010522	0,649	m^3
B3 25/15	4	0,66	2,64	0,00175367	0,0070147	2,633	m^3
Total Volume of Beam B3			**5,58**			**5,510**	m^3
Sloof S1	8	0,91	7,304	0,00595412	0,047633	7,256	m^3
Sloof S1	2	2,12	4,24	0,00595412	0,0119082	4,228	m^3
Sloof S1	1	2,27	2,27	0,00595412	0,0059541	2,264	m^3
Sloof S1	1	2,27	2,27	0,00595412	0,0059541	2,264	m^3
Sloof S1	1	5,07	5,07	0,00595412	0,0059541	5,064	m^3
Total Volume of Sloof S1			**21,154**			**21,077**	m^3
Sloof S2	1	0,22	0,22	0,0022033	0,0022033	0,218	m^3
Sloof S2	1	0,23	0,23	0,0022033	0,0022033	0,228	m^3
Sloof S2	2	0,3	0,6	0,0022033	0,0044066	0,596	m^3
Sloof S2	1	2,4	2,4	0,0022033	0,0022033	2,398	m^3
Total Volume of Sloof S2			**3,45**			**3,438984**	m^3
Sloof S3	1	0,04	0,04	0,00175367	0,0017537	0,038	m^3
Sloof S3	1	0,05	0,05	0,00175367	0,0017537	0,048	m^3
Sloof S3	8	0,1	0,8	0,00175367	0,0140294	0,786	m^3
Sloof S3	2	0,66	1,32	0,00175367	0,0035073	1,316	m^3
Total Volume of Sloof S3			**2,21**			**2,188956**	m^3
K1 35/35	23	0,37	8,46	0,00671008	0,15433184	8,310	m^3
K1 35/35	24	0,57	13,68	0,00671008	0,16104192	13,519	m^3
K2 15/15	11	0,10	1,13	0,00112882	0,01241702	1,115	m^3
K2 15/15	11	0,07	0,75	0,00112882	0,01241702	0,736	m^3
K3 20/20	19	0,12	2,28	0,00182416	0,03465904	2,245	m^3
K3 20/20	20	0,19	3,72	0,00182416	0,0364832	3,684	m^3
Total Volume of Column			**30,020**			**29,608**	m^3

Comparison of Volume Calculations for Column and Beam Structures

This is a comparison of the volume calculations for columns and beams between manual calculations and a 3D model of the Main Lecture Hall Building in the P4T Area created using Autodesk Revit 2024.

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Table 2. Comparison of work volume calculations for beam and column structures

No	JOB DESCRIPTION	Manual Data		Modeling Data		Deviation		Information
		Volume	Unit	Volume	Unit	(+)	(-)	
	Reinforcement Work							
1	Sloof Reinforcement S1 25/50	3.796,65	kg	3.034,32	kg		762,32	Volume Reduced
2	Sloof Reinforcement S2 20/30	394,91	kg	324,33	kg		70,58	Volume Reduced
3	Sloof Reinforcement S3 15/25	342,8	kg	342,8	kg	-	-	Volume Fixed
4	Beam Reinforcement B1 25/50 Floor 1 & 2	5.462,80	kg	5.461,78	kg		1,02	Volume Reduced
5	Beam Reinforcement B2 20/30 Floor 1 & 2	1.512,29	kg	1.469,90	kg		42,39	Volume Reduced
6	Beam Reinforcement B3 15/25 Floor 1 & 2	476,24	kg	516,47	kg	40,23		Volume Increases
7	Column Reinforcement K1 20/20,K2,K3 Floor 1 & 2	3.959,87	kg	4.152,38	kg	192,51		Volume Increases
	K 300 Concrete Works							
1	Sloof S1 25/50	34,75	m^3	21,05	m^3		13,7	Volume Reduced
2	Sloof S2 20/30	3,54	m^3	3,44	m^3		0,1	Volume Reduced
3	Sloof S3 15/25	2,25	m^3	2,19	m^3		0,06	Volume Reduced
4	Beam B1 25/50 Floor 1 & 2	50	m^3	43,10	m^3		6,90	Volume Reduced
5	Beam B2 20/30 Floor 1 & 2	13,32	m^3	18,63	m^3	5,31		Volume Increases
6	Beam B3 15/25 Floor 1 & 2	2,95	m^3	5,31	m^3	2,56		Volume Increases
7	Column K1 20/20,K2,K3 Floor 1 & 2	27,28	m^3	29,61	m^3	2,33		Volume Increases

Table 3. Recapitulation of comparative volume calculations for beam and column structural work

No	JOB DESCRIPTION	Konventional		BIM		Deviation	
		Volume	Unit	Volume	Unit	m^3	(%)
	K 300 Concrete Works						
1	Sloof	40,54	m^3	26,81	m^3	13,86	33,858
2	Beam	66,27	m^3	67,67	m^3	-1,40	-2,18
3	Column	27,28	m^3	29,61	m^3	-2,33	-8,52
	Total Concrete Volume	**134,09**	**m^3**	**124,096**	**m^3**	**9,997**	**23,216**

	Reinforcement Work						
1	Sloof	4.534,35	kg	3.701,45	kg	832,9	18,37
2	Beam	7.451,34	kg	7.448,16	kg	3,18	0,04
3	Column	3.959,87	kg	4.152,38	kg	-192,51	-4,86
Total Reinforcement Volume		**15945,56**	**kg**	**15301,99**	**kg**	**643,57**	**13,55**

Comparing the two methods, the conventional calculation resulted in a total concrete volume of 134.09 m³ and a total reinforcement volume of 15945.56 kg for the columns and beams. However, the BIM model calculated a slightly lower volume of 124.096 m³ for concrete and 15301.99 kg for reinforcement. This represents a difference of 23.216% for concrete volume and 13.55% for reinforcement volume.

CONCLUSION

A comparative analysis between BIM and conventional methods demonstrates that BIM significantly contributes to the calculation of column and beam structures in the Main Lecture Hall Building project. By reducing concrete usage by 23.216% and reinforcement by 13.55%, it proves that BIM is an effective tool for managing modern construction projects. With its ability to enhance efficiency, accuracy, and optimize costs, BIM can become the new standard in construction project management in the future.

The implementation of BIM in this project has yielded various benefits, including increased calculation efficiency and optimized material usage on-site. These results indicate that BIM is a profitable investment in the construction industry. These findings highlight BIM's potential to revolutionize the construction industry and set a new standard for future projects.

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