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VALUE ENGINEERING OF MODERN FORMWORK IN MULTI-STORY BUILDING CONSTRUCTION
Case study on the construction project of the BRIN Building Complex in Yogyakarta

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Value Engineering, Modern Formwork, Multi-Story Building Construction

ABSTRACT
Reinforced concrete is the most commonly used construction material in building construction in the 21st century. In its production, supportive instruments are needed to enhance both quality and economic aspects. Formwork, or shuttering, is a crucial factor in the casting and hardening of concrete. The subject of this research is wooden formwork and its alternatives, analyzed in terms of cost, quality, time, and convenience using the Value Engineering Job Plan analysis. In terms of cost, there is a cost savings of 48,66% for DUO polymer formwork compared to the conventional plywood method. The resulting surface quality of the concrete of this method has a average roughness of 3.492. The total duration of the work is 2.356 days. The total value index obtained for the use of DUO polymer formwork is 98.01, for the plywood film formwork is 37,65, and for conventional plywood formwork is 0.00. Thus, in terms of value, the DUO polymer plastic formwork can be recommended as the best formwork method for multi-story building construction. Considering the advantages and disadvantages of this method, along with the benefits obtained, it would be even more beneficial on a larger construction scale.

INTRODUCTION

The use of concrete as a construction material has been practiced since 1824 and remains the most widely used construction material to date (Harrer et al., 2017). In its production, a framework (reinforcement) and formwork are required until the concrete hardens and can support the building load. These supporting instruments play a crucial role in the quality of the concrete, necessitating methods and materials that can produce good reinforced concrete. As the core structure of a building, concrete along with reinforcement and formwork accounts for a relatively high percentage of costs, reaching up to half of the construction costs for concrete structures (Hyun et al., 2018). Therefore, further research on this aspect of the work is needed.

Formwork, or shuttering, is a molding material that shapes dimensions in the concrete curing process. The first and still the primary choice for formwork is wood/plywood (Yip & Pon, 2008). This type of formwork offers high flexibility and good productivity. However, economically, its use is considered less efficient for large-scale projects. Additionally, the fabrication, installation, and deconstruction processes of this method are time-consuming. From a quality perspective, the concrete's quality may decrease due to the repeated use and environmental factors causing damage to the plywood material.

Research on the material and methods of formwork is considered crucial to maintaining concrete quality and, more importantly, making the cost and time of a construction project more efficient. Various alternative formwork materials to wood are available in the Indonesian market, such as aluminum, plastic, PVC, and ABS (disposable recycled plastic), each with its own material characteristics and methods (Li et al., 2022). This research focuses on comparing wood-based formwork (plywood) with its alternatives to be analyzed in terms of value.

RESEARCH METHOD

The method used in this research is quantitative descriptive through data obtained from the field and laboratory testing. The data is then analyzed using a systematic value engineering approach, making the work and its results orderly and accountable. The value engineering stages used can also be referred to as the Value Engineering Job Plan.

Value engineering (VE) is a structured methodology aimed at enhancing value and quality. The VE methodology allows individuals to identify opportunities to reduce unnecessary cost expenditures without compromising on quality, outcomes, reliability, and other critical factors. According to Dell'Isola (1997), there are several stages in conducting value engineering analysis as follows.

1. **Information phase**

In this phase, various information related to the research object is collected, such as the identification of structural work items in a multi-story building project with exposed concrete characteristics. Initial data required include structural design drawings, the formwork method used, and cost calculations for formwork materials and services, along with various related documentation.

Additionally, a functional analysis is conducted to distinguish it from other cost-saving methodologies. In this stage, the functions of the work items are defined to estimate their utility value. The output of this information phase is as follows:

a. Pareto Analysis

2. **Creative phase**

In this phase, brainstorming is conducted to generate ideas and alternatives for the current research. These alternatives can be examined from various aspects, including:

a. Material or substance
b. Working methods
c. Construction process optimization
d. Design optimization

Subsequently, these alternative methods are evaluated against the functions of the items and the assessment criteria established in the previous phase, leading to the selection of several feasible methods.

3. **Analyze phase**

In this stage, the calculation of the value for each method is carried out based on the specified parameters. These values are then totaled to form an index value. The sum of these index values will serve as the basis for recommending which alternative has the highest value.

Cost

For the calculation of the total cost, the Life Cycle Cost Analysis (LCCA) method is utilized, which is a comprehensive cost calculation throughout the life cycle of the method. The costs are based on the use of formwork items required for the entire structural work in the examined project. According to Dongare & Sonawane (2022), the life cycle of formwork can be divided into three parts:

1. Production cost: Material, service, and transportation costs from the fabrication and installation processes of the formwork.

2. Service life cost: Costs incurred during the functional use of the product, including maintenance and repair costs.

3. End of life cost: Costs associated with the dismantling and disposal of the product at the end of its service life.

From this analysis, the Net Present Value (NPV) or the net amount of the entire life cycle of the work item at a specific time.

In addition to NPV, cost saving or the cost reduction obtained when applying alternative methods is also calculated. A result is considered feasible if the value is greater than 0 ($x > 0$). The formula for calculating cost saving is as follows:

$$\text{Cost saving} = \frac{\text{Alternative cost} - \text{Conventional cost}}{\text{Conventional cost}} \times 100\%$$

Lastly, the cost/worth calculation is performed to determine the rough value comparison in terms of cost compared to the original method. A result is considered feasible if the value is greater than 1 ($x > 1$). The formula for calculating cost/worth is as follows:

$$\text{Cost/Worth} = \frac{\text{Alternative cost}}{\text{Conventional cost}}$$

Surface quality

The data obtained from laboratory tests consist of the average roughness (Ra) and the surface profile of the concrete. The values of average roughness are compared quantitatively, while the surface profiles are compared qualitatively. The formula for average roughness is as follows (Santos, et al., 2012).

$$\text{Ra} \approx \frac{1}{n}\sum_{i=1}^{n} |Zi|$$

Time

As for other parameters, the time for the formwork activities, field observations were conducted to determine the duration of formwork-related activities. The execution process of the formwork work item can be divided into three stages: fabrication, installation, and dismantling (Gudmestad and Warland 1992). The duration of each activity is recorded per unit area in multiple observations and is then averaged (Tn).

The obtained duration of work (Tn) goes through a series of calculation formulas to determine the total work duration (T). This process begins with the following formula. By estimating normality tests and the amount of data, an adjustment factor is used to determine the standard time (Ts) required for this work, as follows (Suwandi et al., 2020).

Ts = Standard work time

Tn = Duration of work from observations

$$\text{Ts} = \text{Tn} + (\text{looseness factor} \times \text{Tn}) \qquad (1)$$

After obtaining the standard work time, the productivity coefficient for unit cost (D) can be calculated using the following formula.

(A) = Total working hours per day

(B) = Number of workers

(C) = Formwork working hours per day

$$\text{C} = \frac{\text{Ts}}{(60\ \text{min} \times \text{A})} \qquad (2)$$

$$\boxed{D = C \times B} \quad (3)$$

After obtaining the productivity coefficient, the total duration of the formwork work item (T) can be calculated using the following formula.

V = Total volume of formwork work

n = Total number of workers

$$\boxed{T = \frac{D \times V}{n}} \quad (4)$$

Score

The data obtained from the above calculations are then converted into values for comparison. Firstly, weighting is applied to the assessment criteria using the pair-wise comparison method. This method is chosen because its objective is to streamline or focus calculations in a multi-criteria situation without eliminating criteria deemed less important (Saaty, 2001). Weighting is done by assigning values to the priority of these criteria compared to each other.

After that, an assessment can be made per criterion using the proportional scoring method. This method is considered most appropriate because it can only be applied to quantitative and representative data with relatively small differences (Dean, 2022). A score of 0 is assigned for the worst performance, and 1 for the best. The scoring formula is as follows.

$$\boxed{\text{Score } (x) = \frac{\text{Performance } (x) - \text{worst performance}}{\text{best performance} - \text{worst performance}}}$$

After that, an assessment was conducted on the processed data using the proportional scoring method according to the predetermined assessment criteria. Finally, the calculation of the final index value was obtained using the following formula.

$$\boxed{\text{Index score} = \text{criteria score} \times \text{individual score}}$$

4. Development phase

The outline of this stage involves further calculations and assessments that were not included in the previous evaluation phase. Analyses such as strengths and weaknesses, comparisons of labor costs, and other relevant factors will be presented at this stage.

5. Recommendation phase

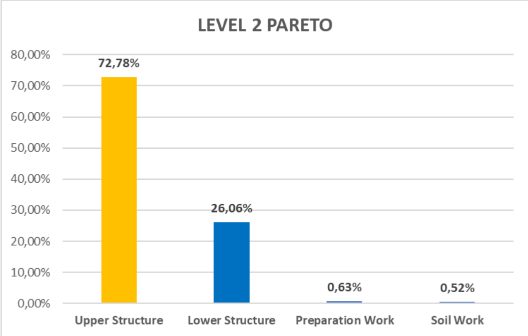
In the final stage of this Value Engineering (VE) analysis, a recommendation for the method is provided based on the assessments from the previous stages.

RESULTS AND DISCUSSION

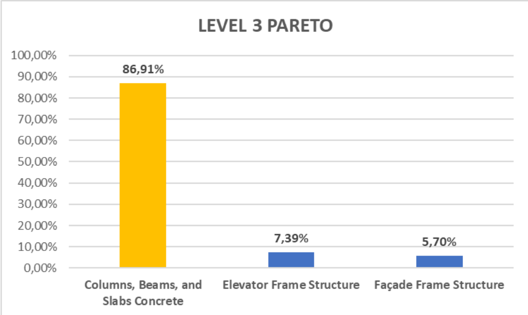
1. Information phase

From the WBS it can be observed that the first Pareto analysis is conducted at level 1, consisting of structural work items, architectural work items, and MEP (Mechanical, Electrical, Plumbing) work items.

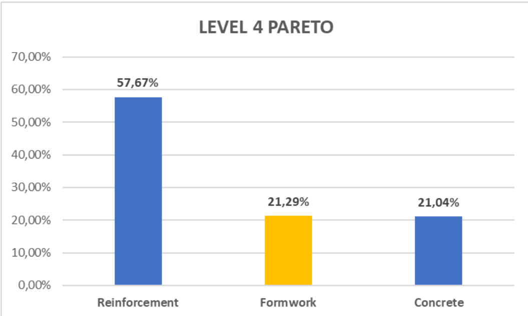
In the Pareto analysis at level 1, the largest percentage of the total project is obtained for structural work, with a figure of 52.44%. With this result, the Pareto analysis can be continued for the next level, which consists of preparation work, earthwork, substructure work, and superstructure work, which will be the focus of the Pareto analysis at level 2.



The Pareto analysis at level 2 reveals the highest percentage in superstructure work, with a figure of 72.78% of the total superstructure work and the highest across all level 1 categories at 37.71%. This result aligns with Tambayong's research (2016), which found that the proportion of superstructure work can reach 77.60% of the entire structural work. This work item includes column-beam-slab work, lift frame structure work, and façade frame structure work. These work items will be the focus of the Pareto analysis at level 3.



In the Pareto analysis at level 3, the highest percentage is obtained for the concrete work of columns, beams, and slabs, amounting to 86.91%. The Pareto analysis is then continued at the next level, which is level 4.



The final Pareto analysis, at level 4, with the formwork work item, is the dominant result in the breakdown of structural work items, amounting to 21.29%. This figure is relatively significant as it slightly exceeds the concrete work itself at 21.04%. Meanwhile, the reinforcement work has the highest percentage but is not discussed in this VE (Value Engineering) study as it is considered to already fulfill the function and safety factor of the building structure. The concrete work is not the focus of the research because there is no alternative considered to have a better value than the original method used.

2. Creative phase

Of all the approaches that can be implemented in this VE Job Plan, optimizing the construction phase is not chosen due to project time constraints that make it impractical for implementation in the construction zone. Therefore, the option of using new systems and materials is selected. Based on research conducted on previous studies and the availability of materials in Indonesia, for alternative 1, a substitute material for conventional plywood is chosen, namely PERI T-plex phenolic film formwork. Meanwhile, for alternative method 2, the PERI DUO polymer formwork system is employed.

No	Method code	Formwork type
1	Alternatif 0	Conventional Plywood
2	Alternatif 1	Film Plywood
3	Alternatif 2	DUO Polymer

3. Analyze phase

After determining the design criteria, the prioritization of each criterion in relation to the others is assessed. The method used is the Analytic Hierarchy Process (AHP) with a pair-wise comparison matrix approach using a 5-point priority scale designed by Saaty (2001). The percentage weight of criteria is obtained from the average comparison (mean) of points for each criterion with the overall average. The result of the weighting calculation for the criteria is as follows.

Cost

In this stage, a breakdown of costs or unit prices for the original method and alternatives is conducted. This unit price analysis is then used as a reference for calculating the total cost for each method. For the execution of concrete structural work, it is divided into four zones for each floor, with two sets of formwork per floor. Thus, the total usage of formwork for the three towers with 21 floors and four zones is 84 usages (2 sets), with 42 usages per set.

No.	Details	Code	Unit	Coefficient	Unit Price (Rp.)	Total Price (Rp.)
A	WORKS					
	Worker	L.01.01	Man-day	0,66000	92.991	61.374,07
	Handyman	L.02.04	Man-day	0,33000	97.641	32.221,39
	Foreman	L.03.01	Man-day	0,03300	99.593	3.286,58
	Overseer	L.04.01	Man-day	0,03300	101.585	3.352,31
				WORK TOTAL COST		100.234,36
B	MATERIAL					
	Class III wood		m3	0,01333	1.200.000	16.000,00
	Nail 5 - 12 cm		Kg	0,40000	18.000	7.200,00
	Formwork oil		Litre	0,20000	10.000	2.000,00
	Class II wooden beam		m3	0,00500	1.100.000	5.500,00
	Plywood 9 mm		Sheet	0,11667	160.000	18.666,67
	Wooden dolken Ø 8-10/400 cm		Pcs	0,66667	8.000	5.333,33
				MATERIAL TOTAL COST		54.700,00
C	TOOL				-	-
				TOOL TOTAL COST		-
D	Work Unit Price (A+B)				-	154.934,00

The unit price for the conventional plywood method is Rp 154,934 per square meter. This result is obtained using the labor and material coefficients derived from the Architectural and Housing Standard (AHS) as per the Ministry of Public Works regulation. A total of seven sets are used, each set utilized three times for a total of 21 floors and four zones

No	Details	Code	Unit	Coefficient	Unit Price (Rp.)	Total Price (Rp.)
A	WORKS					
	Worker	L.01.01	Man-day	0,66000	92.991	61.374,07
	Handyman	L.02.04	Man-day	0,33000	97.641	32.221,39
	Foreman	L.03.01	Man-day	0,03300	99.593	3.286,58
	Overseer	L.04.01	Man-day	0,03300	101.585	3.352,31
				WORK TOTAL COST		100.234,36
B	MATERIAL					
	Class III wood		m3	0,01333	1.200.000	16.000,00
	Nail 5 - 12 cm		Kg	0,40000	18.000	7.200,00
	Formwork oil		Litre	0,20000	10.000	2.000,00
	Class II wooden beam		m3	0,00500	1.100.000	5.500,00
	Plywood film PERI 18 mm		Sheet	0,00833	294.000	2.450,00
	Wooden dolken Ø 8-10/400 cm		Pcs	0,66667	8.000	5.333,33
				MATERIAL TOTAL COST		38.483,33
C	TOOL				-	-
				TOOL TOTAL COST		-
D	Work Unit Price (A+B)				-	138.717,00

The unit price for the PERI film-faced plywood method is Rp 138,717 per square meter. This result is obtained using the same labor and material coefficients as the conventional plywood, but with a different usage quantity. The number of sets used is two sets with a total of 42 uses per set for three towers with 21 floors and four zones.

No	Details	Code	Unit	Coefficient	Unit Price (Rp.)	Total Price (Rp.)
A	WORKS					
	Worker	L.01.01	OH	0,05000	92.991	4.649,55
	Handyman	L.02.04	OH	0,02500	97.641	2.441,01
	Foreman	L.03.01	OH	0,00330	99.593	328,66
	Overseer	L.04.01	OH	0,00330	101.585	335,23
				WORK TOTAL COST		7.754,45
B	MATERIAL					
	PERI Duo Polymer 42x repetition			0,02619	5.779.866	151.377,44
				MATERIAL TOTAL COST		151.377,44
C	TOOL				-	-
				TOOL TOTAL COST		-
D	Work Unit Price (A+B)				-	159.131,00

The unit price for the Duo polymer method is Rp 159,131 per square meter. This result is obtained using labor and material coefficients calculated from field observations and acquired data. Two sets are used, each set employed 11 times for a total of 21 floors and four zones.

From the above unit price analysis of formwork work, a Life Cycle Cost Analysis (LCCA) is conducted, which is a breakdown of the overall cost throughout the life cycle of each method, including production, operation, maintenance, and Salvage value, as shown in Table 17 below. The LCCA analysis yields calculations for NPV, savings amount, percentage, and cost/worth.

	Life Cycle	1 year	*Coeff.*	Conventional Multiplex	Film Multiplex	Duo polymer
	Interest Rate	bank 6,79% Inflation 2,28%				
	Work Volume	9427,11 m2		Present value	Present value	Present value
1	Capital cost (CaPEX)					
	Initial cost	(P/F, 9,07%, 0)	1,0000	1.460.580.171	1.307.700.695	1.500.145.760
2	Operational cost (OpEX)					
	Maintenance cost	(P/A, 9,07%, 1)	0,9233	0	0	0
	Replacement costs			146.058.017	130.770.070	150.014.576
3	Salvage cost (buyback 60%)	(P/F, 9,07%, 1)	0,9168	0	0	- 825.238.339
4	Net Preset Value (NPV)			1.606.638.188	1.438.470.765	824.921.997
5	LC Present value (Deviation)			-	- 168.167.423	- **781.716.191**
6	Saving percentage				10,47%	**48,66%**
7	Cost/worth			1,00000	1,11691	**1,94762**

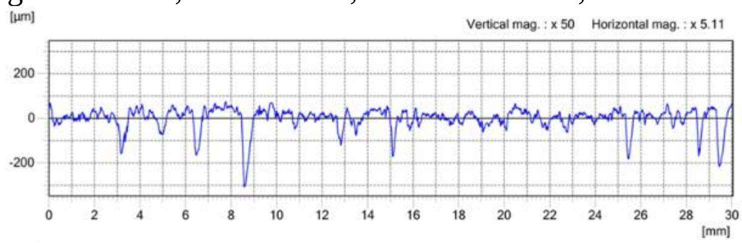
In the cost calculation, assumptions are made using corporate loan rates from Bank Central Asia (BCA) with an average interest rate from 2020-2023 at 6.79%. The inflation rate used is as of September 2023, at 2.28%. The project duration follows the initial implementation plan, which is 1 year starting from January 2023 and ending in December 2023. The total cost for all formwork work in the complex of BRIN Jogja Building is calculated to be 9427.11 m².

The lowest NPV value is obtained for alternative 2, or the PERI DUO formwork, at Rp 824,921,997, resulting in savings of Rp 781,716,191 or **48,66%** compared to conventional plywood. Notably, the cost savings value is greater than zero (x > 0), and the cost/worth is 1.94762 (x > 1), defining the feasibility of using this alternative from a cost perspective.

The cost calculation indicates that the DUO formwork is the most economical, despite having the highest unit price analysis, due to its rental system. PT. PERI Indonesia will repurchase (buyback) all main and supporting materials up to 75% (the amount used in this calculation is 60%) of the purchase price at the end of the project implementation, providing salvage value. On the other hand, cost savings for the film-faced plywood formwork result from the repetition of the main formwork material, which is greater than that of conventional plywood.

Surface quality

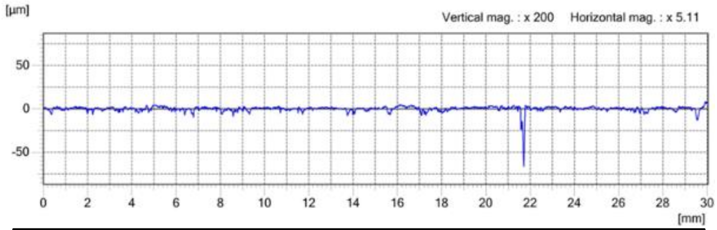
The most commonly used calculation for surface quality is the average roughness (Ra) (Santos, et al., 2012). Surface roughness test were conducted in the laboratory for the concrete resulting from the original method, alternative 1, and alternative 2, with the following results.



Ra	31.8796 µm
Ramax	46.0294 µm
Ramin	21.4032 µm

Ra	24.5497 µm
Ramax	29.4209 µm
Ramin	21.3657 µm

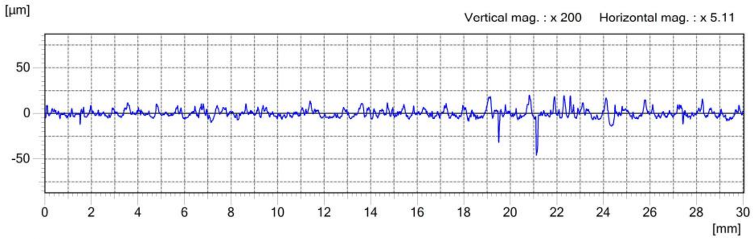
From the surface profile results, it can be observed that the surface of the concrete produced by the conventional wood method has an uneven contour with several concave holes indicated by the depressions in the profile readings. From the observations, these holes are caused by air bubbles trapped in the concrete mix during wet conditions. Meanwhile, for the overall surface roughness, the average roughness (Ra) from both observations is found to be **28.21465 µm**.



Ra	1.8283 µm
Ramax	2.6153 µm
Ramin	1.5006 µm

Ra	1.6579 µm
Ramax	1.8807 µm
Ramin	1.2741 µm

From the surface profile results, it can be observed that the surface contour is very smooth, with no observed concave holes in the concrete surface samples. Meanwhile, for the overall surface roughness, the average roughness (Ra) from both observations is found to be **1.7431 µm**.



Ra	3.4119 µm	Ra	3.5721 µm
Ramax	4.1020 µm	Ramax	5.0162 µm
Ramin	2.7314 µm	Ramin	2.5746 µm

From the results of surface profile, it can be observed that the surface is very smooth but still has contours. Only depressions due to the pattern of the PERI DUO polymer formwork surface were found in the concrete surface samples during the observation. Meanwhile, for the overall surface roughness, the average roughness (Ra) from both observations is **3.492 µm**.

The quality of the concrete surface is greatly influenced by the method and material of the formwork (Schipper, 2015). Surface roughness depicts the conditions during the concrete curing phase inside the formwork mold. Conventional plywood formwork has hydrophilic properties, meaning it attracts water. This results in a significant adhesion force between the concrete surface and the formwork. During the demolition phase, the adhesion force between the two surfaces becomes substantial due to the concrete curing, leading to damage to some parts of the concrete surface that adhere to the formwork or vice versa.

In contrast, the duo formwork, which is made of plastic polymer, minimizes adhesion forces because this material is hydrophobic or water-repellent. Therefore, the cohesive forces between concrete molecules become stronger than those between concrete and formwork. The same principle applies to plywood formwork coated with a film layer.

The surface finish of film-coated formwork lacks the texture found in duo formwork. The texture on the surface of duo formwork is useful in creating air pockets between the formwork and concrete, reducing the force required for demolition. It is observed that the demolition process for film-coated plywood formwork requires the most effort due to its very smooth surface, creating a vacuum space between the formwork and concrete.

Time

The observed duration for the installation of a column with a surface area of 5.94 m² requires an average time of 13.86 minutes with a workforce of 4 people per column. Thus, the rough working time per square meter (Tn) is determined to be 2.3333 minutes/m². By estimating the normality test and the amount of data, an adjustment factor is used to determine the standard time (Ts) required for this task as follows (Suwandi et al., 2020).

$$\boxed{Ts = Tn + (\text{looseness factor} \times Tn)}$$
$$Ts = 2{,}33 + (0{,}285 \times 2{,}33) \qquad (1)$$
$$Ts = 2{,}99405 \text{ minute/m2}$$

After obtaining the standard time, the productivity coefficient for the unit cost (D) can be calculated using the following formula:

Total working hours per day (A) = 8 hours
Number of workers (B) = 4 people
Working hours for formwork per day (C) =

$$\boxed{C = \frac{Ts}{(60 \text{ min} \times A)}}$$
$$C = \frac{2{,}99405}{(60 \text{ min} \times 8)} \qquad (2)$$
$$C =\approx 0{,}00625$$

$$\boxed{D = C \times B}$$
$$D = 0{,}00625 \times 4 \qquad (3)$$
$$D = 0{,}025 \text{ Man} - \text{Day}$$

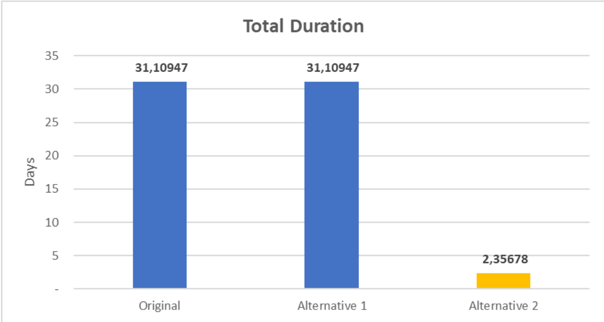
After obtaining the productivity coefficient, the total duration (T) for the formwork job item can be calculated using the following formula:

Total volume of formwork (V) = 9427.11 m²
Total number of workers (n) = 100 people

$$\boxed{T = \frac{D \times V}{n}}$$
$$T = \frac{0{,}025 \times 9427.11}{100} \qquad (4)$$
$$T = \mathbf{2,356\ days}$$

For the original method, namely conventional formwork, and alternative 1, whose coefficients are already known, their duration calculations are also conducted.

$$T = \frac{0{,}330 \times 9427.11}{100}$$
$$T = \mathbf{31,109\ days}$$



For the non-system formwork methods such as conventional plywood and plywood, it is found that their duration is considerably long. This is due to the process of formwork activities, which includes fabrication, installation, and deconstruction. The fabrication of wooden formwork requires a significant amount of labor for cutting and assembling materials, consuming a considerable amount of time (Al-ashwal, 2017). Formwork systems, on the other hand, do not involve a fabrication phase, which can significantly reduce the overall time. As for the PERI DUO polymer formwork, it adopts the theme of "1-man assembly," where the installation and deconstruction processes are made extremely easy and can be performed by a single experienced worker.

Score

After assessing the indices of the original and alternative methods based on cost, surface quality, and duration of work criteria, the evaluation method employed was the proportional scoring method. The summarized data for each method per criterion can be seen in the following table.

	Conventional Multiplex	Film Multiplex	DUO Polymer
Cost	Rp1.606.638.188	Rp1.438.470.765	Rp824.921.997
Surface quality	28,21465	1,7431	3,492
Time	31,109 day	31,109 day	2,356 day

The method used is Multi-Criteria Analysis (MCA) with simple rating and proportional scoring weighting (Dean, 2022). This weighting assigns values to each criterion according to the Likert scale (1-5). The weights are then calculated based on the percentage of the total value of all criteria. The results of the criteria assessment using the questionnaire obtained are as follows.

31	5	3	5
32	5	3	5
33	5	3	4
34	5	3	4
Total	**160**	**138**	**160**
		458	
Percentage	**34,93%**	**30,13%**	**34,93%**

From the data, an assessment was conducted where the worst performance for each criterion was assigned a value of 0, and the best performance was assigned a value of 1. For values in between, the assessment was done using the following formula (Dean, 2022), resulting in the following evaluations.

$$\text{Score (x)} = \frac{\text{Performance (x)} - \text{worst performance}}{\text{best performance} - \text{worst performance}}$$

	Conventional Multiplex	Film Multiplex	DUO Polymer
Cost	0,00	0,22	1,00
Surface quality	0,00	1,00	0,93
Time	0,00	0,00	1,00

The index is then multiplied by the weight of each criterion to obtain the total final score for each method.

Criteria	Weight	Conventional Multiplex		Film Multiplex		DUO Polymer	
		Score	Weighted score	Score	Weighted score	Score	Weighted score
Cost	34,93%	0,00	0,00	0,22	7,52	1,00	34,93
Surface quality	30,13%	0,00	0,00	1,00	30,13	0,93	28,14
Time	34,93%	0,00	0,00	0,00	0,00	1,00	34,93
Total	100,00%	0,00		37,65		98,01	
Ranking		III		II		I	

The highest final score is obtained by PERI DUO formwork with a total score of 98.01, followed by film-faced plywood formwork with a score of 37,65, and lastly, conventional plywood formwork with a total score of 0. This final score will be the basis for consideration in the recommendation phase.

4. Development phase

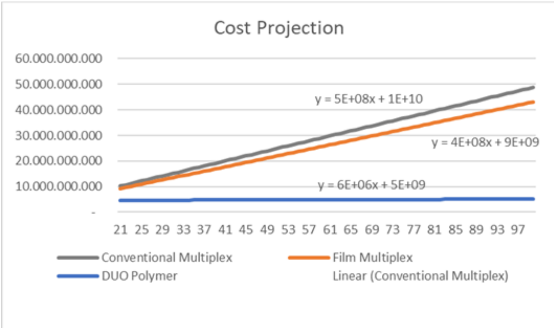
Cost projection

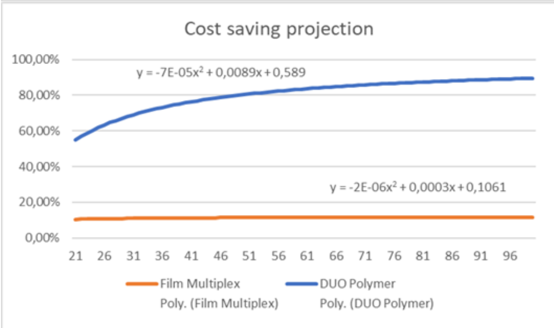
After calculating the total costs for all methods in the evaluation stage, cost projections were made for the future development of the methods. Projections were calculated to determine the impact of method usage on a larger project scale. The table of cost projections per floor number is as follows.

Floor count	Total Cost			Cost Saving	
	Conventional Multiplex	Film Multiplex	DUO Polymer	Film Multiplex	DUO Polymer
0					
1	69.551.437	84.268.366	505.113.115	-21,16%	-626,24%
2	139.102.873	145.440.308	510.761.222	-4,56%	-267,18%
3	208.654.310	206.612.250	516.412.507	0,98%	-147,50%
4	278.205.747	267.784.192	522.066.913	3,75%	-87,65%
5	347.757.183	328.956.133	527.724.384	5,41%	-51,75%
6	417.308.620	390.128.075	533.384.862	6,51%	-27,82%
7	486.860.057	451.300.017	539.048.292	7,30%	-10,72%
8	556.411.494	512.471.959	544.714.619	7,90%	2,10%
9	625.962.930	573.643.901	550.383.787	8,36%	12,07%
10	695.514.367	634.815.843	556.055.742	8,73%	20,05%
11	765.065.804	695.987.784	561.730.429	9,03%	26,58%
12	834.617.240	757.159.726	567.407.794	9,28%	32,02%
13	904.168.677	818.331.668	573.087.784	9,49%	36,62%
14	973.720.114	879.503.610	578.770.346	9,68%	40,56%
15	1.043.271.550	940.675.552	584.455.427	9,83%	43,98%
16	1.112.822.987	1.001.847.493	590.142.975	9,97%	46,97%
17	1.182.374.424	1.063.019.435	595.832.938	10,09%	49,61%
18	1.251.925.861	1.124.191.377	601.525.263	10,20%	51,95%
19	1.321.477.297	1.185.363.319	607.219.901	10,30%	54,05%
20	1.391.028.734	1.246.535.261	612.916.800	10,39%	55,94%
21	1.460.580.171	1.307.707.203	824.926.661	10,47%	43,52%

25	1.738.785.917	1.552.394.970	856.342.185	10,72%	50,75%
30	2.086.543.101	1.858.254.679	895.264.417	10,94%	57,09%
35	2.434.300.284	2.164.114.388	933.802.754	11,10%	61,64%
40	2.782.057.468	2.469.974.097	971.959.512	11,22%	65,06%
45	3.129.814.651	2.775.833.806	1.009.737.325	11,31%	67,74%
50	3.477.571.835	3.081.693.515	1.047.139.123	11,38%	69,89%
55	3.825.329.018	3.387.553.224	1.084.168.107	11,44%	71,66%
60	4.173.086.202	3.693.412.933	1.120.827.723	11,49%	73,14%
65	4.520.843.385	3.999.272.642	1.157.121.643	11,54%	74,40%
70	4.868.600.569	4.305.132.351	1.193.053.747	11,57%	75,49%
75	5.216.357.752	4.610.992.061	1.228.628.098	11,61%	76,45%
80	5.564.114.936	4.916.851.770	1.263.848.927	11,63%	77,29%
85	5.911.872.119	5.222.711.479	1.298.720.619	11,66%	78,03%
90	6.259.629.303	5.528.571.188	1.333.247.690	11,68%	78,70%
95	6.607.386.486	5.834.430.897	1.367.434.777	11,70%	79,30%
100	6.955.143.670	6.140.290.606	1.401.286.625	11,72%	79,85%

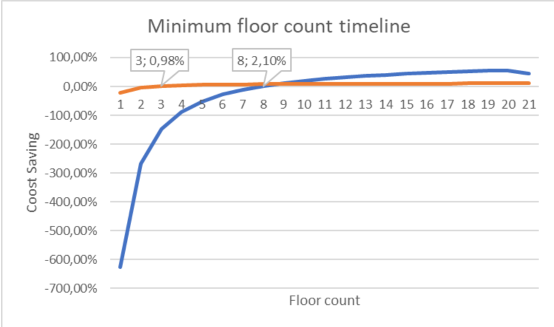
From the table above, a graph of cost projections and savings for the three methods is created as follows.





In terms of cost, all three exhibit a linear cost increase pattern with the order of the steepest gradient being conventional plywood, followed by film-faced plywood, and duo polymer. It is observed that as the number of floors increases, the cost difference between the three methods becomes more significant. Meanwhile, in terms of savings, a polynomial pattern is identified. The savings for the film-faced plywood method almost stabilize at 11% for a high number of floors, while the duo polymer method reaches an 80% saving compared to conventional plywood.

These results are attributed to the substantial percentage of labor costs in the film-faced plywood method (31.94% & 33.99%) relative to its production cost, as well as the suboptimal productivity coefficient of the method (0.330). This situation results in an overall increase in labor costs and total expenses with an increase in the number of floors. Additionally, the supporting materials of the film-faced plywood method need replacement every three uses to maintain quality and strength. In contrast, the labor cost for the duo polymer method is remarkably low (2.64%), and it boasts a favorable productivity coefficient (0.025). Therefore, an increase in the number of floors only leads to a minor additional cost. Moreover, the high repetition rate of this method allows for the possibility of not needing to replace formwork materials within a single project.



The minimum number of floors for this alternative use can also be seen from the table where the minimum floor count The film plywood will begin to achieve savings on a minimum of 3 floors, while for DUO polymer, savings will be realized for usage on a minimum of 8 floors.

5. Recommendation phase

The recommendation for the VE Study on the BRIN Building Complex is the implementation of an alternative method in the form of PERI DUO polymer formwork.

Discussion

The formwork is a work item with a high percentage of the total cost in the construction of multi-story buildings. The use of the duo polymer formwork is the most advantageous in terms of cost, concrete surface quality, and construction duration. The benefits of using this formwork will be even greater on a larger construction scale

CONCLUSION

In conclusion, the journey through this research on concrete formwork methods unveils a compelling narrative of innovation and optimization. Beginning with the historical backdrop of concrete construction dating back to 1824, the narrative progresses to highlight the pivotal role of formwork in ensuring quality and efficiency in construction projects. As the core structure of buildings, concrete and its supporting elements account for a significant portion of construction costs, necessitating a thorough exploration of alternative formwork materials and methods.

Through a systematic value engineering approach, the research delves into quantitative analysis and comparative assessments of various formwork materials, including conventional plywood, PERI T-plex phenolic film formwork, and the PERI DUO polymer formwork system. The analysis encompasses key criteria such as cost, surface quality, and construction duration, with the aim of identifying the most cost-effective and efficient solution.

The findings reveal that the PERI DUO polymer formwork emerges as the standout alternative, offering superior cost-effectiveness, enhanced surface quality, and streamlined construction timelines compared to conventional plywood and film-faced plywood alternatives. Notably, the DUO polymer formwork demonstrates significant cost savings, improved concrete surface quality, and reduced construction duration, making it the recommended choice for the BRIN Building Complex project.

In essence, the narrative of this research underscores the importance of continuous innovation and optimization in construction practices. By embracing alternative materials and methods, such as the PERI DUO polymer formwork, construction projects can achieve greater cost efficiency, quality, and timeliness, paving the way for a brighter future in the realm of concrete construction.

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