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Research Paper

The Influence of LCA on Supperstructure Selection Decision-Making in Sustainable Value Engineering: A Case of a Three-Story Urban Village Office

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ABSTRACT : *This study investigates the application of Value Engineering (VE) to the upper structural system of the three-story Cipayung Jaya Urban Village Office Building, emphasizing the evaluation of material alternatives through both economic and environmental perspectives. The material screening process incorporated green material criteria in accordance with the Ministry of Public Works and Housing Regulation No. 21/2021 on Green Building Performance Assessment[1]. Based on research [2], "The global carbon emissions reached 36.8 billion tonnes in 2023, with cement production accounting for about 7–8% of this total." Therefore, this study aims to identify material alternatives capable of achieving lower emissions while maintaining efficiency relative to the existing structural material. Selected alternatives were subsequently examined using Life Cycle Cost Analysis (LCCA) and compared with initial-stage Life Cycle Assessment (LCA) results covering stages A1–A4, including transportation to the project site. Consequently, this approach is expected to yield alternatives that provide both economic efficiency and enhanced environmental sustainability.*

KEYWORDS: *Value Engineering, Life Cycle Assessment (LCA), Sustaianable material selection, Urban Village Office Building*

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I. INTRODUCTION

The development of sub-district government office buildings constitutes a critical component of public infrastructure, serving as the primary interface for administrative services and community grievance management. As public facilities, these structures are required to meet stringent engineering standards, ensure long-term structural reliability, and maintain consistent operational performance. However, technical planning in regional government projects is frequently constrained by limited budget allocations, resulting in preliminary design documents that emphasize compliance with baseline specifications while lacking a rigorous assessment of life-cycle economic performance. Such conditions often lead to the inclusion of high-cost structural elements whose functional contribution is not commensurate with their long-term economic impact.

To establish a cost structure that remains rational without compromising structural integrity, safety, or architectural quality, the systematic application of Value Engineering (VE) is essential. The optimization framework adopted in this study is further aligned with sustainable construction principles through adherence to the Green Building Criteria (BGH) stipulated in the Ministry of Public Works and Housing Regulation No. 21/2021. In addition to Life Cycle Cost Analysis (LCCA), Life Cycle Assessment (LCA) is incorporated as an environmental performance benchmark to compare embodied emissions across alternative material configurations. In this study, the LCA boundary is limited to stages A1–A4, providing an initial environmental screening based solely on planning-phase data and enabling early identification of material combinations with lower embodied carbon in support of green building compliance. Through this integrated VE–LCCA–LCA approach, the research aims to formulate upper-structure design alternatives that are technically robust, economically efficient across the building's life cycle, and environmentally responsible

II. RESEARCH MTHODOLOGY

The analysis workflow follows the Value Engineering (VE) plan standardized by SAVE International[3], adapted to the context of structural optimization for public building design. The VE process is structured into six stages—Information, Function Analysis, Creative, Evaluation, Development, and Recommendation—with the addition of Life Cycle Assessment (LCA) to align with green building standards. The Stages of research proceses described as follows:

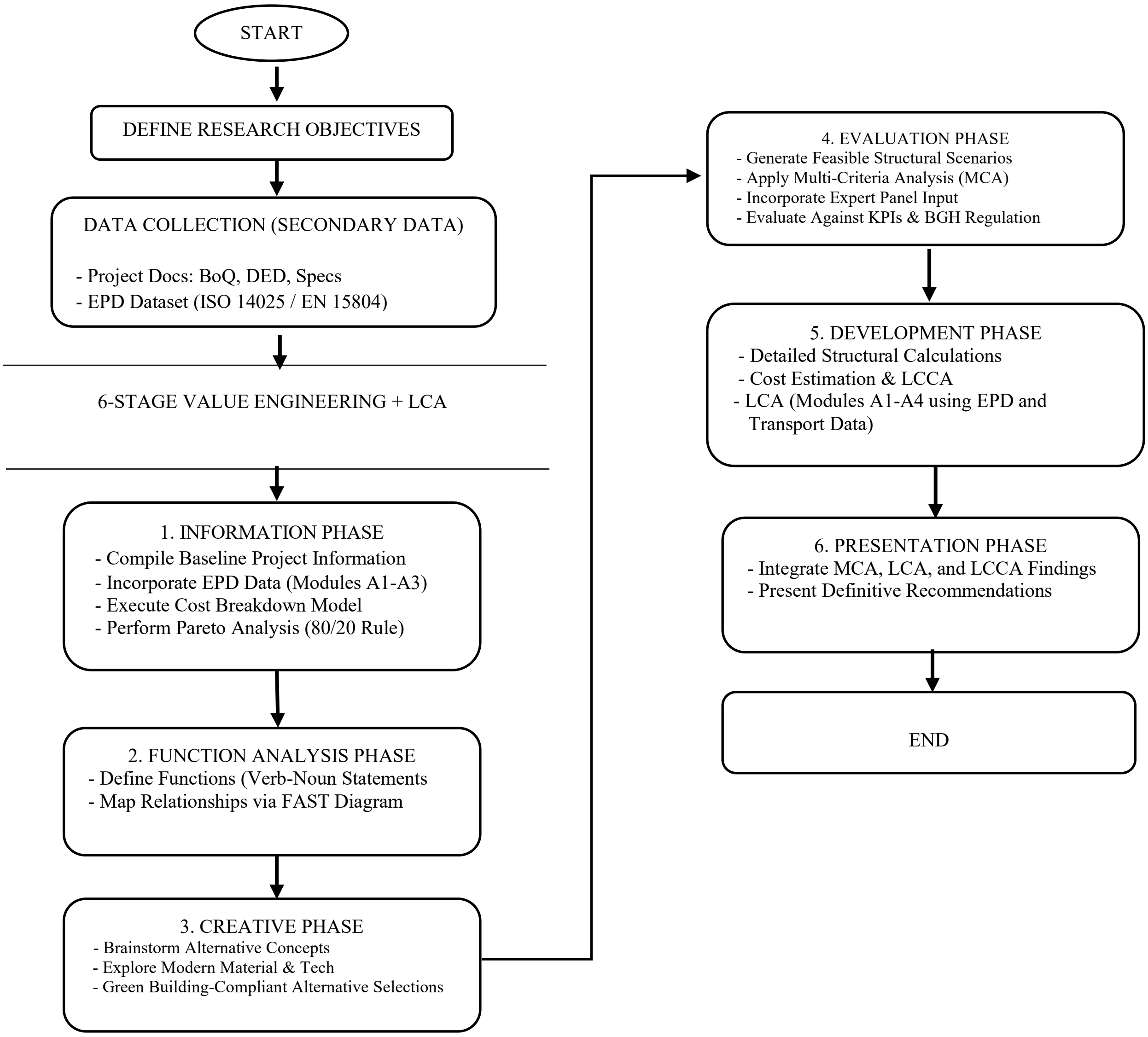

Figure 1: Reasearh Flow
Source : Processed Result, 2026

1. **Information Phase**
   Baseline project information is compiled from secondary documents, including the Bill of Quantities (BoQ), Detailed Engineering Design (DED) drawings, and material technical specifications. In addition, Environmental Product Declarations (EPD) for each structural material are incorporated as part of the secondary dataset to support Life Cycle Assessment (LCA) modules A1–A3. The EPDs provide verified, product-specific environmental performance data compliant with ISO 14025[4] and EN 15804[5], ensuring accuracy in embodied-carbon calculations. Cost structuring is then performed using a Breakdown Cost Model, followed by Pareto Analysis to identify upper-structure components with the highest cost contribution.

2. **Fuction Analysis Phase**
Functional requirements of selected components are defined using verb–noun function statements. Logical relationships among functions are mapped using the Function Analysis System Technique (FAST) diagram to establish functional hierarchy and causal linkage.

3. **Creative Phase**
Alternative concepts for upper-structure redesign—columns, beams, and slabs—are generated by exploring modern material technologies and sustainable construction methods. This phase aims to produce a broad range of feasible structural scenarios.

4. **Evluation Phase**
The alternative ideas generated during the creative phase undergo a rigorous screening and ranking process utilizing a Multi-Criteria Analysis (MCA) framework. To ensure objective decision-making, qualitative weighting and scoring within the MCA matrix are derived from structured interviews and questionnaires distributed to an expert panel consisting of a Structural Engineer, an Architectural Expert, and a Construction Management Academic. Each proposed scenario is evaluated against key performance indicators, including structural reliability, constructability, construction duration, initial cost efficiency, and compliance with Green Building (Bangunan Gedung Hijau - BGH) indicators under Minister of PUPR Regulation No. 21/2021.[1] This systematic evaluation filters out unfeasible options and isolates the highest-performing structural scenarios for deeper developmen.

5. **Development Phase**
Selected alternatives undergo detailed structural calculations, initial cost estimation, and long-term feasibility assessment through Life Cycle Cost Analysis (LCCA). Life Cycle Assessment (LCA) is incorporated at this stage, limited to modules A1–A4, A1–A3 use EPD-based embodied-carbon data, A4 is calculated using project-specific transport parameters (distance, vehicle type, fuel consumption).

6. **Presentation Phase**
In this final phase of the job plan, the formal Value Engineering proposals, accompanied by the comprehensive findings of the multi-criteria selection and environmental life cycle analysis, are systematically structured. Crucially, this phase presents the definitive engineering and management recommendations derived from the selected optimal alternative structural scenario. The final presentation delivers a clear, data-driven rationale to project owners, governmental stakeholders, and decision-makers, validating how the recommended alternative successfully minimizes life-cycle costs and environmental impacts while fully preserving structural integrity and functional requirements

III. RESULT AND DISCUSSION

1. **Information Phase, Gathering information and preliminary data**

(a). Cost breakdown

Cost breakdown is an analytical approach that organizes the total cost into a more structured and transparent form to reveal how the overall value is constructed. This approach is used to enhance clarity in cost composition, identify the most influential elements, and provide a foundation for efficiency analysis and data-driven decision-making

Table 1: Cost Breakdown

NO	URAIAN PEKERJAAN	TOTAL	
A	CONCRETE AND STRUCTURAL WORKS	Rp.	2,786,588,671.64
B	ARCHITECTURAL WORKS	Rp.	2,741,120,926.82
C	MEP WORKS	Rp.	698,843,242.19
D	PARKING AREA, LANDSCAPE AND FENCE WORKS	Rp.	504,738,694.79
E	EARTHWORKS	Rp.	182,635,086.60
F	HSE COST IMPLEMENTATION	Rp.	44,171,125.00
H	PRELIMINARI WORKS	Rp.	41,902,273.60
	TOTAL	**Rp.**	**7,000,000,020.64**

Source : Project Planning Document, 2025 (b). Pareto Alaysis (Level 1)

Pareto Level 1 is an analytical approach that ranks cost components based on their contribution to the total, allowing the most dominant elements to be identified as primary priorities for efficiency evaluation and data-driven decision-making. This approach follows the Pareto Principle, which states that a large portion of the overall impact typically arises from a small number of highly influential factors (commonly expressed as the 80/20 rule)

Table 2: Cost Breakdown (level 1)

URAIAN PEKERJAAN	TOTAL BIAYA (Rp)	PERSENTASE BOBOT %	PERSENTASE KUMULATIF BOBOT %
CONCRETE AND STRUCTURAL WORKS	2,786,588,671.64	39.81%	39.81%
ARCHITECTURAL WORKS	2,741,120,926.82	39.16%	78.97%
MEP WORKS	698,843,242.19	9.98%	88.95%
PARKING AREA, LANDSCAPE AND FENCE WORKS	504,738,694.79	7.21%	96.16%
EARTHWORKS	182,635,086.60	2.61%	98.77%
HSE COST IMPLEMENTATION	44,171,125.00	0.63%	99.40%
PRELIMINARI WORKS	41,902,273.60	0.60%	100.00%
TOTAL	**7,000,000,020.64**	**100.00%**	

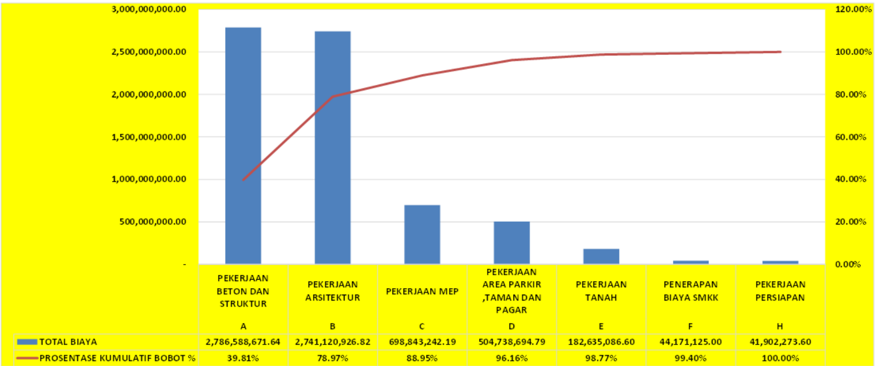

Figure 2: Pareto (Level 1) Chart

Based on the results obtained from the cost breakdown, Pareto Level 1 indicates that the Concrete and Structural Works category contributes 39.81% of the total cost, making it the most dominant component and the key focus area for optimization efforts

(c). Pareto Alaysis (Level 2)

Pareto Level 2 is the continuation of the Pareto analysis that examines the next cost components after the most dominant category identified in Level 1. While Level 1 highlights the single largest contributor, Level 2 expands the focus by incorporating additional cost categories that collectively represent a substantial portion of the total expenditure. This stage provides a broader understanding of cost concentration and helps identify secondary priority areas for efficiency improvement and optimization

Table 3: Cost Breakdown (level 2)

WORK DESCRIPTION	TOTAL COST (Rp)	COST PERCENTAGE %	CUMULATIVE COST PERCENTAGE %
UPPER STRUCTURE	1,854,558,098.65	66.56%	66.56%
SUBSTRUCTURE	572,485,143.85	20.54%	87.10%
NON STRUCTURAL CONCRETE	359,545,429.14	12.90%	100.00%
TOTAL	2,786,588,671.64	100.00%	

Figure 3: Pareto (Level 2) Chart

Based on the results obtained from the cost breakdown, Pareto Level 2 includes the major cost categories following Concrete and Structural Works, allowing the analysis to capture a more comprehensive share of the total cost and strengthen decision-making strategies beyond the primary contributor. At this stage, the analysis shows that upper structural works account for 66.36%, making it the next significant component that requires attention in cost optimization efforts.

(d). Pareto Alaysis (Level 3)

Pareto Level 3 is the subsequent stage of the Pareto analysis that examines sub-components in greater detail within the major cost category identified in Level 2. After determining that upper structural works are the dominant contributor, Level 3 breaks this category down into more specific structural elements to identify which components contribute the most to the total structural cost. This level of analysis provides a deeper understanding of cost concentration and supports more targeted optimization strategies at the component level

Table 4: Cost Breakdown (level 3)

URAIAN PEKERJAAN	TOTAL BIAYA	PROSENTASE BOBOT %	PROSENTASE KUMULATIF BOBOT %
Kolom	680,218,248.88	36.68%	36.68%
Balok	598,571,253.88	32.27%	68.95%
Plat beton Lantai	575,768,595.89	31.05%	100.00%
TOTAL BIAYA	1,854,558,098.65	100.00%	

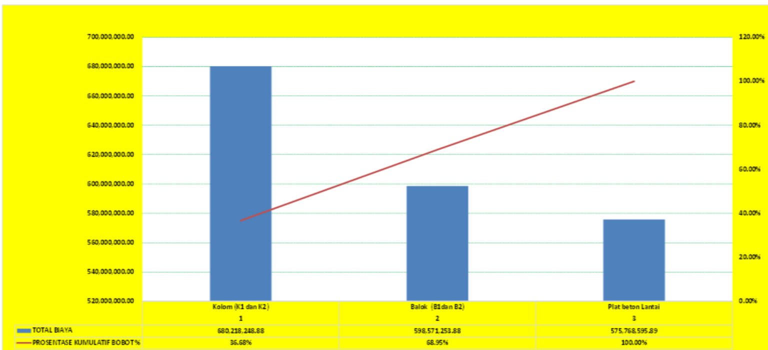

Figure 4: Pareto (Level 3) Chart

Based on the cost breakdown, Pareto Level 3 shows that the upper structural cost is distributed across three main concrete elements: concrete columns (36.68%), concrete beams (32.27%), and concrete slabs (31.05%). These proportions indicate that the upper structural cost is relatively evenly spread across the three components, with concrete columns contributing the largest share. This finding highlights that all upper structural elements require efforts to improve efficiency and strengthen cost control, as each contributes significantly to the total structural cost.

2. Funtion Analysis Phase

Prior to developing the FAST diagram, a structured function identification process was carried out for each structural element—columns, beams, and slabs. All functions were formulated using verb–noun pairs to ensure terminological consistency and analytical clarity. The resulting functions, such as Support Load, Transfer Load, Maintain Stability for columns; Resist Bending, Connect Columns, Limit Deflection for beams; and Accommodate Load, Distribute Force, Act Diaphragm for slabs, were then systematically classified into primary, secondary, supporting, and causative categorie.

Table 5: Functions Identification

Item	Primary Function	Secondary Function	Supporting Function	Causative Function	Design Objective Function	Long-Term Function
Column Element	Support Load	Transfer Load	Maintain Stability	Receive Reaction	Prevent Collapse	Maintain Integrity
Beam Element	Resist Bending	Connect Columns	Limit Deflection	Receive Load	Ensure Rigidity	Maintain Continuity
Slab Element	Accommodate Load	Distribute Force	Divide Space	Receive Activity	Act Diaphragm	Provide Area

This classification provides a functional hierarchy that reflects the operational role of each element within the structural system. It also establishes the foundation for constructing the FAST diagram, where the HOW–WHY logic is used to map functional relationships—showing how each function is performed and why each function is required. The structured function analysis ensures that subsequent value analysis and alternative development remain focused on preserving essential functions while identifying opportunities for performance improvement and cost optimization.

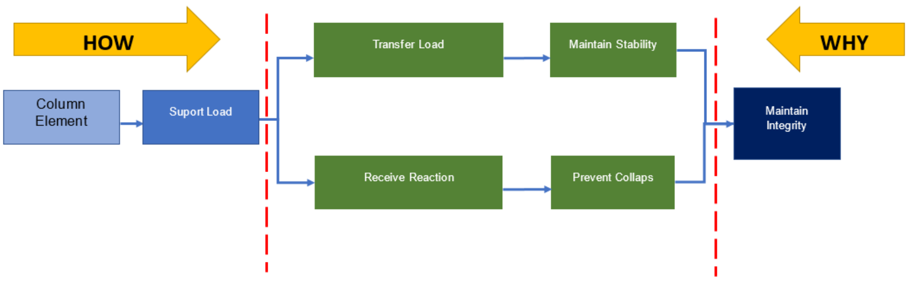

Figure 5: Fast Diagram (column element)

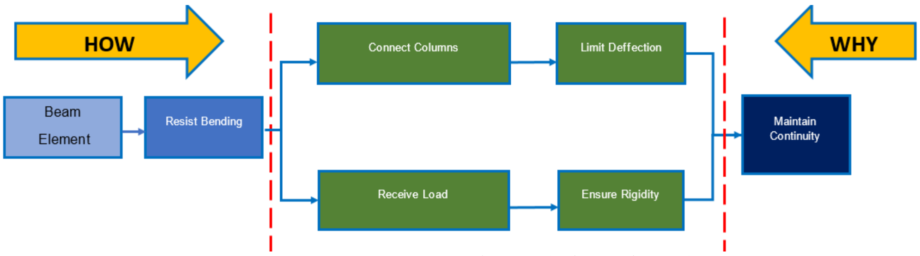

Figure 6: Fast Diagram (column element)

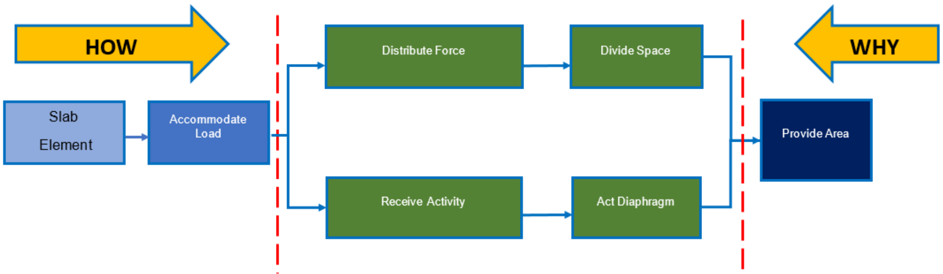

Figure 7: Fast Diagram (column element)

3. Creative Phase Phase

The creative phase in Value Engineering (VE) represents a systematic effort to formulate alternative solutions that may enhance the overall value of a project while preserving functional performance, quality standards, and safety requirements. In the Cipayung Jaya Sub-District Office development, this phase concentrates on upper structural optimization through the exploration of substitute building materials. The evaluation of alternatives incorporates both economic considerations and environmental performance, aligned with the Ministry of Public Works Regulation No. 21/2021 [1] on Green Building criteria, ensuring compliance with at least one aspect of :

Table 6: Green Building criteria

Number	Green Building Criterion	Description
1	Site Management	Management of the project site to minimize environmental disturbance, including erosion and sediment control, vehicle access regulation, vegetation protection, and proper organization of construction areas to avoid negative impacts on the local ecosystem.
2	Energy Efficiency (Electricity and Lighting)	Reduction of energy consumption through passive design strategies, use of energy-efficient equipment, optimization of natural lighting, and implementation of high-performance mechanical and electrical systems to lower electricity demand throughout the building's life cycle.
3	Water Efficiency	Efficient use of water through low-flow fixtures, rainwater harvesting, greywater recycling, and leakage control to reduce total potable water consumption and support long-term water resource conservation.
4	Indoor Air Quality	Control of indoor air conditions through adequate ventilation, air filtration, pollutant reduction (VOC, dust, humidity), and selection of interior materials with low emissions to ensure occupant health and comfort.
5	Environmentally Responsible Materials	Use of environmentally friendly materials with low carbon footprint, high recyclability, long life cycle, local availability, or sustainable sourcing to reduce environmental impacts during construction and operation.
6	Waste Management (Construction Waste)	Management of construction waste through reduction, sorting, recycling, and adoption of low-waste construction methods (such as prefabrication), thereby minimizing environmental burden and improving resource efficiency.

Based on the brainstorming process, several alternative options were formulated, each satisfying at least one of the Green Building criteria presented in Table 6: Green Building Criteria :

Table 6: Coloumn Alternative

Number	Alternative Material Options	Green Building Criteria Compliance (Ministry of Public Works Regulation No. 21/2021)
1	Green Concrete (Fly Ash / GGBS 30-50%)	Highly compliant with Point 5 (Eco-Friendly Material) as it utilizes cement substitute industrial waste (Fly Ash/GGBS) to reduce the embodied carbon of concrete by up to 30-50%. It meets the material life cycle criteria that support a circular economy.
2	Precast Column	Meets the construction waste reduction criteria significantly through a controlled factory prefabrication system (zero site-waste). The proximity of the fabrication plant location in the Jabodetabek industrial corridor to the project site minimizes CO2 emissions from the logistics transportation sector.
3	Composite Structure (Steel Pipe/Box Filled)	Meets Point 5 (Construction Waste Management) because the steel pipe functions directly as permanent formwork, thereby eliminating 100% of the supporting timber/plywood waste at the project site. Additionally, shipping empty steel pipes from the fabrication plant to the project site is highly efficient logistically, minimizing the transportation carbon footprint compared to shipping heavy precast concrete.
4	High-Strength Concrete (HSC) Non-OPC Cement	Supports a massive reduction in global carbon emissions through the use of eco-friendly cement (Non-OPC such as PPC or geopolymer-based cement). Meets the material resource efficiency principles of green buildings.
5	Structural Steel Profile (H-Beam / IWF)	Highly compliant with the material circularity principles of green buildings because steel material has a recyclability rate of up to 100% after the building's lifespan ends. This dry construction method eliminates the use of construction water (zero water waste) during installation. The dry connection system (bolts/welding) completely eliminates the use of construction water on site.

Table 7: Beams Alternative

Number	Alternative Material Options	Green Building Criteria Compliance (Ministry of Public Works Regulation No. 21/2021
1	Balok Pracetak / Prestressed Precast Beam	Meets Point 5 (Eco-Friendly Material) through the optimization of material volume. The use of a prestressed system is capable of significantly reducing the required volume of concrete and reinforcement steel. Factory fabrication ensures compliance with the zero-site waste criteria (free from field formwork waste).
2	Balok Pracetak Konvensional	Meets good construction waste management indicators because it is cast modularly in a factory using reusable steel moulds, thereby completely eliminating residual timber/plywood waste at the project site. The close fabrication range to the work area contributes to reducing logistics carbon emissions.
3	Baja Profil Struktural (H-Beam / IWF)	Highly compliant with the material circularity principles of green buildings because steel material has a recyclability rate of up to 100% after the building's lifespan ends. This dry construction method eliminates the use of construction water (zero water waste) during installation. The dry connection system (bolts/welding) completely eliminates the use of construction water on site.
4	Balok Komposit Castellated Beam	Meets Point 5 (Material Resource Efficiency) through a standard steel profile modification method that is split and re-welded to form hexagonal holes/cavities. It optimizes material usage without leaving residual metal waste (low manufacturing waste).

Table 7: Slabs Alternative

Number	Alternative Material Options	Green Building Criteria Compliance (Ministry of Public Works Regulation No. 21/2021
1	Panel Lantai AAC (Autoclaved Aerated Concrete)	Fully satisfies Point 2 (Energy Efficiency) because the micro air pore structure in AAC lightweight concrete acts as a natural thermal insulator that effectively reduces heat transfer between floors (lowering AC operational load). Its dry installation method eliminates residual timber formwork waste (zero site-waste).
2	Precast Hollow Core Slab (HCS)	Satisfies Point 5 (Eco-Friendly Material) through massive savings in raw cement volume thanks to the longitudinal cavities inside the slab panel. It is industrially produced in a factory, thereby ensuring the absence of residual material waste (zero-waste fabrication) at the project site.
3	Sistem Steel Decking (Bondek Composite)	Satisfies the eco-friendly material management criteria through the utilization of corrugated galvanized steel sheets that serve a dual function as permanent formwork. This system massively reduces the use of timber/plywood materials, thereby lowering the volume of residual construction waste at the project site.
4	Pelat Pracetak Setengah (Half Slab Precast)	Satisfies the construction waste management indicators because the bottom part of the slab is already cast in the factory using reusable steel moulds. This method cuts more than 50% of timber/plywood formwork usage in the field compared to the fully conventional concrete method.

4. **Evaluaton Phase**

At this phase, unrealistic creative ideas that are not feasible for further analysis will be eliminated. The object of this study is a three-story public building (low-rise) located in Depok City. Therefore, an initial evaluation of the structure is conducted based on four basic criteria:

a) Functional suitability for a 3-story sub-district office (public) building
b) Green Building (BGH) criteria
c) Market availability
d) Estimated location and distance from the fabrication site to the project site

Table 8: Feasible Alternatives for Column Materials

No.	Alternative Material	Functional & Cost Suitability (3 Floors)	Green Building (BGH) Criteria Points	Market Availability in Indonesia	Estimated Location & Fabrication Distance to Depok	Next VE Stage Recommendation
1	Green Concrete (Fly Ash 30-50%)	**Highly Suitable** (Normal concrete strength of K-250 to K-350 is appropriate for 3 floors).	**Very High** (Carbon footprint reduction & waste utilization).	**Very High** (Can be produced by local Ready-Mix suppliers).	Nearest Batching Plant (Depok/Cibinong) ± 15 - 25 Km.	**PASSED** (Top Priority for Baseline).
2	Precast Column	**Conditionally Suitable** (Economical if the building design is typical/uniform).	**High** (Zero site-waste, minimal timber scaffolding).	**High** (Many large precast manufacturers).	Precast Factory in Sentul / Klapanunggal Bogor ± 35 - 50 Km.	**PASSED** (Time efficiency option).
3	Composite Structure (Steel Pipe Filled)	**Unsuitable** (Overkill / too expensive for 3-story loads).	**Moderate** (Steel is recyclable but has high embodied energy).	**High** (Abundant steel fabrication & cement).	Steel Fabricator in Jakarta / Bekasi ± 30 - 45 Km.	**ELIMINATED** (Uneconomical).
4	High-Strength Concrete Non-OPC	**Unsuitable** (Overkill).	**High** (Uses eco-friendly cement).	**Moderate** (Requires special ordering / custom mix).	Large Batching Plant in Jakarta/Bogor ± 25 - 40 Km.	**ELIMINATED** (Uneconomical).
5	Structural Steel Profile (H-Beam/IWF)	**Conditionally Suitable** (Drastically reduces total dead load, but material cost is high).	**Moderate** (Material is 100% recyclable at the end of its life cycle, dry construction system).	**Very High** (Extremely abundant steel profile distributors and stockists).	Main Warehouse / Fabricator in Jakarta / Cikarang: ± 40 - 60 Km.	**PASSED** (Comparison option for lightweight & fast structure).

Table 9: Feasible Alternatives for Beams Materials

No.	Alternative Material	Functional & Cost Suitability (3 Floors)	Green Building (BGH) Criteria Points	Market Availability in Indonesia	Estimated Location & Fabrication Distance to Depok	Next VE Stage Recommendation
1	Prestressed Precast Beam	**Unsuitable** (Only economical for wide-span rooms > 8m).	**High** (High accuracy, guaranteed quality, minimal waste).	**High** (Produced by Wika, Waskita, Adhi Precast, etc.).	Precast Factory in Karawang / Bogor: ± 45 - 75 Km.	**ELIMINATED** (Except if there is a wide-span hall/auditorium space).
2	Conventional Precast Beam	**Suitable** (Easily combined with the column system).	**High** (Significantly reduces timber formwork waste).	**Very High** (Can be precast onsite or ordered via fabrication).	Precast Factory in Bogor / Bekasi: ± 35 - 50 Km.	**PASSED** (Ideal prefabrication option).
3	Structural Steel Profile (H-Beam/IWF)	**Conditionally Suitable** (Lightweight structure, but prices are volatile).	**Moderate** (Recyclable, but high carbon footprint during production).	**Very High** (Extremely abundant steel distributors).	Main Warehouse / Fabricator in Jakarta/Cikarang: ± 40 - 60 Km.	**PASSED** (As a comparison for schedule speed).
4	Composite Castellated Beam	**Unsuitable** (High welding fabrication cost, not proportional to 3-story loads).	**Moderate** (Weight efficiency of steel material).	**Moderate** (Must be custom fabricated in a steel workshop).	Fabrication Workshop in Bekasi / Tangerang: ± 45 - 60 Km.	**ELIMINATED** (Cost is too high).

Table 10: Feasible Alternatives for Slabs Materials

No.	Alternative Material	Functional & Cost Suitability (3 Floors)	Green Building (BGH) Criteria Points	Market Availability in Indonesia	Estimated Location & Fabrication Distance to Depok	Next VE Stage Recommendation
1	AAC Floor Panel	**Highly Suitable** (Lightweight, reduces dead load).	**Very High** (Thermal insulation).	**Very High** (Citicon brand, etc.).	Main Distributor / Factory in Serang / Karawang to Depok.	**PASSED** (Top Priority for Savings).
2	Precast Hollow Core Slab (HCS)	**Conditionally Suitable** (Requires a large crane, economical if the floor area is large).	**High** (Reduces concrete volume due to cavities).	**Moderate to High** (Only produced by specific precast manufacturers).	Precast Factory in Karawang / Cikarang: ± 55 - 75 Km.	**CONDITIONALLY PASSED** (Depending on the project site road access in Depok).
3	Steel Decking (Bondek Composite)	**Highly Suitable** (Work method is highly popular and fast).	**Moderate** (Cuts timber scaffolding, but uses steel plates).	**Very High** (Available in all major material stores).	Local Supplier / Manufacturer around Jabodetabek: ± 10 - 30 Km.	**PASSED** (Can be used as a baseline comparison).
4	Half Slab Precast	**Highly Suitable** (Combines precast speed with cast-in-situ flexibility).	**High** (Very minimal timber formwork).	**High** (Widely provided by various precast vendors).	Precast Factory in Bogor / East Jakarta: ± 30 - 45 Km.	**PASSED** (Technical balance option)

Based on the screening matrices in Tables 8, 9, and 10, alternatives classified as ELIMINATED—due to over-specification or insufficient economic feasibility for a three-story building—are excluded from further analysis. Alternatives marked as PASSED are subsequently consolidated into several superstructure combination scenarios, each representing a distinct functional orientation:

(a). Structural Weight Efficiency & Sustainability
Scenario 1: Green Concrete + Lightweight System
Prioritizes dead-load reduction and environmental performance through the integration of green concrete and AAC floor panels.

(b). Execution Speed & Constructability
Scenario 2: Full-Precast System
Emphasizes rapid construction and standardized factory quality by adopting fully prefabricated structural components.

(c). Hybrid Structural Performance
Scenario 3: Composite System
Combines concrete column stiffness with steel profiles and steel decking to enhance installation efficiency while retaining conventional column behavior.

(d). Maximum Schedule Acceleration
Scenario 4: Steel Structure (Fast-Track)
Utilizes dry-connection steel systems to achieve the shortest construction duration, despite higher initial material costs

Table 11: Generated Feasible Structural Scenarios

Alternative Scenario	Combination Alternatives
EXISTING *(Conventional Concrete Scenario)*	**Column:** Conventional Concrete **Beam:** Conventional Concrete **Slab:** Conventional Concrete
Alternative Combination 1 *(Green Concrete & Lightweight Structure Scenario)*	**Column:** Green Concrete (Fly Ash 30-50%) using normal strength (25 - 30 MPa) **Beam:** Conventional Precast Beam **Floor Slab:** AAC Floor Panel
Alternative Combination 2 *(Total Prefabrication / Full-Precast Scenario)*	**Column:** Precast Column **Beam:** Conventional Precast Beam **Floor Slab:** Half Slab Precast
Alternative Combination 3 *(Popular Composite Structure Scenario)*	**Column:** Green Concrete (Fly Ash 30-50%) using normal strength (25 - 30 MPa) **Beam:** Structural Steel Profile (H-Beam/IWF) **Floor Slab:** Steel Decking (Bondek Composite)
Alternative Combination 4 *(Steel Structure Scenario / Fast-Track Construction)*	**Column:** Structural Steel Profile (H-Beam / IWF) **Beam:** Structural Steel Profile (H-Beam / IWF) **Floor Slab:** Steel Decking (Bondek Composite)

Multi-Criteria Analisys (MCA)

Multi-Criteria Analysis (MCA) forms a key component of the evaluation phase in Value Engineering (VE), functioning as a structured decision-making instrument for assessing and comparing multiple alternatives across diverse quantitative and qualitative criteria. Rather than relying on a single parameter such as minimum cost, MCA integrates multiple performance dimensions, including quality, construction duration, Green Building (BGH) regulatory compliance, and constructability.

Because several criteria require expert-level interpretation, the weighting process in this study employs an expert-judgment approach. Inputs from practitioners, academics, and project management professionals are incorporated to reduce subjectivity and enhance the validity of the final decision. Based on this process, the following criterion variables were established from expert assessments.

Table 12: Criteria Variables

Code	Criteria Variable	Description / Aspect
K1	Construction Cost	Financial Aspect
K2	Operational and Maintenance (O&M) Cost	Financial Aspect
K3	Salvage Value	Financial Aspect
K4	Material Reliability and Service Life	Quality Aspect

K5	Ease of Implementation and Maintenance	Technical / Managerial Aspect
K6	Compliance with Green Building Regulations (BGH)	Regulatory / Environmental Aspect
K7	Aesthetic and Architectural Value	Functional / Visual Aspect
K8	Execution Speed / Schedule	Managerial Aspect
K9	Logistics Accessibility and Material Availability	On-site Risk Aspect

Table 13: Weight assessment of parameters on Alternatives

No	Parameter	Code	K1	K2	K3	K4	K5	K6	K7	K8	K9	JLH	RANK	WEIGHT RANGKING	WEIGHT PARAMETER
1	Construction Cost	**K1**		0	1	1	1	0	1	1	1	**6**	**3**	0.80	**15%**
2	Operational and Maintenance (O&M) Cost	**K2**	1		1	1	1	1	1	1	1	**8**	**1**	1.00	**19%**
3	Salvage Value	**K3**	0	0		0	0	0	1	0	0	**1**	**8**	0.30	**5%**
4	Material Reliability and Service Life	**K4**	0	0	1		1	0	1	0	1	**4**	**5**	0.60	**11%**
5	Ease of Implementation and Maintenance	**K5**	0	0	1	0		0	1	0	1	**3**	**6**	0.50	**9%**
6	Compliance with Green Building Regulations (BGH)	**K6**	1	0	1	1	1		1	1	1	**7**	**2**	0.90	**17%**
7	Aesthetic and Architectural Value	**K7**	0	0	0	0	0	0		0	0	**0**	**9**	0.20	**4%**
8	Execution Speed / Schedule	**K8**	0	0	1	1	1	0	1		1	**5**	**4**	0.70	**13%**
9	Logistics Accessibility and Material Availability	**K9**	0	0	1	0	0	0	1	0		**2**	**7**	0.40	**7%**
	TOTAL													5.40	100%

Table 14: Average Expert Assessment

No	Parameters	Weight (%)	EXISTING		ALTERNATVE 1		ALTERNATVE 2		ALTERNATVE 3		ALTERNATVE 4	
1	Short-Term Construction Cost (Initial Cost)	15%	skor	Nilai	skor	Nilai	skor	Nilai	skor	Nilai	skor	Nilai
2	Operational and Maintenance (O&M) Cost	19%	6	0.9	9	1.35	9	1.35	9	1.35	3	0.45
3	Salvage Value	5%	6	1.14	8	1.52	6	1.14	7	1.33	3	0.57
4	Material Reliability and Service Life	11%	6	0.3	6	0.3	6	0.3	9	0.45	9	0.45
5	Ease of Implementation and Maintenance	9%	6	0.66	6	0.66	8	0.88	8	0.88	6	0.66
6	Compliance with Green Building Regulations (BGH)	17%	6	0.54	9	0.81	7	0.63	7	0.63	7	0.63
7	Aesthetic and Architectural Value	4%	6	1.02	9	1.53	7	1.19	6	1.02	4	0.68
8	Execution Speed (Schedule)	13%	6	0.24	7	0.28	9	0.36	7	0.28	7	0.28
9	Logistics Accessibility and Material Availability	7%	6	0.78	7	0.91	9	1.17	9	1.17	9	1.17
	TOTAL WEIGHT	**100%**	6	0.42	8	0.56	5	0.35	6	0.42	6	0.42
	TOTAL WEIGHTED SCORE			**6**		**7.92**		**7.37**		**7.53**		**5.31**
	RANKING		**4**		**1**		**3**		**2**		**5**	

5. Development Phase

A. Live Cycle Cost Analysis (LCCA)

Life Cycle Cost Analysis (LCCA) is an economic assessment tool within the Value Engineering (VE) framework used to determine the total ownership cost of a construction asset. In the planning of this sub-district office building, material and method selection is evaluated not only by initial construction cost but also by long-term expenses throughout the building's design life.

LCCA provides a comprehensive financial comparison of VE alternatives by accounting for all cost components over time, ensuring that recommended options deliver optimal efficiency and align with sustainable (green building) principles.
The cost components analyzed in the LCCA model include:
a. **Initial/Capital Cost** – material procurement, labor, and installation.
b. **Operation & Maintenance Cost** – periodic upkeep during the building's service life.
c. **Salvage/Residual Value** – remaining economic value at the end of the design life.
All future costs are converted into **Present Value** using time-value-of-money factors based on the applicable interest rate.

Table 15: Existing Upper Structure LCCA

NO	WORK DESCRIPTION	YEAR	PRICE IN YEAR-X	Material Price Escalation Indexi=3.88%	PRICE ESCALATION IN YEAR X	Interest Rate + Inflationi=8.63%		TOTAL PRICE
				(F/P, i, n)		(P/F, i, n)	(P/A, i, n)	
a	b	c	d	e	f = d X e	g	h	I = (f X g/h)
1	**CONSTRUCTION COST**	0	**Rp1,854,558,098.65**			**1.0000**		**1,854,558,098.65**
	Column		Rp680,218,248.89			1.0000		680,218,248.89
	Beam		Rp598,571,253.87			1.0000		598,571,253.87
	Slab		Rp575,768,595.89			1.0000		575,768,595.89
2	**MAINTENANCE COST**							-
	no maintenance cost							-
3	**MATERIAL REPLACEMENT COST**							-
	no replacement cost							-
4	**SALVAGE VALUE COST**							-
	no residual value							-
5						**TOTAL COST**		**1,854,558,098.65**

Table 16: Alternative 1 Upper Structure LCCA

NO	WORK DESCRIPTION	YEAR	PRICE IN YEAR-X	Material Price Escalation Indexi=3.88%	PRICE ESCALATION IN YEAR X	Interest Rate + Inflationi=8.63%		TOTAL PRICE
				(F/P, i, n)		(P/F, i, n)	(P/A, i, n)	
a	b	c	d	e	f = d X e	g	h	I = (f X g/h)
1	**CONSTRUCTION COST**	0	**Rp1,408,804,487.52**			**1.0000**		**1,408,804,487.52**
	Green concrete column		Rp674,390,466.93			1.0000		674,390,466.93
	Precast beam		Rp482,434,887.34			1.0000		482,434,887.34
	AAC floor slab		Rp251,979,133.25			1.0000		251,979,133.25
2	**MAINTENANCE COST**							-
	no maintenance cost							-
3	**MATERIAL REPLACEMENT COST**							-
	no maintenance cost (sesuai gambar asli)							-
4	**SALVAGE VALUE (SV) COST**							**-795,568.33**
	Precast beam SV	50	-Rp40,703,813.73			0.0159		-647,190.64
	AAC floor slab SV	50	-Rp9,331,930.00			0.0159		-148,377.69
6						**TOTAL COST**		**1,408,008,919.19**
7						**TOTAL EXISTING LCCA COST**		**1,854,558,098.65**
8						**EFFICIENCY**		**446,549,179.46**
9						**EFFICIENCY PERCENTAGE**		**24.08%**

Table 16: Alternative 2 Upper Structure LCCA

NO	WORK DESCRIPTION	YEAR	PRICE IN YEAR-X	Material Price Escalation Indexi=3.88%	PRICE ESCALATION IN YEAR X	Interest Rate + Inflationi=8.63%		TOTAL PRICE
				(F/P, i, n)		(P/F, i, n)	(P/A, i, n)	
a	b	c	d	e	f = d X e	g	h	I = (f X g/h)
1	**CONSTRUCTION COST**	**0**	**Rp1,344,496,572.56**			**1.0000**		**1,344,496,572.56**
	Column: Precast Column		Rp489,542,027.21			1.0000		489,542,027.21
	Beam: Conventional Precast Beam		Rp482,434,887.34			1.0000		482,434,887.34
	Floor Slab: Precast Half Slab		Rp372,519,658.01			1.0000		372,519,658.01
2	**MAINTENANCE COST**							-
	no maintenance cost							-
3	**MATERIAL REPLACEMENT COST**							-
	no replacement cost							-
4	**SALVAGE VALUE (SV) COST**							**-1,367,537.84**
	Precast column SV	50	-Rp45,304,855.72			0.0159		-720,347.21
	Precast beam SV	50	-Rp40,703,813.73			0.0159		-647,190.64
5						**TOTAL COST**		**1,343,129,034.72**
6						**TOTAL EXISTING LCCA COST**		**1,854,558,098.65**
7						**SAVINGS**		**511,429,063.93**
8						**PERCENTAGE**		**27.58%**

Table 16: Alternative 3 Upper Structure LCCA

NO	WORK DESCRIPTION	YEAR	PRICE IN YEAR-X	Material Price Escalation Indexi=3.88%	PRICE ESCALATION IN YEAR X	Interest Rate + Inflationi=8.63%		TOTAL PRICE
				(F/P, i, n)		(P/F, i, n)	(P/A, i, n)	
a	b	c	d	e	f = d X e	g	h	I = (f X g/h)
1	**CONSTRUCTION COST**	**0**	**Rp1,360,960,571.33**			**1.0000**		**1,880,537,553.05**
	Column: Green Concrete (Fly Ash 30-50%)		Rp674,390,466.93			1.0000		674,390,466.93
	Beam: Structural Steel Profile (IWF)		Rp902,698,980.08			1.0000		902,698,980.08
	Floor Slab: Steel Decking (Composite Bondek)		Rp304,242,152.66			1.0000		304,242,152.66
2	**MAINTENANCE COST**							-
	no maintenance cost							-
3	**MATERIAL REPLACEMENT COST**							-
	no replacement cost							-
4	**SALVAGE VALUE (SV) COST**							
	IWF Beam SV 20% of material price	50	-Rp49,940,039.11			0.0159		-794,046.62
5						**TOTAL COST**		**1,880,537,553.05**
6						**TOTAL EXISTING LCCA COST**		**1,854,558,098.65**
7						**SAVINGS**		**(25,979,454.40)**
8						**PERCENTAGE**		**-1.401%**

B. Live Cycle Assesment (LCA) A1-A4

To generate a precise and project-specific environmental impact assessment, the Life Cycle Assessment (LCA) in this study is restricted to Modules A1–A4, applying a cradle-to-gate with options boundary. This scope focuses exclusively on embodied emissions of the proposed material alternatives prior to the building's operational phase.

The LCA relies on verified secondary data obtained from official Environmental Product Declarations (EPDs) for each material alternative. The assessed stages comprise raw material extraction, internal transport, manufacturing (A1–A3), and external transport of finished materials to the project site (A4).

By integrating EPD-based emission factors within this A1–A4 boundary, the study produces an accurate projection of environmental impacts—particularly the Global Warming Potential (GWP)—for each structural alternative under comparison

Table 17: Existing Upper Structure LCA

Material	Volume	Unit	Global Warming Potential (GWP) A1-A3			Global Warming Potential (GWP) A4				TOTAL GWP A1-A4 kg CO_2eq	Total kgCo2/Ton.KM
			GWP	Total GWP	Unit	Volume (Ton)	Unit	Assumed Site Distance (KM)	Emission Factor kgCo2/Ton.KM		
COLUMN											
Steel	17,128.77	Kg	0.392	6,714.480	kg CO_2eq	17.129	ton	130	0.309	688.06	7,402.54
Formwork 2x	699.56	M2	0.927	648.490	kg CO_2eq	2.896	ton	15	0.309	13.42	661.92
Ready-mix Concrete Fc 24 Mpa	73.06	M3	383.600	28,025.820	kg CO_2eq	168.038	ton	15	0.309	778.86	28,804.67
						-				subtotal	**36,869.13**
BEAM						-					
Steel	16,075.95	Kg	0.392	6,301.770	kg CO_2eq	16.076	ton	130	0.309	645.77	6,947.54
Formwork 2x	583.08	M2	0.927	540.520	kg CO_2eq	2.414	ton	15	0.309	11.19	551.7
Ready-mix Concrete Fc 24 Mpa	54.34	M3	383.600	20,844.820	kg CO_2eq	124.982	ton	15	0.309	579.29	21,424.12
						-				subtotal	**28,923.36**
SLAB						-					
Steel	12,006.09	Kg	0.392	4,706.390	kg CO_2eq	12.006	ton	130	0.309	482.28	5,188.67
Formwork 2x	602.06	M2	0.927	558.110	kg CO_2eq	2.493	ton	15	0.309	11.55	569.66
Ready-mix Concrete Fc 24 Mpa	77.72	M3	383.600	29,813.390	kg CO_2eq	178.756	ton	15	0.309	828.53	30,641.93
										subtotal	**36,400.26**
								TOTAL GWP FOR EXISTING CRADLE TO SITE			**102,192.75**

Table 18: Alternative 1 Upper Structure LCCA

Material	Volume	Unit	Global Warming Potential (GWP) A1-A3			Global Warming Potential (GWP) A4				TOTAL GWP A1-A4 kg CO_2eq	Total kgCo2/Ton.KM
			GWP	Total GWP	Unit	Volume (Ton)	Unit	Assumed Site Distance (KM)	Emission Factor kgCo2/Ton.KM		
COLUMN											
Steel	17,128.77	Kg	0.392	6,714.480	kg CO_2eq	17.129	ton	130	0.309	688.06	7,402.54
Formwork 2x	699.56	M2	0.927	648.490	kg CO_2eq	2.896	ton	15	0.309	13.42	661.91
Green concrete fly ash	73.06	M3	299.710	21,896.810	kg CO_2eq	168.038	ton	30	0.309	1,557.71	23,454.52
						54.340				subtotal	**31,518.97**
PRECAST BEAM						-					
Steel	16,075.95	Kg	0.392	6,301.770	kg CO_2eq	16.076	ton	100	0.309	496.75	6,798.52
Ready-mix Concrete Fc 24 Mpa	54.34	M3	383.600	20,844.820	kg CO_2eq	141.058	ton	45	0.309	1,961.41	22,806.23
						-				subtotal	**29,604.75**
SLAB						-					
AAC 10 CM	60.21	M3	249.000	14.990	kg CO_2eq	31.789	ton	45	0.309	442.02	457.01
										subtotal	**457.01**
								TOTAL GWP FOR ALTERNATIVE 1 CRADLE TO SITE			**61,580.73**

Table 19: Alternative 2 Upper Structure LCCA

Material	Volume	Unit	Global Warming Potential (GWP) A1-A3			Global Warming Potential (GWP) A4				TOTAL GWP A1-A4 kg CO_2eq	Total kgCo2/Ton.KM
			GWP	Total GWP	Unit	Volume (Ton)	Unit	Assumed Site Distance (KM)	Emission Factor kgCo2/Ton.KM		
COLUMN											
Steel	17,128.77	Kg	0.392	6,714.480	kg CO_2eq	17.129	ton	100	0.309	529.28	7,243.76
Ready-mix Concrete Fc 24 Mpa	73.06	M3	383.600	28,025.820	kg CO_2eq	185.167	ton	45	0.309	2,574.74	30,600.56
										subtotal	37,844.32
PRECAST BEAM						-					
Steel	16,075.95	Kg	0.392	6,301.770	kg CO_2eq	16.076	ton	100	0.309	496.75	6,798.52
Ready-mix Concrete Fc 24 Mpa	54.34	M3	383.600	20,844.824	kg CO_2eq	141.058	ton	45	0.309	1,961.41	22,806.23
						-				subtotal	29,604.75
SLAB											
Steel	2,528.65	Kg	0.392	991.230	kg CO_2eq	2.529	ton	100	0.309	78.14	1,069.37
Half Slab 7Cm	42.14	M3	383.600	16,164.904	kg CO_2eq	99.460	ton	45	0.309	1,383.00	17,547.90
Steel	2,528.65	Kg	0.392	991.230	kg CO_2eq	2.529	ton	177	0.309	138.3	1,129.53
Ready-mix Concrete Topping Fc 24 Mpa 5 Cm	30.1	M3	383.600	11,547.510	kg CO_2eq	69.240	ton	30	0.309	641.83	12,189.34
										subtotal	31,936.14
								TOTAL GWP FOR ALTERNATIVE 2 CRADLE TO SITE			**99,385.22**

Table 20: Alternative 3 Upper Structure LCCA

Material	Volume	Unit	Global Warming Potential (GWP) A1-A3			Global Warming Potential (GWP) A4				TOTAL GWP A1-A4 kg CO_2eq	Total kgCo2/Ton.KM
			GWP	Total GWP	Unit	Volume (Ton)	Unit	Assumed Site Distance (KM)	Emission Factor kgCo2/Ton.KM		
COLUMN											
Steel	17,128.77	Kg	0.392	6,714.480	kg CO_2eq	17.129	ton	130	0.309	688.06	7,402.54
Formwork 2x	699.56	M2	0.927	648.490	kg CO_2eq	2.896	ton	15	0.309	13.42	661.91
Green concrete fly ash	73.06	M3	299.710	21,896.810	kg CO_2eq	168.038	ton	30	0.309	1,557.71	23,454.52
						-				subtotal	31,518.97
PRECAST BEAM *(sesuai teks gambar)*						-					-
IWF STEEL	14,187.51	Kg	1.490	21,139.390	kg CO_2eq	14.188	ton	100	0.309	438.39	21,577.78
						-				subtotal	21,577.78
SLAB						-					-
Steel	2,528.65	Kg	0.392	991.230	kg CO_2eq	2.529	ton	100	0.309	78.14	1,069.37
Bondek	4,057.88	M3	1.600	6,492.608	kg CO_2eq	2.529	ton	25	0.309	19.53	6,512.14
Ready-mix Concrete Topping Fc 24 Mpa	60.21	M3	383.600	23,095.020	kg CO_2eq	138.470	ton	30	0.309	1,283.65	24,378.67
										subtotal	31,960.18
								TOTAL GWP FOR ALTERNATIVE 3 CRADLE TO SITE			**85,056.93**

6. Presentation Phase

The integration of Multi-Criteria Analysis (MCA), Life Cycle Cost Analysis (LCCA), and Life Cycle Assessment (LCA) provides a robust framework to evaluate the structural alternatives for this sub-district office building. Based on the data generated across the three evaluation lenses, the performance of each option can be analyzed as follows:

Table 20: Integrated MCA, LCCA, and LCA Summary

Parameter / Evaluation Lens	**Existing Structure**	**Alternative 1 (Green Concrete + Precast Beam + AAC)**	**Alternative 2 (Precast Column + Precast Beam + Half Slab)**	**Alternative 3 (Green Concrete + Steel WF + Bondek)**	**Alternative 4 (Low-Performing Option)**
ECONOMIC (LCCA)					
Total Life Cycle Cost	Rp1,854,558,098.65	Rp1,408,008,919.19	**Rp1,343,129,034.72**	Rp1,880,537,553.05	*Not Feasible / High Cost*
Cost Savings (Rp)	Base (0)	Rp446,549,179.46	**Rp511,429,063.93**	-Rp25,979,454.40	-
Cost Savings (%)	Base (0%)	24.08%	**27.58%**	-1.40%	-
ENVIRONMENTAL (LCA)					
Total GWP (A1–A4)	102,192.75 kg CO_2eq	**61,580.75 kg CO_2eq**	99,385.218 kg CO_2eq	85,056.9279 kg CO_2eq	*Not Calculated*
Carbon Reduction (%)	Base (0%)	**39.74%**	2.97%	16.77%	-
MULTI-CRITERIA (MCA)					
Total Weighted Score	6	**7.92**	7.37	7.53	5.31

Alternative 1 (Green Concrete + Precast Beam + AAC)

This alternative emerges as the most optimal solution, achieving the highest Total Weighted Score of 7.92 in the MCA. Economically, it delivers substantial life cycle savings of 24.08% (reducing total costs by Rp 446,549,179.46). Environmentally, it stands out as the absolute top performer, achieving a massive carbon reduction of 39.74% with a total GWP of only 61,580.75 kg CO_2eq. Its unmatched environmental efficiency and strong alignment with Green Building (BGH) regulations heavily outweigh its slightly higher cost compared to Alternative 2.

Alternative 2 (Precast Column + Precast Beam + Half Slab)

From a strictly financial perspective, Alternative 2 is the most efficient option, yielding the lowest total life cycle cost of Rp 1,343,129,034.72 and the highest cost savings of 27.58% (Rp 511,429,063.93). However, its environmental performance is exceptionally weak, generating a GWP of 99,385.218 kg CO_2eq, which translates to a negligible 2.97% carbon reduction compared to the baseline. Because it compromises environmental sustainability almost entirely for financial gain, its final MCA score is pulled down to 7.37, ranking it third overall.

Alternative 3 (Green Concrete + Steel WF + Bondek)

Alternative 3 ranks second overall with a Total Weighted Score of 7.53. Environmentally, it performs moderately well, yielding a 16.77% carbon reduction with a GWP of 85,056.9279 kg CO_2eq. However, its economic profile is highly disadvantageous; the LCCA reveals a negative cost saving of (-1.40%) (-Rp 25,979,454.40), meaning it is more expensive over its life cycle than the Existing Structure. Despite its technical strengths, this financial penalty keeps it from taking the top spot.

Alternative 4 (Low-Performing Option)

Alternative 4 is definitively disqualified. It scored the lowest in the MCA with a Total Weighted Score of 5.31, falling below the baseline of the Existing Structure (6.00). Its high-cost structure renders it financially unfeasible, and due to its poor initial performance, a detailed environmental LCA was not conducted..

IV. CONCLUSION

The multi-criteria integration conducted in this study confirms that Alternative 1 provides the ultimate triple-bottom-line balance for the project. By sacrificing a minor 3.5% in economic savings compared to Alternative 2, it achieves an extraordinary leap in carbon mitigation (reducing emissions by an additional 37,804.47 kg CO_2eq relative to Alternative 2), making it the most sustainable, compliant, and value-optimized choice for implementation. Ultimately, the decision-making process in this research highlights the profound influence of Life Cycle Assessment (LCA) on superstructure selection within a sustainable Value Engineering framework. Without the inclusion of the LCA lens, a conventional VE study would have yielded a flawed decision by solely recommending Alternative 2 based on its upfront and life cycle cost advantages. By embedding verified EPD-driven environmental data into the criteria weighting, LCA actively shifts the trajectory of engineering decisions toward genuine sustainability—proving to be the decisive parameter in selecting the superstructure for the Three-Story Urban Village.

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