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Research Paper

Implementation of Value Engineering in Construction Projects Based on Building Information Modeling (BIM) Case Study: Factory Construction Project in Cikarang, West Java

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ABSTRACT: *The application of Value Engineering (VE) integrated with Building Information Modeling (BIM) represents an innovative approach to improving cost efficiency and functional value in construction projects. This research aims to examine the integration of VE and BIM in a factory construction project in Cikarang, West Java, focusing on the analysis of the main steel structural element (rafter) to develop a more economical design alternative without compromising quality and functionality. The research methodology includes functional, creative, and evaluative analysis stages, along with the application of Life Cycle Cost (LCC) as a basis for decision-making. The study findings indicate that the alternative design using Castellated Beam provides significant cost efficiency. The material volume is reduced by 64,568 kg, and the initial construction cost decreases by 53.69% compared to the original design. Overall, the total project cost savings reach 3.00%. The LCC analysis further demonstrates long-term savings of 50.07% over the project's lifecycle. Although the salvage value of the alternative design is lower, its advantages in initial and maintenance costs yield greater economic benefits. BIM technology at the 5D level proves effective in enhancing the accuracy of quantity take-offs and cost estimation, while also enabling efficient visualization of design alternatives.This study concludes that the integration of VE and BIM is an effective strategy for improving cost efficiency and design decision quality. Castellated Beam is recommended as an optimal solution for similar projects, and the implementation of VE based on BIM should be expanded to other construction elements to maximize overall project value.*

KEYWORDS: *Value Engineering, Building Information Modeling (BIM), Life Cycle Cost, Castellated Beam, Cost Efficiency, Factory Project.*

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I. INTRODUCTION

The construction industry plays an important role in national infrastructure development and economic growth. However, construction projects especially factory buildings are often complex and involve high costs, tight schedules, and the need for precise coordination between disciplines. To improve project value and reduce unnecessary costs, Value Engineering (VE) is a method that helps evaluate the function of a design and find better alternatives without lowering quality. VE is usually applied during the planning stage to achieve cost efficiency while maintaining the required performance. With the advancement of digital technology, Building Information Modeling (BIM) can support the VE process. BIM allows for 3D modeling, quantity take-off, and real-time cost estimation in a single integrated system. By combining VE with BIM, design evaluation becomes faster, more accurate, and data-driven.

In Indonesia, the integration of VE and BIM is still limited, especially in industrial building projects. Therefore, this study analyzes the application of VE based on BIM in a factory construction project in Cikarang, West Java. The aim is to improve cost efficiency by identifying design alternatives using BIM data. This research focuses on structural and architectural elements, particularly the main steel structure (rafter). Using tools like Life Cycle Cost (LCC), this study compares the initial and long-term costs of different design options. The results are expected to provide practical strategies for improving the value of industrial construction projects through the use of VE and BIM.

II. LITERATUR REVIEW

VALUE ENGINEERING

Value Engineering (VE) is a structured methodology focused on improving the value of a product or project by analyzing its functions and identifying cost-effective alternatives without compromising performance or quality. Originally introduced by Miles in the 1940s, VE aims to eliminate unnecessary costs while maintaining or enhancing required functions [1]. It has been widely applied in construction to optimize cost, quality, and schedule.

VE is typically conducted in several distinct phases, including information gathering, functional analysis, creative ideation, evaluation, development, and recommendation. Each phase contributes to a systematic decision-making process to ensure that value is maximized throughout the project lifecycle [2]. Moreover, VE fosters interdisciplinary collaboration to develop innovative solutions that respond to both technical and economic requirements.

BUILDING INFORMATION MODELING (BIM)

Building Information Modeling (BIM) is a digital representation of the physical and functional characteristics of a facility. It provides a collaborative platform that integrates data across architectural, structural, and MEP (mechanical, electrical, plumbing) disciplines, enabling enhanced coordination throughout a project's lifecycle [3].

BIM supports improved visualization, quantity take-off, scheduling, and cost estimation. It also facilitates clash detection and construction sequencing (4D), contributing to better project control and decision-making. According to Eastman et al. (2011), BIM's comprehensive database and visualization capabilities allow stakeholders to assess design options more effectively and anticipate project outcomes with greater precision [4].

INTEGRATION OF VALUE ENGINEERING AND BIM

The integration of Value Engineering and Building Information Modeling presents a transformative approach in construction management. BIM enhances the VE process by enabling real-time simulation, data-driven analysis, and rapid visualization of design alternatives. This synergy allows stakeholders to evaluate cost-function relationships with greater accuracy and to validate proposed alternatives through digital modeling [5].

Through clash detection, automated quantity extraction, and visual simulation, BIM supports the identification of high-cost elements and the development of optimized alternatives during VE workshops. The combined application contributes to improved cost efficiency, reduced change orders, and higher-quality project outcomes [6].

In complex industrial projects, such as factory developments, this integration is especially beneficial due to the need for precise coordination and performance analysis. Therefore, exploring VE-BIM integration provides a foundation for enhancing value-based decision-making in modern construction practices.

III. RESEARCH METHODS

This research employs a quantitative approach, focusing on evaluating cost efficiency through the integration of Value Engineering (VE) and Building Information Modeling (BIM) in an industrial building construction project. The objective is to identify and quantify potential cost savings by optimizing designs and selecting more economical materials, using project data extracted from BIM models.

DATA COLLECTION

The data used in this study are categorized into two types:

1. **Project Data (Bill of Quantity and BIM Model Output)**
    - This includes the cost estimates before and after VE implementation. The data consist of:
    - Project's initial and optimized Bill of Quantities (BoQ/RAB).
    - Quantity take-off results and cost estimations directly extracted from the BIM model.
    - These were obtained from technical project documentation, including working drawings, specifications, and BIM files of the case study.

2. **Market Price Data**
    - To ensure realistic cost analysis, updated market prices of materials and labor were collected via:
    - Market surveys.

- Official standard price lists from professional associations.
- Supplier quotations for relevant materials and services.

RESEARCH STAGES

This study follows a structured research flow, integrating VE methodology with BIM technology, supported by Multi-Criteria Analysis (MCA) and Life Cycle Cost Analysis (LCCA). The following stages were conducted:

1. **Problem and Objective Definition**
   Formulation of the main research question and specific objectives related to the integration of VE and BIM for cost-efficiency analysis.
2. **Literature Review**
   Review of previous studies and theories related to VE, BIM, MCA, and LCCA. This stage formed the theoretical basis and analytical framework of the study.
3. **Data Acquisition**
   Collection of initial BoQ, BIM models, and technical drawings from the industrial building project in Cikarang, West Java. Verification of BIM model accuracy was also conducted to ensure reliable volume extraction.
4. **Identification of High-Cost Items**
   An initial cost analysis was conducted using the existing RAB and BIM model to identify major cost contributors. BIM tools were used to extract precise material quantities.
5. **Development of Design Alternatives**
   The VE team (researchers) proposed alternative designs or material options for high-cost items. Each alternative was modeled in BIM to allow accurate quantity extraction and visualization.
6. **Technical Evaluation (MCA)**
   Each design alternative was assessed based on multiple technical criteria using Multi-Criteria Analysis (MCA). Scoring and weighting were assigned to evaluate performance.
7. **Cost Evaluation (LCCA)**
   Life Cycle Cost Analysis (LCCA) was used to compare long-term financial implications, including:
   a. Initial construction cost.
   b. Operational and maintenance costs.
   c. Replacement and end-of-life costs.

   All costs were converted to Present Worth (PW) values for a fair comparison.
8. **Alternative Comparison and Selection**
   The design alternatives were compared based on MCA scores and LCCA results. BIM outputs, including 3D visualization and quantity data, supported the decision-making process to select the optimal solution.
9. **Conclusion and Recommendations**
   Final conclusions were drawn from the integrated analysis. Practical recommendations for applying VE through BIM in future construction projects were proposed.

DATA ANALYSIS

Three main analysis techniques were used:

1. **Descriptive Quantitative Analysis**
   Cost components were compared before and after VE implementation. The percentage of cost savings and major contributing items were identified.
2. **Multi-Criteria Analysis (MCA)**
   Technical feasibility of each alternative was evaluated using weighted scoring based on predefined criteria (e.g., performance, durability, ease of construction).
3. **Life Cycle Cost Analysis (LCCA)**
   Each design alternative was assessed based on life cycle cost components. Present Worth (PW) calculations were used to identify the most cost-efficient option over the building's life span.

TOOLS AND SOFTWARE

To support the research process, the following tools were utilized:

- Building Information Modeling (BIM): For 3D modeling, design simulation, quantity take-off, and visualization.
- Spreadsheet Applications (MS Excel/Google Sheets): For budget calculations, cost efficiency analysis, LCCA, and MCA matrix processing.

VE FRAMEWORK IMPLEMENTATION

The study follows the standard Value Engineering job plan, consisting of seven phases:

1. Information Phase
   Document review, project cost analysis, and Pareto identification of high-impact items.
2. Creative Phase
   Idea generation through literature synthesis and team brainstorming to develop feasible alternatives.
3. Analysis Phase
   Functional analysis to classify primary and secondary functions of design components.
4. Evaluation Phase
   Assessment of each alternative using technical, economic, and operational criteria.
5. Development Phase
   Use of LCCA and MCA methods to analyze and score each alternative in detail.
6. Presentation Phase
   Review and synthesis of the best-performing alternatives based on integrated analysis.
7. Recommendation Phase
   Final selection of the most cost-efficient and technically feasible solution, followed by implementation recommendations.

IV. FINDING AND DISCUSSION

PROJECT OVERVIEW

he construction of this factory project is part of PT XYZ's production facility expansion to meet increasing market demands. The project includes the construction of a main factory building, office spaces, cafeteria, supporting areas, and associated infrastructure such as drainage, piping systems, and parking areas. Strategically located in the Jababeka Industrial Area, Cikarang, West Java, the project is expected to support operational efficiency and logistical distribution. Key stakeholders involved in the project include the project owner, design consultants, and contractors selected based on their expertise and experience in industrial construction.

INFORMATION PHASE

The Information Phase is the foundation of the VE process, involving comprehensive understanding of the technical, functional, and economic aspects of the project. It involves collecting all relevant documents—technical specifications, working drawings, and the Bill of Quantities (BoQ). This ensures proper identification of each structural element and its impact on overall project costs.

COST ESTIMATION

The Bill of Quantities (BoQ) or Cost Estimation Plan for the industrial factory construction project in Cikarang, West Java, outlines the overall financial scope and resource allocation across various work packages. The total project cost amounts to IDR 56,311,510,849.90, distributed over 14 major construction items. These components include structural, architectural, mechanical, and preliminary works, each with varying significance and weight in the total budget.

The largest share of the budget is allocated to the Structural Works of the Factory, Office, and Canteen, accounting for 38.46% of the total cost. This highlights the primary focus of the project, which involves establishing the core physical facilities.

Table 1 - Cost Estimation Plan (BoQ)

No	Work Item	Estimated Cost (IDR)	Weight (%)
1	Site Preparation	568,851,159.96	1.01
2	Fence Construction	654,559,136.89	1.16
3	Box Culvert (Deuker)	302,792,036.83	0.54
4	Security Post	235,444,780.49	0.42
5	Piling Work	4,396,265,048.68	7.81
6	Factory, Office, and Canteen Structure	21,659,452,954.83	38.46
7	Architectural Work	3,972,347,814.17	7.05
8	Drainage Channels	1,301,429,324.82	2.31
9	Canopy Roofing	583,710,325.49	1.04
10	Roads and Parking Area	4,439,875,260.40	7.88
11	Car Canopy Roof	287,661,668.74	0.51
12	Interior Work	2,917,697,136.90	5.18
13	Mechanical, Electrical, and Plumbing (MEP)	14,031,971,495.00	24.92
14	Miscellaneous Works	959,452,706.71	1.70
	Total	**56,311,510,849.90**	**100%**

Source: Processed by the author

PARETO ANALYSIS LEVEL 1

In order to identify the most influential cost components within the overall project budget, a Level 1 Pareto Analysis was conducted based on the consolidated Bill of Quantities (BoQ). This approach aims to prioritize work items with the highest cost contribution, which are potential targets for Value Engineering (VE) studies. According to the Pareto principle, approximately 80% of the project cost typically arises from about 20% of the work components. By highlighting these key cost drivers, resources can be more effectively allocated to explore value optimization.

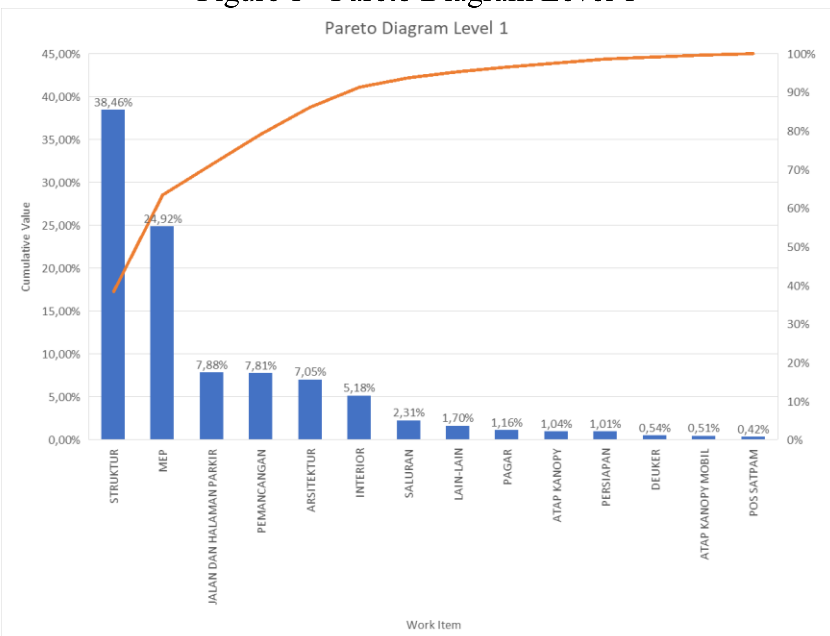
Table 2 below presents the ordered list of project work items based on their percentage contribution to the total project cost. The cumulative percentage is also shown to demonstrate how a small number of items dominate the budget allocation.

Table 2. Pareto Analysis – Level 1

No	Work Item	Estimated Cost (IDR)	Weight (%)	Cumulative (%)
6	Factory, Office, and Canteen Structure	21,659,452,954.83	38.46	38.46
13	Mechanical, Electrical, and Plumbing (MEP)	14,031,971,495.00	24.92	63.38
10	Roads and Parking Area	4,439,875,260.40	7.88	71.27
5	Piling Work	4,396,265,048.68	7.81	79.07
7	Architectural Work	3,972,347,814.17	7.05	86.13
12	Interior Work	2,917,697,136.90	5.18	91.31
8	Drainage Channels	1,301,429,324.82	2.31	93.62
14	Miscellaneous Works	959,452,706.71	1.70	95.32
2	Fence Construction	654,559,136.89	1.16	96.49
9	Canopy Roofing	583,710,325.49	1.04	97.52
1	Site Preparation	568,851,159.96	1.01	98.53
3	Box Culvert (Deuker)	302,792,036.83	0.54	99.07
11	Car Canopy Roof	287,661,668.74	0.51	99.58
4	Security Post	235,444,780.49	0.42	100.00
	Total	**56,311,510,849.90**	**100.00**	**100.00**

Source: Processed by the author

Figure 1 - Pareto Diagram Level 1



Source: Processed by the author

As illustrated in Table 2 and figure 1, the Factory, Office, and Canteen Structural Work ranks as the highest cost contributor, amounting to IDR 21.66 billion or 38.46% of the total budget. This makes it the most dominant and strategic component in the project's cost structure. While the MEP (Mechanical, Electrical, and Plumbing) category also presents a significant cost share at 24.92%, this study does not focus on MEP works, as the primary scope of analysis is limited to physical building elements with structural characteristics. Consequently, MEP is excluded from the core Value Engineering evaluation. Overall, the top seven items account for over 90% of the total project cost, aligning with the Pareto Principle, which asserts that a small number of elements typically contribute to the majority of the effect. Therefore, in this study, high-cost components—particularly structural works—are selected as the main focus for VE exploration, where alternative designs or construction methods can offer potential cost savings and increased project value.

PARETO ANALYSIS LEVEL 2

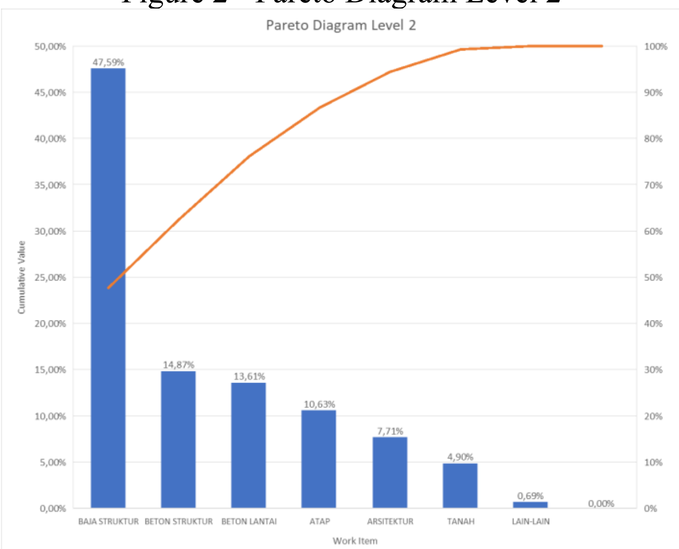
To deepen the analysis of structural components, a Pareto Level 2 analysis was conducted to identify which sub-components within the structural work contributed most significantly to the overall structural cost. This analysis aims to prioritize areas that have the greatest potential for cost optimization in the Value Engineering (VE) study. Table 3 shows the sorted cost contribution of each structural sub-component, along with its percentage weight and cumulative percentage. The principle of Pareto is used here, suggesting that a small number of dominant components account for the majority of the cost.

Table 3 – Pareto Analysis Level 2

No	Work Item	Cost (IDR)	Weight (%)	Cumulative (%)
3	Steel Work	10,307,520,820.72	47.59%	47.59%
2A	Reinforced Concrete Structure	3,221,346,610.28	14.87%	62.46%
2B	Concrete Floor	2,946,841,553.69	13.61%	76.07%
4	Roof Work	2,301,660,981.89	10.63%	86.69%
5	Architectural Work	1,670,829,740.26	7.71%	94.41%
1	Earth Work	1,060,975,006.34	4.90%	99.31%
6	Miscellaneous Work	150,278,241.65	0.69%	100.00%

Source: Processed by the author

Figure 2 - Pareto Diagram Level 2



Source: Processed by the author

The analysis in Table 3 indicates that steel work holds the highest cost contribution, amounting to IDR 10,307,520,820.72 or 47.59% of the total structural cost. This highlights that nearly half of the structural expenses are allocated to steel components, such as columns, beams, roof trusses, and other structural steel elements. Given its substantial share of the cost, steel work presents a significant opportunity for further evaluation under the Value Engineering framework. By examining steel-related construction methods and materials, there is potential to optimize cost without compromising structural integrity, functionality, or safety. As such, steel work has been selected as the primary focus in the next stages of this research. The study will proceed with function analysis, aiming to understand the core purpose and role of steel components within the overall building system. This step is essential in developing cost-effective and high-value alternatives that still meet user and technical requirements.

Function analysis is a critical phase in the Value Engineering (VE) methodology. It aims to evaluate the roles of each component based on their functionality rather than cost or appearance. This approach helps identify alternative solutions that are more cost-effective while still meeting project requirements. In this study, the focus is on steel structure components, which were previously identified as the dominant cost contributors. Each function is expressed in two words: an active verb and a noun, to clearly define what the element does and what it acts upon. Functions are divided into two categories:

- Primary Functions: Core purposes that must be fulfilled for the structure to operate properly.

- Secondary Functions: Supportive roles that enhance efficiency or ease of implementation.

Table 4 - Function Worksheet of Steel Structure Components

No	Material	Function	Function Criteria	How	Why
1	Double T & L Profiles (Rafter)	Support Load	Primary Structure	Form roof frame	Provide strength to resist roof loads
2	WF Beam	Transfer Load	Primary Structure	Distribute force to columns	Connect and transfer forces between components
3	WF Column	Support Vertical Load	Primary Structure	Transfer load to foundation	Withstand compression from upper structures
4	Castellated Beam	Reduce Weight	Primary Structure	Use lightweight high-strength profile	Reduce weight and cost while maintaining strength
5	Bolts & Connection Plates	Connect Elements	Secondary Structure	Unite structural components	Ease construction and maintenance

Source: Processed by the author

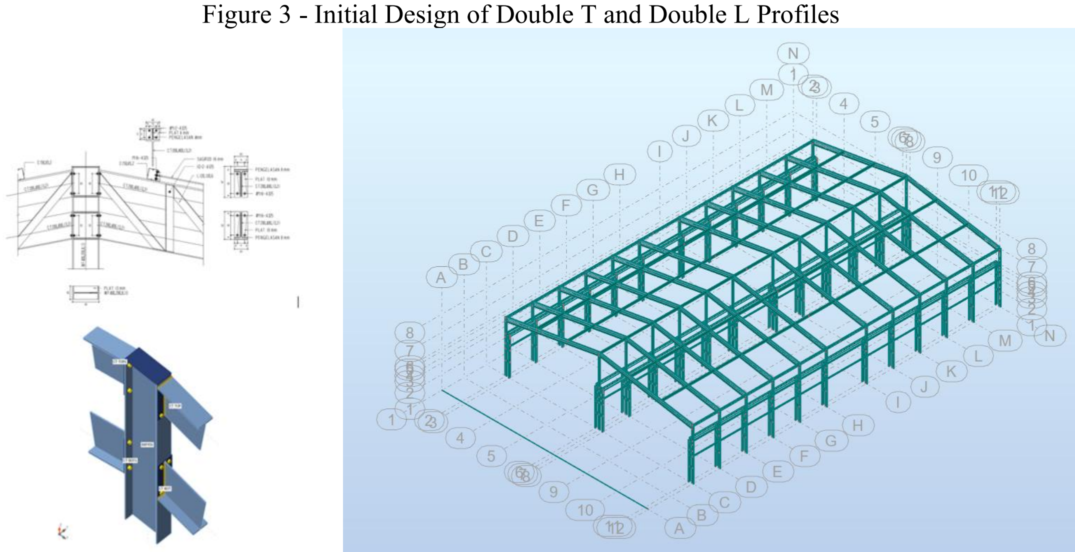
This worksheet emphasizes the essential roles of components like rafters, beams, and columns in maintaining building integrity. Secondary components like bolts and plates, although less critical structurally, play a key role in facilitating construction efficiency. In conclusion, this function analysis forms the foundation for the Creative Phase, where alternative solutions can be developed. By understanding the purpose of each component, it becomes possible to propose alternatives that maintain or improve functional performance while reducing cost or improving efficiency—aligning with the core principles of Value Engineering.

CREATIVE PHASE

The Creative Phase is a core step in the Value Engineering (VE) process. Its goal is to explore alternative ideas to the existing design in order to produce more efficient solutions—both technically and economically—without reducing the primary function of the structure. This study focuses on developing an alternative design for the rafter element of the steel structure, which plays a key role in the industrial building's roof system. Alternative ideas were developed through technical review, literature studies, and considerations of integration with Building Information Modeling (BIM). The main approach involves identifying a design that can reduce structural weight, and lower material costs

INITIAL DESIGN

Figure 3 - Initial Design of Double T and Double L Profiles



Source: Project documentation

The initial rafter design used Double T and Double L steel profiles. Although this design has high load-bearing capacity, it has several weaknesses:

- High structural weight leads to expensive material and transport costs.
- Overdesign: The section capacity often exceeds the actual required loads.

These issues encourage the development of an alternative rafter design that maintains its structural function but is more material-efficient and flexible.

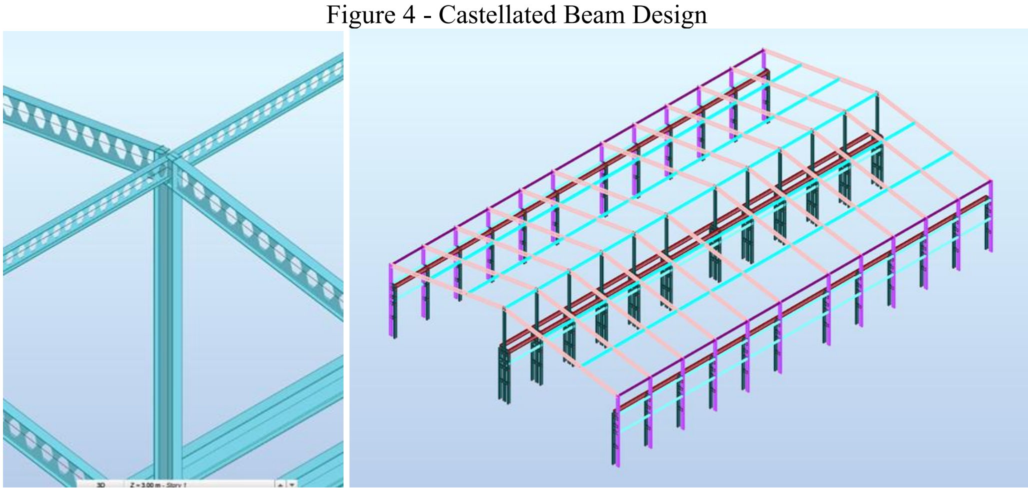
DESIGN ALTERNATIVE: CASTELLATED BEAM

The proposed alternative design uses a Castellated Beam (or Honeycomb Beam). This is a steel beam modified with hexagonal openings along its web.

Key features of the Castellated Beam:

- Made from standard Wide Flange (WF) beams cut in a zigzag pattern and rejoined vertically to form a deeper profile.
- Creates hexagonal or square openings in the web.
- Increases the moment of inertia without significantly increasing steel volume.
- Lightweight yet strong.
- Openings allow for routing of cables, ducts, and pipes (MEP systems), improving integration flexibility.

Figure 4 - Castellated Beam Design



Source: Author's illustration

This design provides benefits such as weight reduction, improved structural stiffness, and easier MEP coordination.

TECHNICAL AND FUNCTIONAL JUSTIFICATION

Table 5 - Technical and Functional Justification of Rafter Alternatives

Aspect	Double T and L Profiles (Existing)	Castellated Beam (Alternative)
Structural Weight	Very heavy	Lighter
Moment of Inertia	Depends on individual section size	Greater due to increased profile height
Aesthetics	Massive and rigid appearance	Open and visually lighter
Material Efficiency	Uses two large profiles	Optimized single profile with openings

Source: Author's analysis

Explanation of Comparison:

1. Weight: Castellated Beams reduce total structural weight, minimizing material, transport, and installation costs.
2. Moment of Inertia: Higher effective height increases flexural capacity without increasing material significantly.
3. Aesthetics: Castellated Beams look lighter and more modern, suitable for exposed industrial structures.
4. Efficiency: Using one optimized profile instead of two large profiles results in better material use.

COST-SAVING POTENTIAL AND BIM INTEGRATION

Using Castellated Beams not only improves structural performance, but also offers potential cost savings. Lighter weight and optimized material use lead to lower procurement, transport, and labor costs. Moreover, integration with BIM strengthens the application of this design alternative by providing a data-driven and visual validation process.

Benefits of BIM Integration:

1. 3D Visualization: Castellated Beams can be accurately modeled, allowing all stakeholders to understand form, placement, and interaction with MEP systems.
2. Automated Quantity Take-Off: BIM provides precise material volume and cost estimates quickly.
3. Cross-Discipline Coordination: BIM enables early coordination between structure and MEP, ensuring ducts, pipes, and cables can pass through the beam openings as planned.

Through BIM and Value Engineering, the Castellated Beam solution offers a high-value, practical alternative that meets structural requirements while reducing costs and improving system integration.

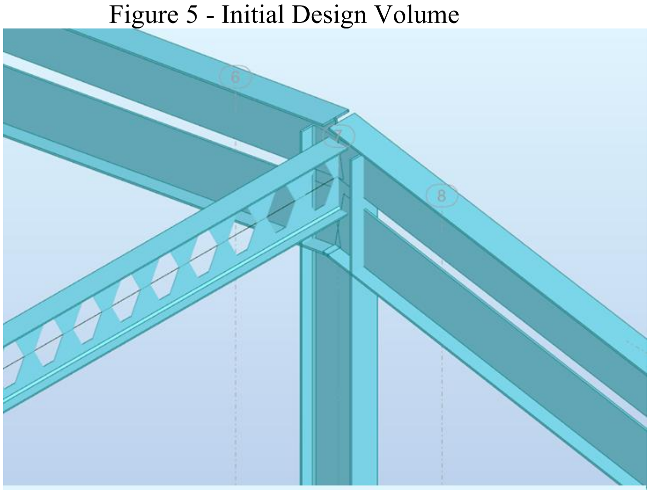
EVALUATION PHASE

The evaluation phase is a subsequent stage in the Value Engineering (VE) methodology, aimed at analyzing and comparing the design alternatives developed during the creative phase. Evaluation is conducted both qualitatively and quantitatively to assess the strengths and weaknesses of each alternative based on technical, economic, and functional criteria. In this research, the Castellated Beam design alternative is systematically compared to the existing design (Double T and Double L Profiles) to determine the alternative that offers the best value, which is defined as the optimal balance between cost and function.

QUANTITATIVE EVALUATION BASED ON VOLUME

Quantitative evaluation begins with the analysis of material volume for each steel structure alternative, namely the initial (existing) design and the design resulting from the Value Engineering (VE) process. Material volume refers to the total weight of the steel elements used, measured in kilograms (kg). This volume serves as a key indicator in assessing material efficiency and directly impacts procurement, transportation, and installation costs.

Figure 5 - Initial Design Volume



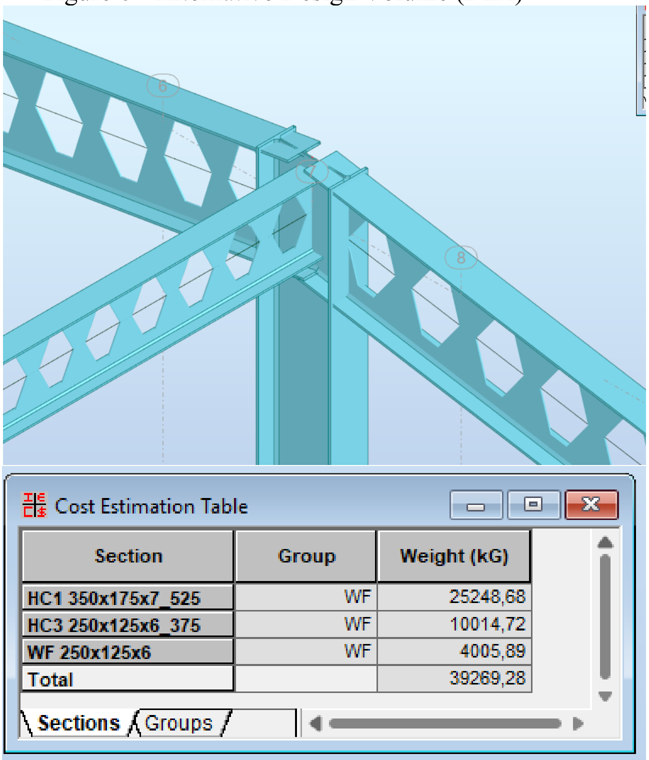
Cost Estimation Table

Section	Group	Weight (kG)
HIWF 400x200x8	T Profile	9033,56
L 120x120x8	Castellated Beam (HC)	15378,12
RAFTER HC 300x150x6.5_450	T Profile	12672,12
T Shape 200x400	T Profile	66866,51
Total		103950,32

Sections / Groups

Source: Project Document

Figure 6 - Alternative Design Volume (BIM)



Source: Author's analysis

Table 6 - Comparison of Structural Steel Material Volumes

No	Description	Volume (kg)	Notes
1	Initial Steel Structure	103,837	
	IWF 400.200	7,811	WF Profile
	HC 300.150	12,662	Honeycomb Profile
	T 200.400	68,020	T Profile
	2L 120.120.8	15,345	Double L Profile
2	VE Steel Structure	39,269	
	HC1 350x175x7.5	25,249	Castellated Beam
	HC3 250x125x6	10,015	Honeycomb Profile
	WF 250x125x6	4,006	WF Profile
3	Material Volume Efficiency	-64.18%	Total volume reduction

Source: Author's analysis

DEVELOPMENT PHASE

The development phase in the Value Engineering (VE) methodology aims to evaluate design alternatives from a long-term cost perspective through a Life Cycle Cost (LCC) approach. LCC includes all expenses incurred throughout the structure's service life, starting from initial construction costs, periodic maintenance, to salvage value at the end of its lifespan. This evaluation compares the original design, which uses a combination of Double T Profile and Double L Profile, with the VE design alternative using Castellated Beam. The calculation adopts a Present Value approach, where all future costs and benefits are discounted to present value for fair comparison.

LIFE CYCLE COST (LCC)

In the Life Cycle Cost (LCC) analysis, the Present Value method is used to calculate the total cost over the building's service life while considering the time value of money. This method is essential because future costs carry different values compared to current costs due to inflation and discount rates. Therefore, all cost components initial cost, maintenance cost, and salvage value are converted into present value to allow objective and comprehensive comparison between alternatives.

Table 7 – Life Cycle Cost Analysis

No.	Remarks	Life Cycle Cost (Rp)			
		Original Design		Alternative 1	
		Double T Profile & Double L Profile		Castellated Beam	
A	INITIAL COST (IC)	Future Cost	Present Value	Future Cost	Present Value
	1. Construction cost :	Rp3.147.316.173	Rp3.147.316.173	Rp1.457.478.575	Rp1.457.478.575
	Total Initial Cost Impact (IC)		Rp3.147.316.173		Rp1.457.478.575
B	MAINTENANCE	Future Cost	Present Value	Future Cost	Present Value
	1. Maintenance (Annual)	Rp 5.816.501.790	Rp 1.623.297.302	Rp 4.985.572.963	Rp 1.034.888.237
	2. Maintenance (10 Years)	Rp 617.354.629	Rp 361.418.278	Rp 423.103.765	Rp 247.697.882
	3. Maintenance (20 Years)	Rp 743.015.324	Rp 254.652.872	Rp 509.225.275	Rp 174.526.251
	4. Maintenance (30 Years)	Rp 894.253.878	Rp 179.426.689	Rp 612.876.562	Rp 122.970.015
	5. Maintenance (40 Years)	Rp 1.076.276.589	Rp 126.422.830	Rp 737.625.760	Rp 86.643.840
	Total Maintenance Cost		Rp 2.545.217.971		Rp 1.666.726.224
C	SALVAGE VALUE				
	Salvage Value Cost (50 years)	Rp 1.311.104.912	Rp 90.160.116	Rp 495.832.688	Rp 34.096.686
	Total Salvage Value	Rp 1.311.104.912	Rp 90.160.116	Rp 495.832.688	Rp 34.096.686
	Total Worth Life Cycle Cost		Rp 5.782.694.261		Rp 3.158.301.485
	Life Cycle Saving				Rp 2.624.392.776
	Percentage Life Cycle Saving				45,38%
	Total Worth Construction Cost		Rp 3.147.316.173,40		Rp 1.457.478.574,83
	Construction Cost Saving				Rp 1.689.837.598,58
	Percentage Construction Cost				53,69%
	Total Construction Project				Rp 56.311.510.850
	Percentage Construction Cost Total Project				3,00%

Source: Author's analysis

The analysis results show that the alternative design using Castellated Beam is not only more efficient in terms of initial construction cost but also provides significant long-term savings. This is due to the reduced material volume that directly lowers construction costs and decreases maintenance requirements, while still meeting technical standards. In addition, the salvage values of both alternatives were also considered. Although the nominal salvage value of the original design is higher, its impact is relatively small when discounted to present value. The alternative design still demonstrates superiority due to cumulative efficiency across all cost components.

Based on Table 7, it is known that the total life cycle cost (LCC) for the initial design reaches Rp4,252,622,580, while the alternative design only amounts to Rp2,123,413,248. This difference indicates a cost efficiency of Rp2,129,209,332, which is equivalent to a 50.07% saving over the building's lifetime. The initial construction cost of the original design is Rp3,147,316,173, while the alternative design offers significant savings with a total of Rp1,457,478,575, resulting in savings of Rp1,689,837,598.58 or approximately 53.69% of the initial cost. Additionally, the maintenance cost for the VE design is lower, at Rp631,837,987, compared to Rp1,015,146,291 in the original design. Although the salvage value of the VE design (Rp34,096,686) is lower than the initial design (Rp90,160,116), its impact on the overall LCC is relatively minimal.

When compared to the total construction project value of Rp56,311,510,850, the savings from Value Engineering on the initial construction cost contribute to an overall project efficiency of 3.00%. This is considered significant, especially in the context of large-scale construction projects, and reflects the success of the Value Engineering approach. Based on the LCC analysis, the alternative design using Castellated Beam not only excels in material and initial cost efficiency but also offers substantial long-term economic benefits throughout the building's service life. These results support the selection of the alternative design as the best value solution, balancing both cost and structural function.

MULTI-CRITERIA ANALYSIS (MCA)

Multi-Criteria Analysis (MCA) is an evaluation method used to assess and compare several alternatives based on a set of relevant criteria aligned with project objectives. In the context of Value Engineering (VE), MCA plays a critical role in providing a systematic and objective foundation for selecting design alternatives that consider not only cost aspects but also the technical quality and functionality of the proposed solutions.

EVALUATION CRITERIA

In this study, a comparison between two structural design alternatives—namely the original design and the alternative using castellated beams—is conducted using the MCA approach. The objective of MCA is to provide a systematic, objective, and measurable evaluation framework to assess the feasibility of alternatives based on several key criteria influencing both technical and economic aspects of the project.

The six main evaluation criteria are as follows:

- Life Cycle Cost (LCC)
- Initial Construction Cost
- Construction Time
- Material Weight
- Maintenance Cost
- Salvage Value (after 50 years)

These criteria encompass all direct and indirect costs, implementation time, and the long-term economic potential of the structure. Scoring is based on an ordinal scale from 1 to 4, as outlined in Table 8.

Table 8 - Evaluation Score Scale

Score	Interpretation
1	Very low (poor performance)
2	Low
3	High
4	Very high (excellent performance)

Source: Processed data

The scores are assigned based on quantitative comparisons between the two design alternatives for each criterion. To maintain objectivity, specific thresholds and assumptions are used as the basis for scoring, as described in Table 9.

Table 9 - Scoring Thresholds for Each Criterion

Criterion	Evaluation Parameter	Score 4	Score 3	Score 2	Score 1
LCC	% cost savings vs. original	≥ 40% savings	20–40% savings	< 20% savings	More costly
Initial Cost	Difference in direct cost	≥ 50% cheaper	30–50% cheaper	< 30% cheaper	More costly
Construction Time	Duration efficiency (days)	≥ 40% faster	20–40% faster	< 20% faster	Slower
Material Weight	Structural mass difference	≥ 50% lighter	30–50% lighter	< 30% lighter	Heavier
Maintenance Cost	Long-term efficiency	≥ 30% savings	15–30% savings	< 15% savings	More costly
Salvage Value	Residual value (50 years)	≥ 100% higher	50–100% higher	< 50% higher	Lower value

Source: Processed data

The evaluation refers to the results of cost calculations, fabrication and erection time estimates, structural modeling outputs, and the depreciated metal value for salvage value. The scoring for both alternatives is summarized in Table 10.

Table 10 - MCA Scoring Result

No	Criterion	Original Design	Score	Castellated Beam	Score	Basis of Evaluation
1	Life Cycle Cost	Rp4,252,622,580	2	Rp2,123,413,248	4	50.07% savings
2	Initial Cost	Rp3,147,316,173	2	Rp1,457,478,575	4	53.69% cheaper
3	Construction Time	±30 days	2	±14 days	4	~53% faster
4	Material Weight	103,837 kg	2	39,269 kg	4	~62% lighter
5	Maintenance Cost	Rp1,015,146,291	2	Rp631,837,987	4	~37.7% savings
6	Salvage Value	Rp90,160,116	4	Rp34,096,686	2	Original design has higher value

Source: Processed data

Based on the results of the Multi Criteria Analysis, the castellated beam alternative achieved a total score of 22, higher than the original design's score of 14. This gap illustrates the relative advantages of the castellated beam design, particularly in life cycle cost, initial cost, construction time, structural weight, and long-term maintenance savings. Although the original design has a higher salvage value, this does not significantly offset the comprehensive benefits of the castellated beam alternative. Thus, the castellated beam is concluded to be a more efficient and feasible solution.

CRITERIA WEIGHTING

In MCA, assigning weights to each criterion is essential to reflect its relative importance in the decision-making process. These weights indicate the influence of each criterion on achieving the project goals, from both technical and economic perspectives. In this study, a simple pairwise comparison method is used for weighting. A value of 1 is assigned if one criterion influences another, and 0 if it does not.

Table 11 Influence Matrix and Criterion Weighting

No	Criteria	LCC	Initial	Time	Weight	Maintenance	Salvage	Total Influence
1	Life Cycle Cost		1	1	1	1	1	5
2	Initial Cost	1		1	1	1	1	5
3	Construction Time	0	0		1	0	0	1
4	Material Weight	1	0	0		1	0	2
5	Maintenance Cost	1	1	0	1		0	3
6	Salvage Value	0	1	0	0	1		2

Source: Processed data

Table12 - Final Weight Summary

No	Criterion	Total Influence	Rank	Weight	Weight (%)
1	Life Cycle Cost	5	1	0.28	27.78%
2	Initial Cost	5	1	0.28	27.78%
3	Construction Time	1	6	0.06	5.56%
4	Material Weight	2	4	0.11	11.11%
5	Maintenance Cost	3	3	0.17	16.67%
6	Salvage Value	2	4	0.11	11.11%

Source: Processed data

From the above, both LCC and Initial Cost receive the highest weights, highlighting their dominant role in design selection. Maintenance Cost follows as the third most important criterion. Construction Time, while relevant, has the lowest influence in this context.

WEIGHTED SCORING EVALUATION

After determining the weights, the final step in MCA is to calculate the weighted scores by multiplying each criterion's score by its respective weight.

Table 13 - Weighted Multi-Criteria Evaluation

No	Criterion	Weight	Original Design	Score × Weight	Castellated Beam	Score × Weight
1	Life Cycle Cost	0.28	2	0.56	4	1.11
2	Initial Cost	0.28	2	0.56	4	1.11
3	Construction Time	0.06	2	0.11	4	0.22
4	Material Weight	0.11	2	0.22	4	0.44
5	Maintenance Cost	0.17	2	0.33	4	0.67
6	Salvage Value	0.11	4	0.44	2	0.22
	Total	**1.00**		**2.22**		**3.78**

Source: Processed data

The results show that the castellated beam design significantly outperforms the original design, scoring 3.78 compared to 2.22. This demonstrates its overall superiority in long-term cost efficiency, structural weight reduction, construction time, and maintenance savings. While the original design offers a higher salvage value, this is not enough to offset the multiple benefits provided by the castellated beam. Therefore, the castellated beam is considered the more efficient, feasible, and economical option for implementation in this project.

PRESENTATION STAGE

The presentation stage is the final step in the Value Engineering (VE) process. Its purpose is to communicate all findings and recommendations to decision-makers such as project managers, owners, or design teams in a clear and data-driven manner. This includes technical, functional, and economic evaluations, supported by Building Information Modeling (BIM). Summary of Findings:

1. VE Focus: The VE study focused on the steel rafter structure, originally designed using a Double T and Double L profile combination. A new alternative, the *Castellated Beam*, was proposed. This beam has openings in its web, reducing material usage while maintaining strength.
2. Multi-Criteria Analysis (MCA): Using six evaluation criteria life cycle cost, initial cost, construction time, material weight, maintenance cost, and salvage value the Castellated Beam scored 3.78, outperforming the original design which scored 2.22.
3. BIM-Based Material Quantification: BIM analysis showed that the original design used 103,837 kg of steel, while the Castellated Beam used only 39,269 kg a reduction of 64,568 kg. This decreases structural load and cost.
4. Initial Cost Savings: The new design reduced construction cost by Rp1.68 billion, or 53.69% compared to the original rafter structure. This also represents a 3.00% saving from the total project cost of Rp56.31 billion.
5. Life Cycle Cost (LCC): Over a 50-year lifespan, the Castellated Beam had a total LCC of Rp2.12 billion, compared to Rp4.25 billion for the original saving around Rp2.13 billion (50.07%).

6. Maintenance Cost Efficiency: The present value of 40-year maintenance was Rp631 million for the Castellated Beam, compared to Rp1.01 billion for the original. The beam's open geometry reduces painting surface and eases maintenance access.
7. Salvage Value: Although the salvage value at year 50 is lower (Rp34 million vs. Rp90 million), this does not offset the significant cost savings achieved earlier.

Based on all technical and economic analyses, the Castellated Beam is recommended as the best alternative because it:

- Supports structural loads efficiently.
- Significantly reduces weight and cost.
- Facilitates easier MEP system integration.
- Reduces maintenance needs.
- Aligns with the VE principle of achieving the *best value* by balancing performance, function, and cost.

RECOMMENDATION STAGE

Based on the results of VE evaluation and BIM simulation, the use of Castellated Beams is recommended for the steel rafter component of this factory construction project. This alternative provides clear advantages in terms of reduced weight, lower initial cost, and lower life cycle cost (LCC), while maintaining the same level of function and performance. Key benefits include:

- Steel weight reduction of 64,568 kg.
- Initial cost saving of up to Rp1.68 billion (53.69%).
- Life cycle cost saving of Rp2.12 billion (50.07%) over 50 years.

With both technical and economic benefits, Castellated Beams are highly recommended for this project and should be considered for similar future projects as part of a value-optimized design strategy using VE and BIM.

CONCLUSION

This study has demonstrated the effective application of Value Engineering (VE) integrated with Building Information Modeling (BIM) in optimizing structural elements within a construction project. Using the case of a factory development project in Cikarang, West Java, the VE process focused on evaluating and improving the rafter steel structure, originally designed using a combination of Double T and Double L profiles. Through functional analysis, brainstorming, and detailed evaluation, the Castellated Beam was identified as a viable and superior alternative. The comparison based on technical, functional, and economic criteria led to the following key conclusions:

- Material efficiency: The Castellated Beam design reduced the steel volume from 103,837 kg to 39,269 kg, achieving a structural weight reduction of 64,568 kg (over 62%).
- Cost savings: The initial construction cost for the rafter structure was reduced by IDR 1.68 billion (53.69%). Additionally, the Life Cycle Cost (LCC) analysis showed a potential savings of IDR 2.12 billion (50.07%) over a 50-year service life.
- Maintenance efficiency: The unique geometry of the Castellated Beam led to a lower surface area for painting and facilitated easier access for maintenance, reducing the present value of maintenance costs significantly.
- Multi-Criteria Analysis (MCA) results reinforced the superiority of the alternative design, with a total score of 3.78 versus 2.22 for the initial design.
- BIM quantification supported accurate, data-driven comparison of material volume and cost parameters.

Overall, the Castellated Beam design met the core principles of Value Engineering achieving best value through a balance of performance, function, and cost. The integration of BIM played a vital role in enhancing accuracy, visualization, and decision-making throughout the process.

LIMITATION & FURTHER RESEARCH

This study is limited to the evaluation of a single structural component (rafter) in one industrial building project using Value Engineering (VE) and Building Information Modeling (BIM). The analysis does not include other structural or architectural elements, and the life cycle cost (LCC) estimation is based on general assumptions without considering dynamic economic variables. Furthermore, the BIM application was limited to quantity take-off and visualization, without full integration of advanced BIM features such as 4D (time). Future research should expand the scope to other building elements, include multiple case studies for broader applicability, integrate environmental impact assessments through Life Cycle Assessment (LCA), and apply more comprehensive BIM functionalities to maximize value optimization.

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