Enhancing Construction Performance
BIM-Based Time Performance, Cost Efficiency, and Energy Analysis

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ABSTRACT
Cost analysis and scheduling are crucial aspects that determine the success of a construction project. Cost analysis aims to ensure the necessary budget for completing the project, while scheduling analysis aims to control each construction process effectively and prevent delays. Another essential aspect often overlooked is building energy analysis, primarily for buildings with complex geometries and structures, due to the intricate process involved. Energy analysis seeks to design environmentally friendly and energy-efficient buildings. BIM produces detailed 3D models with precise data, improving cost efficiency and providing accurate duration estimates for efficient construction processes. Moreover, BIM assists in energy analysis during the design phase for eco-friendly buildings. In this study, 3D modelling using Autodesk Revit was conducted for the structural and architectural elements of the Dentistry Faculty building at Brawijaya University. The volume calculations from the 3D structural modelling were used to create a new Budget Plan and determine the duration of each task, which were then compared with the project data to identify potential efficiency gains. Benefit-cost ratio analysis was also carried out by comparing the procurement costs of Autodesk Revit with the potential cost efficiency achieved. The 3D architectural modelling was used to analyse possible scenarios to maximize natural lighting in the building. The study's results showcase the achievable cost efficiency, the BCR value as a measure of Autodesk Revit's feasibility, a comparison of task durations analysed with BIM and project data, and recommended scenarios for energy-saving in the building, along with estimated costs to implement those scenarios. In conclusion, the research establishes the significant advantages and practical value of implementing Autodesk Revit and BIM in modern construction projects, ensuring both economic and environmental sustainability.

Keywords: *Building Information Modelling (BIM), Time Performance, Cost Efficiency, Energy Analysis, Autodesk Revit.*

1. INTRODUCTION

With the continuous development of technology, the challenges frequently encountered in the construction industry must be addressed with innovative solutions, supported by Alaloul et al [1]. Issues such as project delays, inaccurate cost calculations, and environmental sustainability concerns have driven breakthroughs in the utilization of Building Information Modelling (BIM) technology to its fullest potential, supported by Almujibah [2]. By harnessing BIM, activities related to time, cost, and quality management can be seamlessly integrated, enabling construction project processes to operate more efficiently, supported by Zhang et al [3].

BIM is capable of providing detailed and precise information about construction projects, supported by Razali et al [4]. Its advanced implementation can yield accurate and efficient construction durations, along with recommendations to enhance project timeline performance in case of delays, supported by Mounla et al [5]. Regarding costs, the calculations obtained from BIM modelling offer more accurate volume measurements and precise cost estimations, supported by Fazeliet al [6]. Its benefits can also be analysed through a Cost-Benefit Analysis (CBA) approach, providing a comprehensive overview of its investment value, supported by Kim et al [7]. In terms of sustainability, BIM can be utilized to analyse environmentally friendly architectural design scenarios and estimate the costs associated with energy-efficient designs, supported by Rodriguez [8]. It enables calculating CO_2 emission reductions by analysing electricity consumption and local emission conversion factors, supported by Li et al [9].

Y. A. Yusran et al. (eds.), *Proceedings of the 2023 Brawijaya International Conference (BIC 2023)*, Advances in Economics, Business and Management Research 294,
https://doi.org/10.2991/978-94-6463-525-6_39

2. METHODS

This study will conduct several analyses using Autodesk Revit's structural model to calculate construction volume and costs. Investment feasibility will be assessed through the Cost-Benefit Ratio method. Microsoft Project and Autodesk Navisworks will be integrated to analyse construction timeline performance. Autodesk Insight 360 will assess energy consumption and propose energy-efficient strategies. Finally, carbon emission reductions from engineering interventions will be evaluated. The detailed process is shown in the flowchart below.

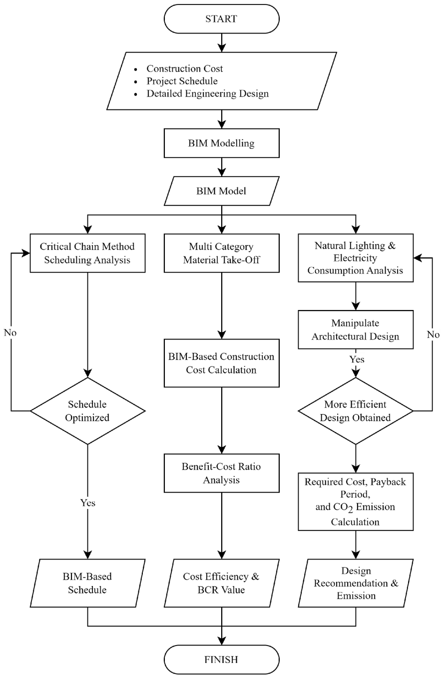


Figure 1 Research Methodology

3. CASE STUDY

The primary focus of the study centres on the construction phase of the Faculty of Dentistry building at Universitas Brawijaya. Currently, the construction is being carried out by PT Santoso Shafanara Graha as the primary contractor.

3.1. *Research Object Details*

This seven-floor building, constructed using reinforced concrete, spans an area ranging from 1049 to 1225 square meters. The walls of the building are made up of brick pairs, plaster layers, and standard wall paint, and in some sections, shear wall construction and gypsum partition installations are incorporated. Furthermore, the floors are also constructed with reinforced concrete for stability and durability. Notably, the building's exterior facade boasts flexi tile pairs made from modified clay, which undergoes a low-temperature heating process.

3.2. *Model Setup*

BIM modelling is carried out based on the Detailed Engineering Design obtained from the project executor. Parameters that are unknown but required for modelling are assumed using approaches based on the norms prevalent in Indonesia. Results of structural and architectural modelling along with Building Energy Model visualizations, are shown in the figures below.

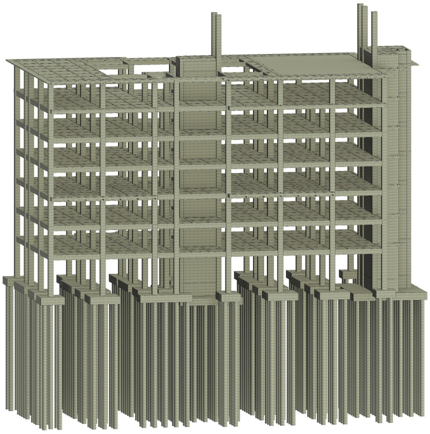


Figure 2 Building Structure Visualisation

Figure 3 Architecture Design Visualisation

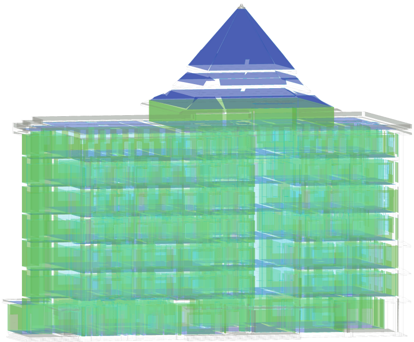


Figure 4 Building Energy Model

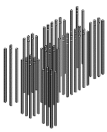
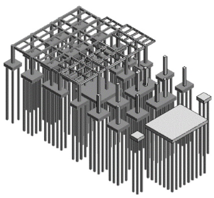
4. RESULT

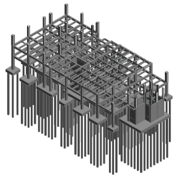
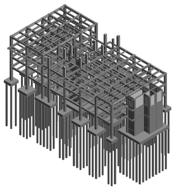
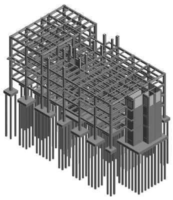
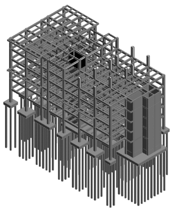
Initially, simulations were conducted without using BIM for building design. Subsequently, optimizations were performed to improve scheduling, costs, and energy consumption.

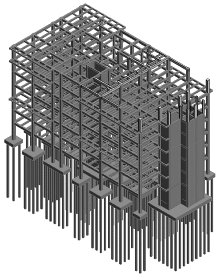
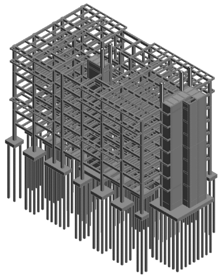
4.1. ***Project Schedule Simulation***

To analyse the time performance of the Faculty of Dentistry building construction project at UB, the duration of each task is calculated using work volume, work index, and the number of workers. Microsoft Project software is used for the analysis, and a detailed work breakdown structure (WBS) is created. Both the WBS from BIM calculations and project data are made identical for a thorough comparison of the overall duration. Out of 28 phases visualized with Autodesk Navisworks, some scheduling visualizations are shown in **Table 1**.

Table 1. Navisworks' Phasing Visualisation

Phase	Navisworks Visualisation
1	
5	

Phase	Navisworks Visualisation
9	
13	
16	
20	

Phase	Navisworks Visualisation
24	
28	

4.2. *Comparison of Volume and Structural Work Costs*

The volume of structural elements, calculated using Autodesk Revit, is used to prepare the latest Structural Work Budget Plan. The new plan employs the same unit price for the work as the previous project's Budget Plan (IDR996,280.00 per 1 m^3 of concrete with a compressive strength of f'c = 29.05 MPa). A comparison is made with the previous project's Budget Plan to determine cost efficiency as shown in **Table 2**.

Table 2. Volume Comparison for Structural Works

Type of Work	Material Volume (m^3)		Percentage of Difference
	Budget Plan	BIM	
Foundation	2192.41	2157.66	1.59%
Column	659.25	666.97	-1.17%
Beam	947.86	917.17	3.24%
Slab	810.89	776.87	4.20%
Shear Wall	281.06	279.20	0.66%
Total	**4891.47**	**4797.86**	**1.95%**

If the obtained volume is multiplied by the unit cost for each type of work, the cost for each type of work is obtained as shown in **Table 3**.

Table 3. Cost Comparison for Structural Works

Type of Work	Cost (IDR)	
	Budget Plan	BIM
Foundation	2,184,252,323.93	2,149,663,426.14
Column	656,799,084.42	664,506,561.59
Beam	944,335,704.29	911,335,581.96
Slab	807,872,362.52	773,989,267.00
Shear Wall	280,011,467.96	266,441,080.60
Total	**4,885,051,954.12**	**4,765,935,917.29**

The cost difference is IDR 117,525,247.00, equivalent to 1.95% efficiency when using BIM volume for Structural Work Cost Estimate calculations.

4.3. ***Building Energy Usage Intensity (EUI)***

4.3.1. *Baseline Design EUI*

Adjustments were made to match the actual conditions of the building upon accessing the model in the Autodesk Insight 360 platform, supported by Maglad et al [10]. A baseline scenario with an Energy Usage Intensity (EUI) value ranging from 115 to 333 kWh/m^2/year, averaging at 211.39 kWh/m^2/year, was revealed.

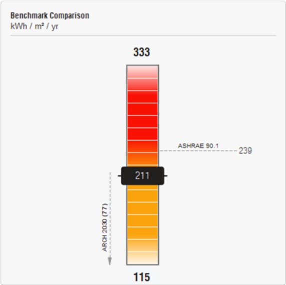


Figure 5 EUI of the Baseline Scenario

4.3.2. *Optimized Design EUI*

Based on the research criteria and considering the ongoing construction phase, feasible design adjustments for the building include adding fire-rated glass on the top side, openings on the north and south sides, installing shades on the north, west, and east walls, and using clear glass for the northern and southern facades, and double-layered clear glass for the western and eastern facades. These adjustments result in a reduced Energy Use Intensity (EUI) ranging from 106 to 326 kWh/m^2/year, averaging at 203.14 kWh/m^2/year.

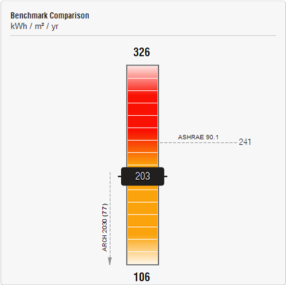


Figure 6 EUI of the Optimized Scenario

5. **DISCUSION**

Innovative engineering based on Building Information Modelling is applied in terms of scheduling, costs, and sustainability.

5.1. ***Duration of Work Items Comparison***

Upon analysing the duration calculations for individual tasks, it becomes evident that certain durations obtained from Building Information Modelling (BIM) are longer than those recorded in the project data. This results in a faster duration obtained using BIM by 5 days (from 99 days to 94 days).

Table 4 displays the differences obtained between BIM and the initial project data. It also presents the specific items that vary along with the corresponding duration variances measured in days.

Table 4. Comparison of Durations in BIM with Project Data

Activity	Duration		Deviation (Days)	Item
	BIM	Baseline		
1st Floor				
Rebar Installing	12	16	4	Pile Cap
2nd Floor				
Rebar Installing	6	5	1	Beam
Rebar Installing	6	4	2	Slab
3rd Floor				
Rebar Installing	6	5	1	Beam
Rebar Installing	6	4	2	Slab
Rebar Installing	4	3	1	Column
4th Floor				
Rebar Installing	6	5	1	Beam
Rebar Installing	6	4	2	Slab
5th Floor				
Rebar Installing	6	5	1	Beam
Rebar Installing	6	4	2	Slab
6th Floor				
Rebar Installing	6	5	1	Beam
Rebar Installing	6	4	2	Slab
7th Floor				
Concr. Pouring	1	2	1	Beam
Rebar Installing	5	3	2	Slab

5.2. *Benefit-Cost Ratio Analysis*

Benefit-cost ratio analysis for investing in Autodesk Revit software at Brawijaya University's Dentistry Faculty building project was conducted. It compares benefits from Autodesk Revit's volume-based calculation with the Budget Plan, along with licensing and training expenses from Autodesk's site and AcAdemia, supported by Umam et al [11]. Two options are presented: Alternative 1 with a monthly license and 6-month training, and Alternative 2 with an annual license and 1-year training.

The benefit-cost ratio calculation for the first alternative is illustrated in **Table 5**, and the benefit-cost ratio calculation for the second alternative is illustrated in Table **6**.

Table 5. BCR Calculation for the 1st Alternative

BIM Procurement Cost	Required Cost (IDR)	Total Benefit (IDR)	B/C
Revit Monthly Subscription	25,035,192.00	117,125,247.49	3.93
Training	1,786,439.77		
Total	**29,772,011.27**		

Table 6. BCR Calculation for the 2nd Alternative

BIM Procurement Cost	Required Cost (IDR)	Total Benefit	B/C
Revit Monthly Subscription	41,799,829.50	117,125,247.49	2.42
Training	1,787,929.96		
Total	**48,382,413.00**		

The researchers recommend Alternative 1, which offers a monthly license and training package for 2 BIM Modelers over 6 months, due to its higher benefit-cost ratio of 3.93 and alignment with the typical duration required for building planning using Building Information Modelling (BIM), which ranges from 3 to 6 months.

5.3. *Evaluation of Sustainability Aspects*

5.3.1. *Calculation of CO_2 Emissions*

Based on data from the Department of Energy and Human Resources, Directorate General of Electricity and Energy Utilization, the emission factor value on the island of Java (Jamali grid) is 0.87 tons of CO_2 per megawatt-hour (MWh). This factor is used to calculate CO_2 emissions using the EUI data obtained previously in Autodesk Insight 360 as shown in **Table 7**.

Table 7. Calculation of CO_2 Emission

Scenario	EUI (kWh/m²/year)	Conversion (ton/CO_2/MWh)	CO_2 Emission (ton/year)
Baseline	211.39	0.87	1372.85
Optimized	203.14	0.87	1319.27

5.3.2. *Required Cost for Sustainable Design*

Overall, the renovations carried out on this building include: adding 6 window units on the north wall; adding shades on the north, west, and east sides of the building; and using clear glass on the north and south sides, as well as double-layered clear glass on the east and west sides of the building. The total material cost for implementing the planned alternative design, including windows, shades, and glass materials, is calculated in **Table 8**.

Table 8. Sustainable Design Cost Calculation

Material	Unit Price (IDR)	Unit	Qty.	Total Price (IDR)
Window Shades				
Ø10 Reinforcement	11,433.00	kg	227.06	2,595,931.25
Ø6 Reinforcement	11,433.00	kg	111.65	1,276,508.17
M6 Wire Mesh	65,811.00	m²	64.40	4,238,228.40
K-225 Concrete	1,080,705.00	m³	4.51	4,871,818.14
Window Glass				
Single Clear Glass	122,242.00	m²	236.93	28,963,102.67
Double Clear Glass	185,141.00	m²	495.53	91,743,382.58
Fire Rated Glass	750,000.00	m²	37.11	27,832,500.00
Window Frame				
Aluminium Frame	479,789.00	kg	78.03	37,436,736.20
			Total	198,958,207.40
			Tax (10%)	19,895,820.74
			Grand Total	218,854,028.14
			Rounded	218,855,000.00

5.3.3. *Building Lighting Performance*

Based on the conducted simulation, 57% of the buildings meet the requirements of LEED 2009 IEQc8 opt1, which means they have natural lighting ranging from 10 to 500 foot-candles. The specific distribution of light on each floor as shown in **Table 9**.

Table 9. The Floor Area that Meets the 2009 IEQc8 opt1 Threshold

Level	Area	9 AM		3 PM		9 AM & 3 PM	
		%	Area	%	Area	%	Area
Floor-1	1026 m²	44	448 m²	60	611 m²	37	379 m²
Floor-2	1067 m²	70	749 m²	72	766 m²	60	635 m²
Floor-3	1067 m²	76	809 m²	74	790 m²	66	702 m²
Floor-4	1104 m²	60	662 m²	56	623 m²	44	486 m²
Floor-5	1075 m²	87	930 m²	79	848 m²	75	804 m²
Floor-6	1069 m²	64	682 m²	66	703 m²	56	601 m²
Floor-7	1203 m²	69	833 m²	73	878 m²	61	732 m²

6. CONCLUSION

Using BIM for scheduling resulted in shorter durations than the project data due to its more accurate work volume estimation, causing overall duration variations. The BIM analysis showed a total work duration of 94 days, while the project data indicated 99 days. Using Autodesk Revit to calculate the total volume for the building led to a difference of 105,467 m³ from the Budget Plan, increasing cost efficiency by 1.95%. The total cost using Autodesk Revit was IDR4,765,935,917.29, differing by IDR117,125,247.49 from the initial cost of IDR4,885,051,954.12. The benefit-cost ratio analysis demonstrated values of 3.93 for Alternative 1 and 2.42 for Alternative 2, proving the software's worthwhile investment. In the baseline condition, 56% of the building met the LEED 2009 IEQc8 opt1 threshold. Autodesk Insight 360 simulations revealed an average Energy Usage Intensity (EUI) of 211.39 kWh/m²/year. Implementing energy-efficient design alternatives, such as fire-rated glass, additional openings, shades, and specific glass materials, reduced the average EUI to 203.14 kWh/m^2/year, resulting in a 3.90% decrease in CO_2 emissions, from 1372.85 tons/year to 1319.27 tons/year.

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