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Research Article

Cost-Saving Strategy Using Value Engineering Analysis on Basement Construction Work

M. Fanshurullah Asa[1*], Syahreza Iskandar[1], Saipol Bari Bin Abd Karim[2], Mohammed Ali Berawi[3]

[1]Universitas Pertamina, Planning and Infrastructure Faculty, Civil Engineering Dept, Jalan Teuku Nyak Arief, Simprug, Jakarta 12220, Indonesia

[2]University of Malaya, Faculty of Engineering, Civil Engineering Dept, 50603 Kuala Lumpur. Malaysia

[3]University of Indonesia, Faculty of Engineering, Civil Engineering Dept, Jl. Prof. Dr. Sudjono D Pusponegoro, Depok, West Java, 16424. Indonesia

[*]Corresponding author's email: m.fanshurullahasa@universitaspertamina.ac.id; Telp: 0811120569; Fax: (021) 3507008

Abstract: Infrastructure development in Indonesia is increasing continuously, requiring efficient project management to address cost, time, and quality challenges. Therefore, this study aimed to examine the basement construction at Gatot Subroto BRI Tower project in South Jakarta, with a budget of USD 54,021,493.20. Changes in construction methods, from ground anchors to island-type strutting and steel platform, were analyzed using value engineering (VE) techniques. A combination of quantitative and qualitative methods, using Pareto Analysis and Analytical Hierarchy Process (AHP), was applied to evaluate alternative construction methods for cost efficiency. The results showed that steel platform method wasthe most effective, achieving cost savings of USD 257,010.56 (26.7% reduction) and a lower total Life Cycle Cost (LCC) compared to island-type strutting. This showed the significance of VE in optimizing project costs and improving overall efficiency.

Keywords: Analytical hierarchy process; Island-Type strutting; Life cycle cost; Steel platform, Value engineering

1. Introduction

Infrastructure development in Indonesia is continuously increasing, requiring efficient project management to address cost, time, and quality challenges. Between 2017 and 2022, the APBN of the Ministry of PUPR experienced significant growth from a nominal value of USD 6.13 Billion to approximately USD 9.8 Billion, with a realization of more than 90% (Prihapsari et al., 2022). This increased budget and realization rate shows the need to support infrastructure need in a nation's economy through good project management Moreover, project management is a series of efforts starting from planning to execution construction with an organizational system and control of all elements, ensuring that the planned targets can be achieved at an efficient cost (Hosaini et al., 2021).

A method in project management related to efficiency cost is value engineering (VE). According to a previous study, VE is closely related to the function and value of a job with cost efficiency (Sheikh et al., 2022). It has several advantages such as the more systematic method to keep the analysis according to the topic problems to produce optimal final results (Diputera et al., 2018). To apply VE analysis at the pre-construction step to avoid potential major redesigns and more opportunities for improvement can be implemented. Many academics and researchers from Indonesian institutions regularly publish their work in VE studies due to the belief in the benefits of VE in public and private project practice (Miraj et al., 2019). In this study, Gatot Subroto BRI Tower, South Jakarta, was selected as the object due to the inclusion of significant

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basement construction work, which provided an ideal case to apply and evaluate VE method. The project experienced changes in construction methods, from ground anchors to island-type strutting and steel platform, showing suitability for analyzing cost efficiency and construction optimization through VE. Additionally, the large budget of USD 54,021,493.20 allowed for an in-depth investigation of cost-saving strategies The method used was based on the existing condition, where a development project was on the side of the basement work area. Therefore, the ground anchor method was changed to island-type strutting. Since strutting work required a longer time, particularly in excavating and installing steel strutting, changeswere made to design a steel platform. There are many changes in work methods in the basement work area. Consequently, investigations were carried out on the basement work area of Gatot Subroto BRI Tower, South Jakarta, using VE method. The analysis focused on each step of VE to identify the most appropriate method.

Based on the description, this study aimed to determine the amount of efficiency that could be generated from the cost of the existing design of the basement area job of BRI Tower located on Jl. Gatot Subroto - South Jakarta. The analysis was carried out by making a selection of alternative designs from the ground anchor to island-type strutting and the steel platform, with the implementation of VE method.

1.1 Value Engineering (VE)

VE is a method that has been devised to obtain increased value. Various extensive studies have been conducted to determine the supremacy of VE, where cost savings show a higher advantage compared to other values. For example, the implementation of VE during school development in Libya led to cost reduction in the overall project by approximately between 20% and 30% (Youssef et al., 2023). Although it was shown that the basic benefits were acceptable to stakeholders and customers from the application of VE and the material return the role of consulting firms was enhanced in the construction industry in Egypt (Abdelalim, 2020, Abdelalim et al., 2021). Regarding the development of underground construction, VE improves product costs by reducing the unnecessary costs associated with the product (Abdelfatah et al., 2020). Introducing a systematic VE method for major sewer projects in Egypt was proven to reduce costs and improve sustainability. This method also successfully reduced costs by approximately 27% and the value of the project increased after the process (Usman et al., 2018). Therefore, integrating risk management, value management, and quality management would assist clients in using resources more effectively, in addition to saving time and money (Abdelalim et al., 2021). Cost efficiency at 9.8% savings had been obtained for clean and dirty water installation work (Rahayu, 2023). A ship designer who emphasized cost reductions and profit maximization during the design process applied Multi-Criteria Analysis, which included VE method (Buana et al., 2022). With some variations in the implementation, such as plug-in utilities, VE processes can be developed as catalyst tools for facilitating project-based solutions by producing new plugins for time-saving and quantity management (Kabaca and Yalnız, 2022).

Previous studies reported that VE could enhance construction efficiency by integrating risk management, reducing work duplication, and improving project outcomes (Masengesho et al., 2021). The combination of VE with BIM can reduce project costs and duration by 10% (Li et al., 2021). The method also helps evaluate material use efficiency (MUE), closing gaps in project performance (Choi et al., 2023, Choi et al., 2020), and optimizes small-scale LNG carrier designs by reducing hull shell area by 1.57% (Wibisana and Budiyanto, 2021).

Recent investigations over the last decade have shown that VE improves productivity and cost efficiency (Chen et al., 2022; Janani et al., 2018). In this digital era, VE integrates measurable and immeasurable concepts, leading to mathematical models that support AI-based systems (Woodhead and Berawi, 2022). The method has also been used to develop multi-story buildings and optimize residential projects, such as selecting cost-effective flat slabs (Elhegazy, 2022; Albasyouni, 2021). BIM and VE combined enhance green building designs and balance owner requirements (Wei and Chen, 2020).

The environmental impact of VE is shown by reducing embodied carbon by 8% and costs by 10% in post-tensioned concrete structures (Robati et al., 2021). It also brings environmental benefits (Adnan et al., 2018) and optimizes green building envelopes for energy savings and lifecycle costs (Yuan et al., 2020). Integrating BIM with VE promotes sustainable designs (Baarimah et al., 2021), thereby improving customer loyalty by minimizing waste and unnecessary expenses (Elfargani, 2023). VE and life cycle costing in the oil and gas sector ensure quality at the lowest cost, considering sustainability (Al-Yafei et al., 2017). To achieve these objectives, VE applies a functional method across various scientific fields to enhance project value (SAVE International, 2007). The 6 stages included in the analysis are stated in Figure 1.

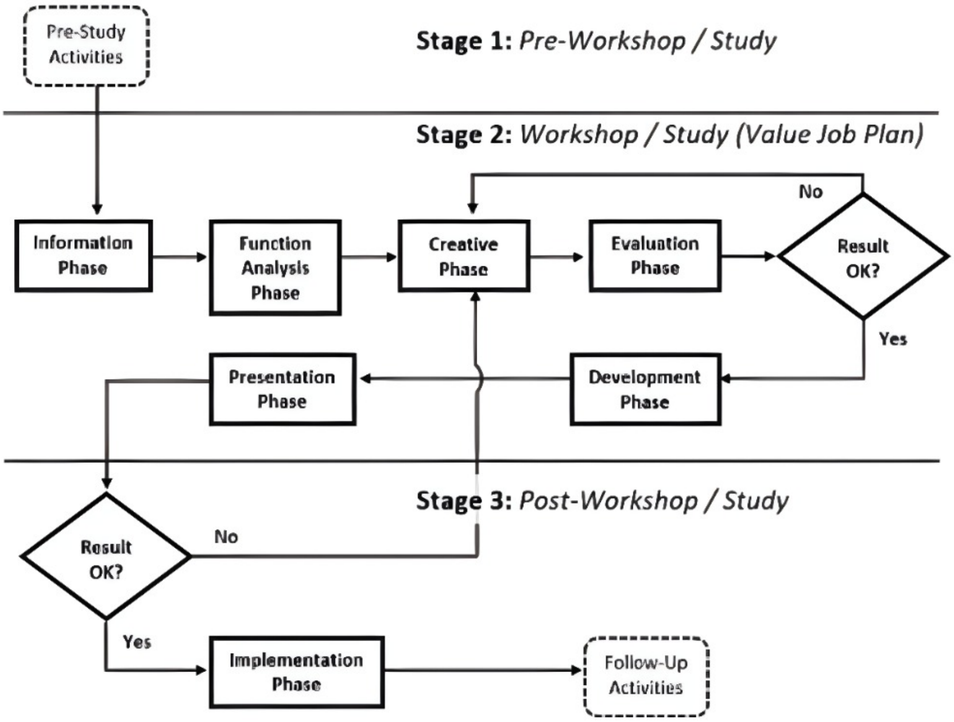

Figure 1 VE Methodology

1) **Information Stage**
   Information stage is the initial stage in conducting VE (SAVE International, 2007). Tools used at the information stage include Pareto Analysis, Tear Down Analysis, and SWOT (Strength, Weakness, Opportunity, Threat) Analysis.

2) **Function Analysis Stage**
   Function analysis is an activity to define and evaluate the work identified during the information stage. The tools used include Function Analysis System Technique (FAST) and Function Tree.

3) **Creative Stage**
   Creative stage is carried out to find ideas and solutions based on the understanding obtained at information and function analysis stages, remaining function-oriented. Tools used to obtain ideas and solutions include Brainstorming, TRIZ, and the Gordon Technique. Meanwhile, a developed BIM-based VE Idea Bank enables the systematic retrieval of past VE data from over 23 industry professionals (Park et al., 2016).

4) **Evaluation Stage**
   Evaluation stage is carried out to eliminate ideas collected based on creative stage. Tools used at the evaluation stage are Analytical Hierarchy Process (AHP), Pugh Analysis, and T-Charts.

5) **Development Stage**
Development stage is conducted to gain a deeper understanding of the selected ideas, particularly cost analysis (SAVE International, 2007). The tools used are Life Cycle Cost (LCC).

6) **Presentation Stage**
Presentation stage is to obtain conclusions based on the analysis carried out for the interested parties to easily understand the reports and make decisions. Further presentation development using technologies such as VR/AR, BIM (Building Information Modelling), AI (Artificial Intelligence), IoT, and automation can stimulate innovation, collaboration, and growth among research teams and industry experts (Shihata et al., 2023). The future of VE will include advanced digital technologies such as AI and the Internet of Things (IoT).

Studies from the Far East and Europe show AI integration in high-production industries. Reports from Lithuanian and Iranian have applied VE in supply chain cost management using the gray multi-criteria decision-making method, showing model stability in actual cases (Heidary Dahooie et al., 2020). South Korean studies showed that generative design could improve productivity by automating design alternatives (Lee et al., 2023).

AI and optimization methods, combined with BIM data, provide energy-efficient solutions while balancing cost and functionality (Kiavarz et al., 2024). AI and IoT are also crucial for sustainability, with new ecological indicators proposed to assess construction project sustainability (Kulejewski and Rosłon, 2023)

1.2 Pareto Analysis

According to Sunarto and WN, 2020 in Juran and Godfrey, 1999, Pareto analysis law stated that 80% of work originated from 20% of the main causes Predominantly comprising high-cost work. Pareto principle, also known as the 80/20 rule, states that 80% of results or problems are often caused by 20% of the factors. In the construction context, 20% of the costly work often explains approximately 80% of the issues or challenges that arise (Alkaiyat, 2021, M. Alkaiyat, 2021). This principle is often visualized in the form of a diagram showing the comparison between a small portion of significant causes (20%) and most of the less (80%). This diagram facilitates the identification of essential factors that must be considered to achieve maximum improvement (Buku Saku Analisis Pareto, 2020) allowing the allocation of resources more effectively.

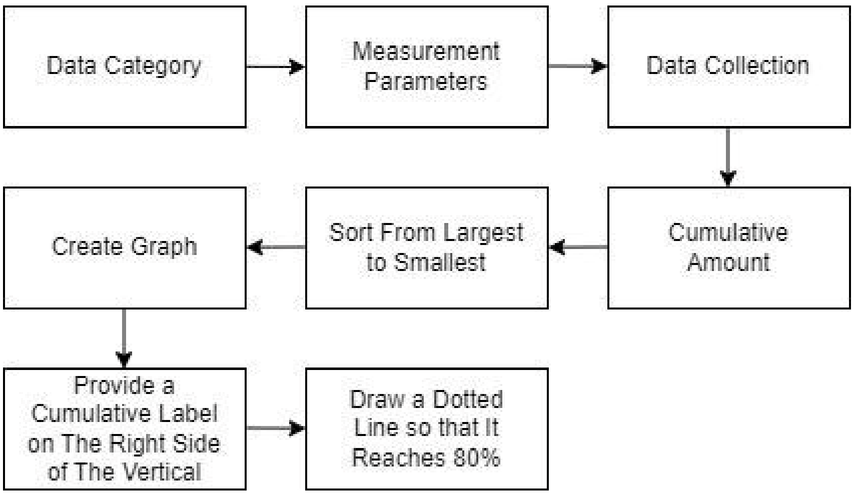

Figure 2 Steps to Create a Pareto Diagram

1.3 Function Analysis System Technique (FAST)

FAST Diagram is a tool used in the function analysis stage in VE According to Silviana et al., 2020, Charles Bytheway developed FAST diagram to determine linkages among different functions in a job. Major definitions of this diagram include:

1) **Higher Order Function**
Higher order function is shown on the left side of the diagram, indicating the desired function that will be carried out in less than a second. It is a lower-order function that depends on a higher-level function.

2) **Lower Order Function**
Lower order function is the input of FAST Diagram positionedto the right side of a diagram.

3) **Basic Function**
Basic function of the higher-order function serves as the basis for others.

4) **Secondary Function**
Secondary function explains and supports basic function.

5) **Design Objective**
Design objective includes parameters or goals that should be achieved in the design.

6) **All the Time Function**
A function is obtained from a higher-order function and applies all the time.

7) **At the Same Time Function**
This is a function that only occurs at specific moments or conditions.

According to Berawi, 2014, FAST Diagram has several essential functions, that allow the understanding of the work being analyzed. It helps avoid mistakes in determining and finding functions that may not be directly visible by simplifying and explaining the problems as well as improving technical skills. In making FAST Diagram, several factors must be considered according to Silviana et al., 2020 with the two main keywords being ”How” and ”Why (Silviana et al., 2020). Basic to secondary function is the scope of the problem that must be identified based on higher-order and lower-order functions. This process starts with the question, ”How can the basic function be achieved?” is answered on the right side as a secondary function and continues until all functions are identified. Subsequently, the question ”Why does this function need to be done?” is answered on the left side as a further explanation until all functions can be understood in depth.

1.4 Analytical Hierarchy Process (AHP)

AHP was a decision-making tool and method created by Thomas L. Satty. This method is commonly applied in decision support for business, engineering, and public policy planning. AHP dissects grand challenges into small sub-challenges and prioritizes each criterion in terms of contribution-enabled resources to consume distributed solutions for the best result (Supriadi et al., 2018).

The stages in AHP include:

1) **Determining the Problem**
The problem faced must be clearly described to facilitate the creation of a hierarchical structure.

2) **Constructing a Hierarchy**
Hierarchy starts with the primary goal at the top, followed by the criteria and solutions that must be evaluated.

3) **Making a Pairwise Comparison Matrix**
Criteria and alternative solutions are compared with one another and each to finally determine the most important.

4) **Scale**
All comparisons are rated by weight from 1 to 9, where each number represents an increasing level of significance.

1.5 Life Cycle Cost (LCC)

Life Cycle Cost (LCC) is the calculation of the total cost of an asset in its life cycle, starting from the planning stage, construction, operation, maintenance, to demolition. By calculating LCC, the most efficient alternative can be determined in terms of cost. Moreover, LCC depends on the planned service life (Royal Institution of Chartered Surveyors (RICS), 2016), with the main components as follows.

1) **Initial Cost**
Initial cost is the expenses incurred to start a project or produce a product, which is often considered an investment. Includes four main components, namely building, development, implementation, and other additional costs (Berawi, 2014).

2) **Annual Cost**
Annual cost is incurred routinely during the life of the asset, such as operational, maintenance, and other recurring expenses (Berawi, 2014).

3) **Nonrecurring Costs**
Nonrecurring costs arise at the concluding period, such as demolition costs and the residual value of the asset (Berawi, 2014).

2. Methods

The combination of quantitative and qualitative analyses was used in this study. Quantitative analysis is based on the data and method used, including several stages to focus on calculations tested using certain instruments. Furthermore, the form of qualitative analysis in this study is focused on understanding the project problems and alternative solutions in depth. with the flow diagram presented in Figure 3:

2.1 Data Collection

In this study, the data collection methods used were questionnaires and statistical datasets. The questionnaire was given to 3 respondents who were employees of an ongoing project. Each respondent received 1 questionnaire containing personal identification and fill in values for the 3 provided parameters, namely implementation time, ease of implementation, and construction costs. The data obtained were used for AHP analysis.

The questionnaire method included distributing intensity assessment questionnaires to stakeholders or experts to compare different construction methods (ground anchors, island-type strutting, and steel platforms). This was based on criteria such as cost, implementation time, and ease of use. The responses were used to populate the comparison matrices in AHP.

2.2 Pareto Analysis

Pareto analysis is a statistical decision-making method that identifies a limited number of input factors with a significant impact on outcomes, whether positive or negative. In this study, Pareto analysis was firstly carried out based on the Budget Estimate Plan of the work structure. Secondly, the analysis was carried out based on the Budget Estimate Plan of the selected jobs during the first Pareto Analysis.

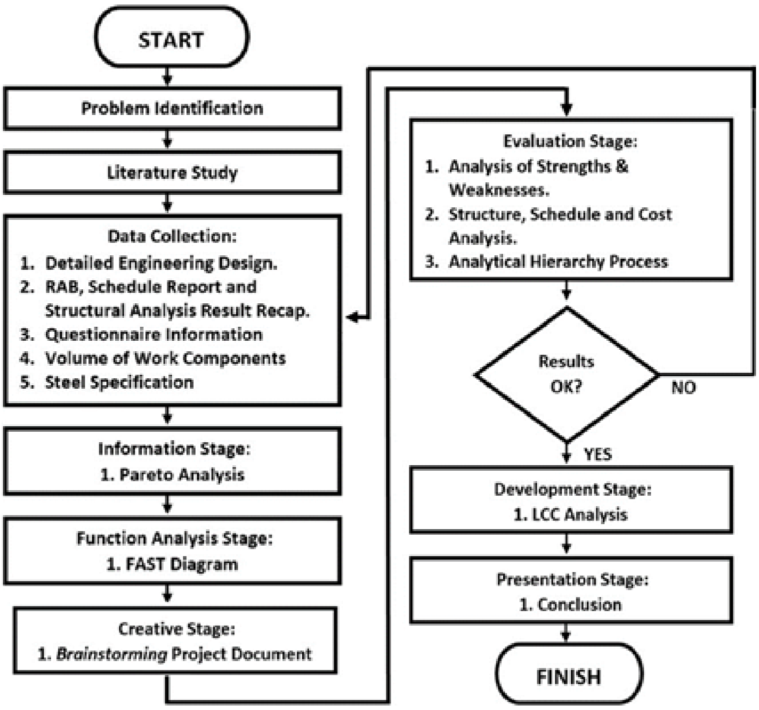

Figure 3 Flow Diagram of this Study

2.3 FAST Diagram

FAST Diagram is a method used to develop a graphical representation showing the logical relationships between the functions of a project, product, process, or service based on the questions "how" and "why".

2.4 Strength and Weakness Analysis

Strength and weakness analysis is used in a competitive environment focusing on a company's strength and weakness. The method is similar to SWOT analysis but merely focuses on the first two of the four aspects.

2.5 Analytical Hierarchy Process (AHP)

AHP is a process that uses hierarchical decomposition to solve complex information for achieving decision-making, such as information technology vendor and product evaluation. The stages included in AHP is stated as follows:

The First Stage is to make the 3×3 matrix from the results of the intensity assessment questionnaire for comparisons between criteria according to the number and analyze each comparison. In this study, the 3×3 matrix was used in AHP corresponding to the number of criteria being compared. The 3×3 matrix simplifies the process of calculating eigenvalues and ensuring the consistency of the judgments made in the comparison. The green color is given when the comparison is performed homogeneously. Meanwhile, the blue color is given according to the assessment of comparison intensity between criteria.

The Second Stage is the calculation of the eigenvalues based on the values of the Criteria Comparison Matrix. This analysis is carried out by dividing the values in certain matrix columns by the total value in each criterion column. When all the values are ready, the values are summed per row. Subsequently, each value is divided by three because the matrix used is 3×3, to obtain the average eigenvalue per row.

The Third Stage is to calculate the value of λmax. by multiplying the total value in the comparison matrix by the average value as shown in Equation 1

The Fourth Stage is the calculation of index consistency as shown in Equation 2.

The Fifth Stage is to calculate the ratio consistency (Equation 3).

$$\lambda maks = \Sigma\ Value\ of\ the\ Comparison\ Matrix \times the\ Average\ Value \tag{1}$$

$$CI = (\lambda maks - n)/(n-1) \tag{2}$$

$$CR = \frac{CI}{IR} \tag{3}$$

Consistency Index (CI) is a parameter used to measure the consistency of the values provided by each respondent in the pairwise comparison of criteria. A lower CI value shows greater consistency in the judgments. The use of CI is essential to ensure that the data is reliable and valid for further analysis.

Random Index (IR) is a benchmark value determined based on the number of parameters or criteria used in the comparison. It is derived from a standard table, serving as a reference point in consistency calculations.

Consistency Ratio (CR) is the result of dividing CI by IR. showing the overall level of consistency in the assessments. When CR value is less than 0.1, the given judgments are considered reasonable and acceptable. However, for a value exceeding 0.1, the judgments are considered inconsistent and require further review.

3. Results and Discussion

3.1 Results of Pareto Analysis

Firstly, Pareto analysis was carried out based on the work structure budget estimate plan. Secondly, the analysis was performed using the Budget Estimate Plan of the selected jobs in the first Pareto Analysis. The objective of applying Pareto analysis during the process control in construction is to identify priorities, which functions as a measuring method to verify the efficacy of the model (Moon et al., 2015).

Based on Figure 3, the work that reaches more than 80% in tower and basement structures has a percentage of 81/50. Due to basement structure work related to steel, two jobs were selected based on the availability of analysis data, namely basement and steel structure work. In Figure 4, the same percentage of Pareto analysis was obtained by 94/66 with the same procedures.

3.2 Results of FAST Diagram

In the creation of FAST Diagram all functions follow the principle of basement work. Figure 5 describes the scope of basement work, starting from basic to secondary functions. The diagram explains that the higher-order thinking basement is to add room. The basic function of building the basement structure is to create a structural framework. This is followed by a secondary function describing how to generate the function base. The objective is to accelerate the structure and produce innovation. The overtime function of basement work is to increase stability and access. This is defining the sets of transformation processes applicable to different groups of benchmarking data classified according to their attributes (Choi et al., 2020, Choi et al., 2023).

3.3 Alternative Method

1) A ground anchor is a structural component mounted on a retaining wall to move the tensile load applied to the ground to withstand lateral loads (Aldo and Susilo, 2018).

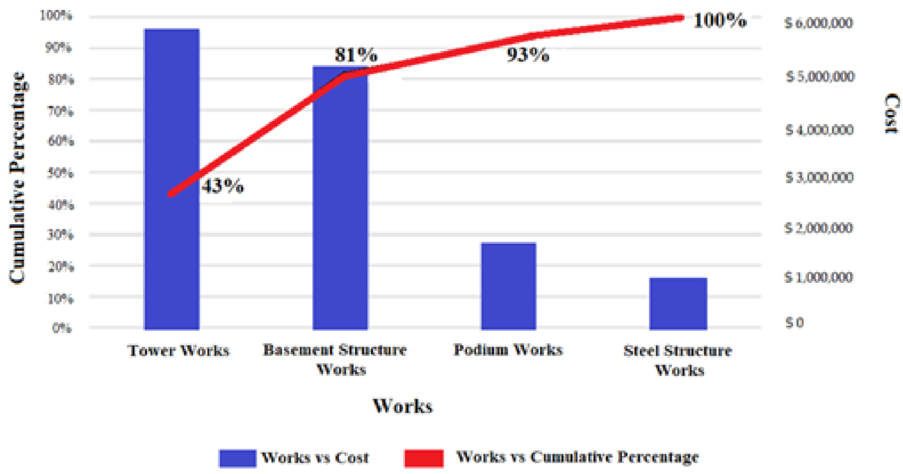

Figure 4 Pareto Analysis of Total Work Distribution in BRI Tower Basement Construction Project

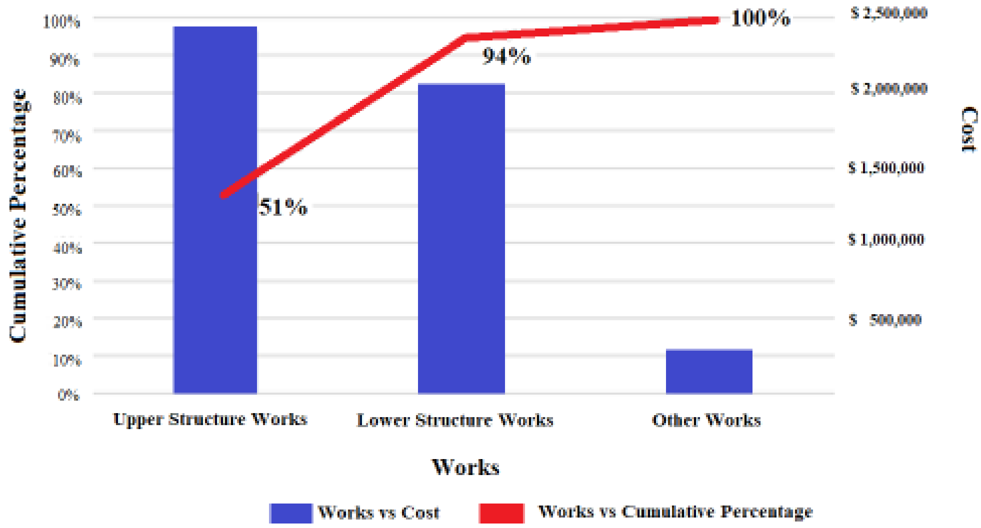

Figure 5 Pareto Analysis Focused on the Basement Structure Work in BRI Tower Project

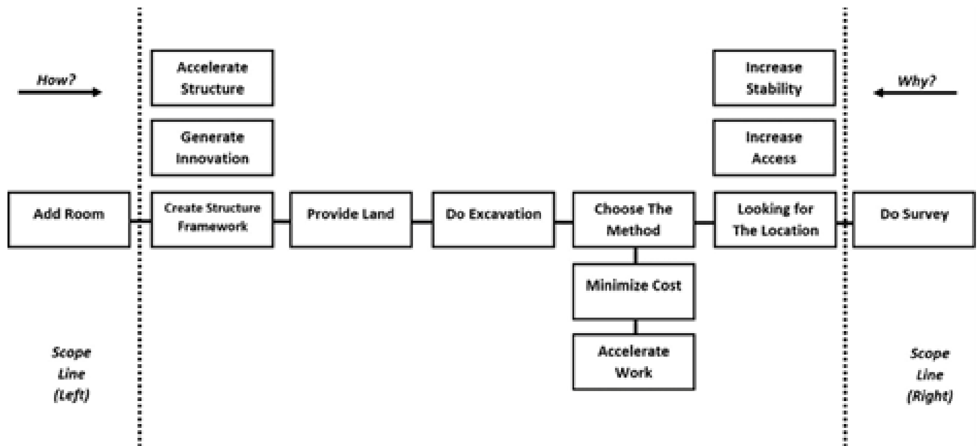

Figure 6 FAST Diagram of Basement Structure

The installation of ground anchor is also divided into two systems, namely active and passive. The active system is the pulling given to the anchor, while the passive is the force that occurs during load.

2) Strutting is one of the soil reinforcement methods arranged sequentially according to the excavation elevation. At the end of the side, it will be connected to a sheet pile to

resist lateral forces caused by soil.

3) Using a steel plate
WF 588x300x12x20
with specifications: h = 588 mm, b = 300 mm, tf = 20 mm, tw = 12 mm, fy = 240 MPa, fu = 370 MPa, and E = 200,000 MPa.

3.4 Result of AHP

AHP was developed by Thomas L. Saaty in 1980 (Haddad et al., 2015). The method allows decision-makers to consider quantitative and qualitative criteria based on pair-wise comparisons. This shows the relationship between objectives, evaluation criteria, sub-criteria, and alternatives hierarchically. The initial stage in applying AHP is to define the decision problem, identify the criteria, and establish the structural hierarchy. Subsequently, decision-makers or experts conduct pair-wise comparisons using a scale ranging from 1 - 9 to evaluate the importance of each criterion relative to the other (Cambrige, 2012). Weightage calculation is carried out, where relative weights of each criterion are determined using the eigenvector method. These weights are used to prioritize the alternatives based on individual performance about each criterion. The process helps determine the relative weights of each criterion. This includes defining the main objectives (minimizing costs and ensuring quality), evaluation criteria (material costs, labor costs, and project duration), as well as sub-criteria (specific types of materials, and labor efficiency. AHP is used to identify, analyze, and reduce construction risks by organizing complex problems into a structured hierarchical model.

1) AHP Comparison Between Criteria

The results of intensity assessment questionnaire for comparisons between criteria are shown as follows

Table 1 Comparison Intensity Between Criteria

Comparison	Intensity
Implementation Time vs Ease Implementation	1
Construction Cost vs Implementation Time	4
Construction Cost vs Ease of Implementation	8

The First Step is to make a 3×3 matrix according to the number of criteria and analyze for each comparison. In Table 1, the intensity values provided by respondents were based on the questionnaire. The intensity values provided by respondents were subjective or reflective of real events.

Table 2 Criteria Comparison Matrix

Criteria	Implementation Time	Construction Time	Ease Implementation
Implementation Time	1	0.25	1
Construction Time	4	1	8
Ease Implementation	1	0.125	1
Total	6	1.375	10

As shown in Table 2, the green color is given because the comparison is performed homogeneously. The blue color is designated according to the assessment. For values that are not given color, the distribution value of the assessment is in Table 1.

The Second Step is the calculation of the eigenvalues based on the values in Table 2. This is carried out by dividing the values in certain matrix columns with the total value in each criterion column. After obtaining all values, summation is carried out per row. Subsequently, each value is divided by three because the matrix used is 3×3, to obtain the average eigenvalue per row.

Table 3 Eigenvalue Criteria

Eigenvalue Criteria			Total	Average
0.167	0.182	0.1	0.448	0.149
0.667	0.727	0.8	2,194	0.731
0.167	0.091	0.1	0.358	0.119

The Third Step is to calculate the value of λmax by multiplying the total values in the comparison matrix with their average. Eigenvalue is calculated to make more realistic decisions based on subjective assessments. This is represented mathematically as follows in Equation (1):

$$\lambda \text{ max} = \Sigma \text{ Value of the Comparison Matrix} \times \text{the Average Value}$$

For Example, the corresponding values, are substituted to obtain:

$$(6 \times 0.149) + (1,375 \times 0.731) + (10 \times 0.119) = 3,094$$

The Fourth Step is the calculation of index consistency, as shown in Equation 2.

$$CI = (\lambda\text{max-n})/(n-1) = (3,094-3)/(3-1) = 0.047$$

The Fifth Step is the calculation of the consistency ratio (CR) between the consistency index (CI) and the random index (IR). as expressed in Equation (3):

For this example, substituting the values gives:

$$CR = CI/IR = 0.047/0.58 = 0.0814 < 0.1 \quad \text{(OK)}$$

2) AHP Comparison of Methods to Implementation Time

The results of the intensity assessment questionnaire for comparison of methods based on implementation timeare shown in Table 5. The green color shows that the comparison is performed homogeneously. While the blue color indicates the assessment. Meanwhile, the distribution of colorless values is shown in the assessment from Table 4.

Table 4 Intensity Comparison of Execution Time, Construction Time, and Ease Implementation

Intensity Comparison	Comparison	Time
Execution Time	Steel Platform vs Island-Type Strutting	6
	Steel Platform vs Ground Anchor	9
	Island-Type Strutting vs Ground Anchor	3
Construction Time	Steel Platform vs Island-Type Strutting	5
	Steel Platform vs Ground Anchor	3
	Island-Type Strutting vs Ground Anchor	1
Ease Implementation	Steel Platform vs Island-Type Strutting	1
	Steel Platform vs Ground Anchor	0.5
	Island-Type Strutting vs Ground Anchor	0.333

Table 5 Comparison Matrix against Execution Time, Construction Time, and Ease Implementation

Comparison Matrix	Implementation Time	Steel Platform	Island - Type Strutting	Ground Anchor
Against Execution Time	Steel Platform	1	6	9
	Island-Type Strutting	0.167	1	3
	Ground Anchor	0.111	0.333	1
	Total	1.278	7,333	13
Against Construction Cost	Steel Platform	1	6	9
	Island-Type Strutting	0.2	1	1
	Ground Anchor	0.333	1	1
	Total	1,533	7	5
Against Ease Implementation	Steel Platform	1	1	0.5
	Island-Type Strutting	1	1	0.333
	Ground Anchor	2	3	1
	Total	4	5	1,83

The First Step shows the measurement matrix for analyzing the implementation time, construction cost, and ease of implementation of three structuresnamely steel platform, island-type structuring, and ground anchor.

The Second Step calculates the eigenvalues based on the values in Table 5. This is performed by dividing the values in certain matrix columns by the total value in each criterion column. After obtaining all values, summation is carried out per row. Subsequently, each value is divided by three because the matrix used is 3×3 to obtain the average eigenvalue per row.

The Third Step is to calculate the value of λmax, which represents the maximum eigenvalue. The calculation is performed by multiplying each value in the comparison matrix by the corresponding average eigenvalue. The formula used to calculate λmax is shown in Equation (1):

$$\lambda \text{ max} = \Sigma \text{ Value of the Comparison Matrix} \times \text{the Average Value}$$

By applying this formula, the values from the comparison matrix are substituted and their respective average eigenvalues are as follows:

$$\lambda \text{ max} = (1,278 \times 0.764) + (7,333 \times 0.166) + (13 \times 0.070) = 3.1$$

This gives a result of:

$$\lambda \text{ max} = 3.1$$

The Fourth Step includes calculating the consistency index (CI), which measures the consistency of the comparison matrix. The formula for calculating CI is given by Equation (2):

$$CI = (\lambda \text{ max} - n)/(n-1) = (3.1-3)/(3-1) = 0.05$$

The Fifth Step 5 calculates the consistency ratio (CR), which is used to assess how consistent the judgments are relative to random consistency. The formula for CR is given by Equation (3):

3) AHP Comparison of Methods to Construction Costs

To compare methods based on construction costs, the formula in Equation 1 is used to calculate λmax :

$$\lambda \text{ max} = \Sigma \text{ Value of the Comparison Matrix} \times \text{the Average Value}$$

$$(1,533 \times 0.655) + (7 \times 0.158) + (5 \times 0.187) = 3,043$$

Table 6 Eigenvalue of Execution Time, Construction Time, and Ease of Implementation

Eigenvalue of	Eigenvalue Criteria			Total	Average
Execution Time	0.783	0.818	0.692	2,293	0.764
	0.130	0.136	0.231	0.498	0.166
	0.087	0.045	0.077	0.209	0.070
Construction Time	0.652	0.714	0.6	1,966	0.655
	0.130	0.143	0.2	0.473	0.158
	0.217	0.143	0.2	0.560	0.187
Ease Implementation	0.252	0.2	0.273	1,723	0.241
	0.250	0.2	0.182	0.632	0.211
	0.05	0.6	0.545	1.645	0.548

The consistency index (CI) is then calculated using Equation (2):

$$CI = (\lambda \text{ max} - n)/(n-1) = (3,043 - 3)/(3-1) = 0.022$$

The consistency ratio (CR) is computed using Equation (3):

$$CR = CI/IR = 0.022/0.58 = 0.0372 < 0.1 \quad \text{(OK)}$$

4) AHP Comparison between Criteria

For the comparison between criteria, λmax is calculated using the same formula:

$$\lambda \text{ max} = \Sigma \text{ Value of the Comparison Matrix} \times \text{the Average Value}$$

$$(4 \times 0.241) + (5 \times 0.211) + (1.833 \times 0.548) = 3,022$$

The consistency index (CI) is calculated using Equation (2):

$$CI = (\lambda \text{ max} - n)/(n-1) = (3,022 - 3)/(3-1) = 0.011$$

The consistency ratio (CR) is computed using Equation (3):

$$CR = CI/IR = 0.011/0.58 = 0.0192 < 0.1 \quad \text{(OK)}$$

Since $CR = 0.0192$ $CR = 0.0192$ $CR = 0.0192$ is less than 0.1, the consistency is acceptable.

5) Ranking of Alternative Methods

A rating assessment is performed for each method using the average eigenvalue of the criteria multiplied by the average eigenvalue of the comparison of implementation time, construction cost, and ease of implementation.

The steel platform using Equation (4), strutting, and Ground Anchor using Equation (4):

$$\text{Steel Platform} \quad = \quad (\Sigma \text{ Eigenvalue Criteria} \times \text{Eigenvalue Method})$$

$$
\begin{aligned}
& = (0.149 \times 0.764) + (0.731 \times 0.655) + (0.119 \times 0.241) \\
& = 0.6223 \\
\text{Strutting} & = (\Sigma \text{ Eigenvalue Criteria} \times \text{Eigenvalue Method}) \\
& = (0.149 \times 0.166) + (0.731 \times 0.158) + (0.119 \times 0.211) \\
& = 0.1653 \\
\text{Ground Anchor} & = \Sigma \text{ Eigenvalue Criteria} \times \text{Eigenvalue Method}) \\
& = (0.149 \times 0.070) + (0.731 \times 0.187) + (0.119 \times 0.548) \\
& = 0.2124
\end{aligned}
$$

6) LCC Analysis of Island-Type Strutting

For LCC calculation of strutting, the process accounts for the initial installation cost of USD 488,810.93, combined with the present maintenance costs, assuming a 12% interest rate over 30 years, which amounts to USD 472,484.65. From this total, the dismantling costs are subtracted, with the same assumption, which is USD 1,959.15 to obtain LCC of USD 959,336.43.

7) LCC Analysis of Steel Platform

For LCC calculation of the steel platformusing an initial cost of USD 359,177.36 and assuming a 12% interest rate and a 30-year service life for maintenance costs. Therefore, the total LCC obtained is USD 706,358.19.

4. Conclusions

In conclusion, this study showed that implementing VE on the basement structure work in Gatot Subroto BRI Tower project provided significant cost savings. According to Pareto analysis results, basement and steel structure work accounted for a dominant percentage of the total project cost, specifically 81/50 and 94/66, respectively. The steel platform method was selected as the best alternative compared to others, such as island-type strutting and ground anchor. The results of AHP showed that the steel platform had the highest value of 0.6223 in terms of execution time, construction cost, and ease of implementation. LCC analysis also showed that the steel platform method produced a cost saving of USD 256,827.85, or 26.7%, compared to the initial design using island-type strutting. Therefore, the application of VE in this project provided tangible benefits in terms of cost reduction and efficiency improvement without compromising work quality. Further studies were recommended to explore other benefits of applying VE in a broader construction project context.

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Conflict of Interest

The authors declare no conflicts of interest.

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