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Comparative Analysis of Formwork Systems: Cost Efficiency and Time Management in Construction Projects

Auliyah Shabirah Supriyono[1], I Nyoman Dita Pahang Putra[1*], Bambang Trigunarsyah[2]

[1]Department of Civil Engineering, Faculty of Engineering and Science, Universitas Pembangunan Nasional Veteran Jawa Timur, Raya Rungkut Madya Street, Gunung Anyar, Surabaya, 60294, Indonesia

[2]School of Property, Construction and Project Management, RMIT University, 360 Swanston Street, Melbourne, Australia

*putra_indp.ts@upnjatim.ac.id

Abstract. Formwork systems are essential for achieving efficiency and sustainability in multi-story construction. This study compares the cost and time efficiency of multiplex and aluminum formwork systems for constructing beams and slabs on the 6th to 13th floors. Field observations and a literature review were employed to gather data using a mixed-methods approach. This study adopts a mixed-methods approach, combining quantitative and qualitative methods. The findings reveal that aluminum formwork requires 60 days to complete, compared to 112 days for multiplex formwork, saving 52 days. Regarding cost, aluminum formwork amounts to IDR 1,805,910,198, offering savings of IDR 159,540,423 compared to multiplex formwork at IDR 1,965,450,621. Graphical analysis highlights the advantages of aluminum formwork in optimizing project workflows and reducing delays. These results demonstrate aluminum formwork potential to enhance efficiency, minimize material waste, and support sustainable construction practices. Future research is encouraged to explore alternative materials and labor strategies to advance sustainability in the construction industry further.

Keywords: formwork efficiency, sustainable construction, cost and time optimization.

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1. Introduction

In a construction project, material efficiency is a crucial factor influencing the project's success and sustainability. Construction materials such as concrete, steel, wood, and other resources often account for the largest portion of the total project cost. Therefore, material optimization is a strategic approach to reducing costs and enhancing project profitability. Incorrect material selection not only results in financial losses but can also prolong project duration, compromise the quality of the built structure, and increase environmental impacts due to construction waste [1-3].

Formwork is crucial in construction projects, contributing to overall costs. It is a temporary mold that shapes and supports fresh concrete until it achieves the desired strength. It requires sufficient rigidity to prevent excessive deflection and ensure tight connections between panels [4, 5]. Previous studies have focused on comparing the cost and time efficiency of various formwork systems, such as conventional, aluminum, semi-conventional, and peri systems. Additionally, aspects such as sustainability, labor efficiency, and the influence of material types on construction quality have been widely explored [1-3]. However, most research has focused on general cost comparisons, often neglecting in-depth analyses of project duration or large-scale sustainability considerations. Moreover, the relationship between formwork systems and repetitive floor patterns in high-rise buildings remains underexplored [6, 7]. This study addresses these gaps by evaluating the cost and time efficiency of multiplex and aluminum formwork systems in repetitive floor construction, providing new insights into sustainable and efficient construction practices.

Various formwork methods have been widely implemented in Indonesia, including conventional and semi-modern approaches. A primary drawback of the conventional method is material waste that cannot be reused for subsequent formwork operations [8]. Formwork costs account for approximately 40% to 60% of the total cost of concrete works or around 10% of the overall building construction expenses. This highlights that formwork is a critical aspect that warrants thorough review, particularly considering that the current conventional systems still offer potential for efficiency improvements [9]. In addition, the availability of timber for formwork has been steadily declining over time. This is primarily due to the limited and decreasing supply of raw materials from forests, compounded by the growing demand for timber to meet various other needs [10].

Conventional formwork is generally constructed using timber planks or beams supported by wooden frameworks. While it can be dismantled and reused in various configurations, its limited service life and susceptibility to damage pose challenges to its efficiency and durability, particularly in long-term construction projects [11]. One of the main challenges in using conventional formwork is the potential decline in concrete quality due to various factors, such as imperfections in the formwork surface, deformation caused by moisture, and shifts during the pouring process. These issues result in additional costs, extend project duration, and reduce overall work efficiency [12-14]. As an alternative, aluminum formwork offers several advantages, particularly in quality and durability. Aluminum is more resilient, not easily damaged or deformed during the pouring process, and it produces smoother and more consistent concrete surfaces. Aluminum formwork offers the advantage of faster installation times, supported by its ease of implementation. This type of formwork is particularly suitable for high-rise building construction with typical floor layouts [6, 15, 16].

This study focuses on the construction of a 13-story building. It will provide a detailed analysis of the technical aspects of formwork in construction projects. The formwork used in this project is conventional, made of wood or plywood, which is still widely used in the industry. This research focuses on calculating floor slabs and beams, as these structural elements are critical in determining the stability and overall strength of the multi-story building. Floor slabs and beams require an amount of formwork, so selecting and managing the appropriate formwork type can impact the project's overall efficiency, both in terms of cost and time [17].

Therefore, comparing conventional formwork and aluminum formwork is essential, particularly in cost and time. This analysis will provide a clearer understanding of the efficiency of both methods. The findings of this study will serve as an essential reference in decision-making regarding the most suitable formwork method to achieve optimal quality and efficiency in construction projects [18].

2. Methods

This study adopts a mixed-methods approach, combining quantitative and qualitative methods to compare the efficiency of conventional and aluminum formwork in multi-story building projects. The quantitative method analyses data related to conventional formwork through field observations, interviews, and reviews of project documents, reports, plans, and installation methods. It aims to provide detailed cost and time efficiency calculations based on field data. The qualitative method evaluates aluminum formwork efficiency using secondary data from previous studies and scientific journals. These sources provide insights into concrete quality, formwork durability, and time and cost efficiency from similar projects. By leveraging qualitative insights from the literature, this study explores the benefits and challenges of aluminum formwork in greater depth [19, 20]. Statistical analysis was conducted using Microsoft Excel and MS Project software to ensure cost and time calculations. The methodology has certain limitations. The cost analysis focuses solely on material and installation costs and the duration of formwork construction, excluding additional expenses like logistics and transportation. This study also does not address potential technical issues during installation, such as equipment damage or assembly errors.

The subsequent step involves compiling a unit price list for materials for each formwork method. An analysis is then conducted on the unit cost of work based on the respective formwork methods. Following this, cost estimates for each formwork method are prepared. Finally, a construction schedule is developed for each formwork method, designed based on field observations, interviews with relevant parties, and a review of the literature [21].

The next step is to calculate the required volume of formwork. The calculation of the volume of formwork needed for beams and slabs follows these equations:

$$\text{Formwork area for Beams} \quad = 2 \times (Height \times Length) + Width\ x\ Length \tag{1}$$

$$\text{Formwork area for Slab} \quad = Length \times Width \tag{2}$$

Equation 1 calculates the formwork volume for beam elements, while Equation 2 provides the surface area required for slab formwork. These calculations yield precise data on the material quantities needed for beams and slabs. To calculate the time comparison for each implementation method, the calculation is performed using Equation 3 [22].

$$\text{Duration} \quad = \frac{Work\ Volume \times Productivity}{Number\ of\ Workers} \tag{3}$$

Equation 3 integrates work volume, labor productivity, and the number of workers to calculate the project duration. It evaluates the differences in completion times between aluminum and conventional formwork systems. The calculations were performed for floors 6 to 13, as these are typical floors, making aluminum formwork more practical. Aluminum formwork was selected due to its reusable nature, which enhances efficiency in construction execution. The results were presented using a line chart to compare the costs of the two formwork methods for each project floor. The graph features the X-axis representing the execution dates and the Y-axis displaying the expenses incurred, measured in billions of Indonesian Rupiah (IDR). This visual representation provides a clear comparison of the costs for both formwork methods across the project floors and offers insights into the time efficiency of each technique.

3. Results and Discussion

3.1. Data Analysis

The data analysis conducted in this study focuses on the costs and time associated with using multiplex and aluminum formwork. The calculations related to costs and time require data on the volume of formwork needed for floor slabs and beams. The beam and slab layouts are presented in figure 1.

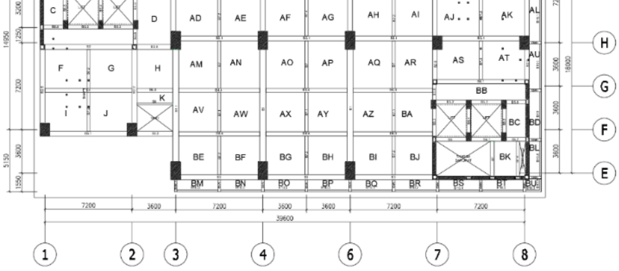

Figure 1. Beam and slab layout

Further details on the dimensions of each beam type can be found in table 1.

Table 1. Detail on the dimensions of Beam

Beam Name	Dimensions (mm)
B1	500.900
B2	400.800
B3	400.700
B4	350.650
B5	300.500
B7	250.400
B8	150.350
B9K	200.350
B10	150.300
BT	300.400

Table 1 provides the dimensions of each type of beam used in the project, further categorized based on the span length of each beam.

3.2. Calculation Analysis

3.2.1 Volume Calculation

Calculations were performed using the obtained data to determine the required volume of formwork. Below is an example calculation for the volume needed for beams and floor slabs.

1. Beam Calculation

Using the type of Beam B7 (250.400) mm with a span of 3.251 m

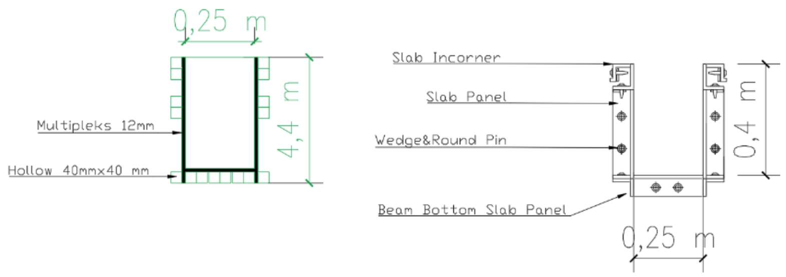

Figure 2. Detail of Beam B7.1 with Aluminum and Conventional Formwork

Figure 2 illustrates the detailed structure of Beam B7.1, comparing conventional formwork (on the left) and aluminum formwork (on the right).

Using the equation in number 1 to calculate the multiplex formwork required

= 2 × (Height × Length) + Width × Length

= 2 × (0.44 ×3.251) + 0.25 × 3.251

= 3.67363 m^2

The calculation example shown above was carried out for a beam with a span of 3.251 m, which in this project is further classified as beam B7.1. The naming of the beam follows a specific numbering system based on its span length, making identification easier.

Table 2. Beam Formwork Volume Calculation

Beam Name	Dimensions (mm)	Volume of Formwork (m^2)
B1	500.900	63.882
B2	400.800	170.3685
B3	400.700	107.4985
B4	350.650	148.9885
B5	300.500	57.948
B7	250.400	81.8685
B8	150.350	6.4975

Beam Name	Dimensions (mm)	Volume of Formwork (m^2)
B9K	200.350	18.806
B10	150.300	75.1865
BT	300.400	7.714
Total		738.758 m^2

The calculation of formwork volume presented in table 2 includes the total material requirements for each beam type. Table 2 serves as a reference for quantitatively assessing formwork needs, while also aiding in calculating costs and installation durations for each project floor. In conventional formwork, the main requirements include 40 mm x 40 mm hollow sections with four length variations: 1 meter, 1.5 meters, 2 meters, and 3 meters. Additionally, conventional formwork uses multiplex as the primary material for the mold, supporting the pouring process. In contrast, aluminum formwork uses a more modern panel system, consisting of slab panels and beam bottom slab panels to support the beam elements. Aluminum formwork is designed to simplify the installation and dismantling process, with the main advantages being more extended durability and the ability to be reused multiple times. This system does not require hollow sections or multiplex, thus reducing material waste. The next step involves calculating the volume of formwork for each beam type, with results shown in Table 2.

2. Slab Calculation

The names of the floor slab types can be seen in figure 1 and the beam and slab layout. An example calculation is shown for floor slab type AB, with a length of 3.475m and a width of 3.225m.

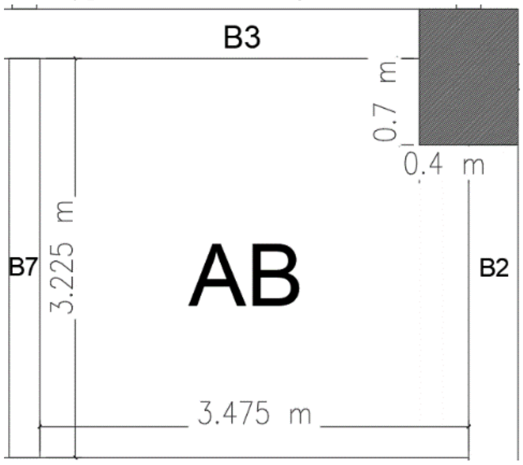

Figure 3. Beam Type AB

The calculation is performed using equation number 2.

Formwork area for slab = Length × Width = 3.475 × 03.225 = 11.20688 m^2

In calculating formwork requirements for the floor slab, it is important to consider the reduction in area occupied by other structural elements such as columns or shafts. This reduction is necessary because these areas already have their formwork, so they are not included in the calculation of the slab formwork area.

Next, the floor slab formwork area is reduced by the area occupied by the column

Formwork area for slab = Length × Width = 0.7 × 0.4 = 0.28 m^2

Floor slab formwork area = Formwork area for Slab – Column Area

= 11.20688 - 0.28 = 10.926875 m^2

The next step involves calculating the volume for each type of floor slab individually. After completing the calculations for all slab types, their volumes are summed up, resulting in a total floor slab volume of 562.984 m^2.

In conventional formwork for floor slabs, the primary requirement remains to use 40 mm x 40 mm hollow sections as support elements beneath the slab, which are then supported by the mainframe. Additionally, the multiplex is used as the primary material for the mold to help the pouring process on the surface of the floor slab. In contrast, aluminum formwork for floor slabs employs a more modern system that utilizes slab panels as the primary mold element. This system is supported by unique prop heads explicitly designed to support the slab panels, aiming to improve the efficiency of both installation and dismantling processes.

3.2.2 Unit Price Analysis Formwork

Differences in material prices and labor wages across regions lead to variations in unit costs for construction work. Therefore, project budget calculations must be adjusted to reflect local material prices and labor wages. Each task in the project plan should have its unit price calculated based on the quantity, type, and specifications of materials, as well as the labor required, including formwork [23].

A. Conventional Formwork

The analysis involves calculating material volumes and labor productivity. The unit price of work (HSP) is derived from Surabaya's HSPK, which is subsequently processed and adjusted to align with actual field conditions. These adjustments aim to ensure more precise calculations that meet the specific requirements of the construction project. Based on the findings, the cost of slab construction using conventional formwork is IDR 218,954/ m^2, while the price of beam construction using conventional formwork is IDR 249,176/ m^2.

B. Aluminum Formwork

This analysis involves a detailed calculation of the main components and supporting accessories used in aluminum formwork for beam and slab construction. The components analyzed include slab bottom panels, round pins and wedges, release agents, slab corners, supports, and head props [18]. The analysis is based on literature and technical references discussing the characteristics of aluminum formwork, which the authors further process. Additionally, the unit price of work (HSP) is evaluated using a theoretical approach supported by relevant field data. The analysis reveals that the cost of slab construction using aluminum formwork is IDR 720,622/m^2, while the price of beam construction with aluminum formwork is IDR 969,022/m^2 for the initial usage. For subsequent reuse, however, the cost per square meter decreases to IDR 75,102/m^2 for both slabs and beams. After performing the price analysis for the slab and beam work, the next step is to conduct a formwork cost analysis.

3.2.3 Formwork Cost Analysis

The cost analysis is done by multiplying the work volume by the unit price per meter [24]. The structure from the 6th to the 13th floor is typical, making the calculation pattern uniform. Conventional formwork can be used twice, while aluminum formwork is reusable multiple times. In its second use, conventional formwork requires additional materials such as nails and release agents to maintain its function. On the other hand, in its second use and beyond, aluminum formwork utilizes the same components, only requiring the addition of a release agent. In this analysis, after detailed calculations of volume and cost, a price comparison between conventional and aluminum formwork was obtained, as presented in the table below.

Table 3. Total formwork cost for all floors.

Formwork Type	Slab (IDR)	Beam (IDR)	Total (IDR)
Multiplex	678,480,393	979,621,476	1,658,101,869
Aluminums	701,664,975	1,104,245,223	1,805,910,198

Table 3 compares the total material costs of formwork for various types of work, specifically for slabs and beams, using multiplex and aluminum formwork. The results show that multiplex formwork requires a total cost of IDR 678,480,393 for slab work, while aluminum formwork costs IDR 701,664,975. For beam work, multiplex formwork costs IDR 979,621,476, whereas aluminum formwork costs IDR 1,104,245,223. The total cost for conventional formwork amounts to IDR 1,658,101,869, while aluminum formwork costs IDR 1,805,910,198, resulting in a cost difference of IDR 147,808,328.

3.2.4 Comparison of Formwork Duration

The scheduling of aluminum formwork is adjusted to the project schedule, ensuring its implementation aligns with the overall construction workflow. Meanwhile, the duration of the installation of the aluminum formwork depends on the volume of work that needs to be completed [25]. The time comparison for each implementation method is calculated using Equation 3. This study's workforce is standardized, with ten workers assigned to column and shear wall tasks and 20 workers assigned to slab and beam tasks. Working hours are from 08:00 to 12:00, followed by a break, and then from 13:00 to 17:00, with work scheduled from Monday to Sunday. Based on interviews with the formwork subcontractor in the field, the labor productivity for conventional formwork work is 0.2.

For aluminum formwork, worker productivity values are obtained from relevant literature. The duration of work per square meter, measured in minutes, calculates the execution coefficient of aluminum formwork for columns, beams, and slabs per day. The total work coefficient is determined by summing the time coefficients for three tasks: formwork installation, formwork reinforcement, checking the alignment and stability (verticality), and formwork removal after the pouring process is completed. The productivity value is calculated based on similar working conditions, including the same workdays as the current project schedule, which is 0.05.

The total work duration is derived by summing the time required for each process step for aluminum formwork on beams and floor slabs. These steps include formwork installation (15 minutes), adjustments (2 minutes), and formwork removal (6 minutes). The total time for all processes is 23 minutes. To calculate the daily work execution coefficient, the total duration is divided by the total minutes in one working day (480 minutes, with 8 hours of work per day). Based on this calculation, the execution coefficient is 23 divided by 480, which equals 0.05 per day. This indicates that in one working day, the productivity rate for aluminum beam formwork is 0.05 units. The project uses MS Project software to calculate the duration for each floor [22].

This project's conventional formwork process is repeated for each typical floor with a uniform pattern, covering the installation of formwork for structural elements such as floor slabs, beams, columns, and shear walls. The duration of each component has been determined: 13 days for columns and shear walls and 14 days for slabs and beams. Therefore, the total time required to complete the structure on one floor is 20 days. In the conventional formwork schedule, column and shear wall work begins first, but slab and beam work starts a few days after the column work begins, so both activities run concurrently. The construction work starts on the 6th floor and progresses to the 13th floor, with each stage dependent on the completion of the preceding one. The process of conventional formwork begins on June 21, 2024, and is scheduled to be completed by October 10, 2024, requiring 112 days to complete the conventional formwork process. The calculation of the work duration for columns using aluminum formwork is performed using Equation 3

$$\text{Duration} = \frac{Work\,Volume\ \ x Productivity}{Number\ of\ Workers} = \frac{643.428\ x\ 0.05}{10} = 3.2 \approx 4$$

The duration obtained from the calculation is rounded to 4 days for the column work. Next, for the beam and slab work.

$$\text{Duration} = \frac{Work\,Volume\ \ x Productivity}{Number\ of\ Workers} = \frac{1.309.209\ x\ 0.05}{20} = 3.2 \approx 4$$

The duration obtained from the calculation is rounded to 4 days for the beam and slab work.

The start of aluminum formwork installation differs from the conventional formwork due to the dependency of the 6th-floor construction on the completion of supporting structural elements, such as columns and shear walls on the 5th floor, which are assumed to have been constructed using conventional formwork. The aluminum formwork installation began on June 27, 2024, and is scheduled to finish on August 25, 2024, resulting in a total duration of 60 days.

3.3. Graphical Representation of Findings

After conducting calculations of cost and time between aluminum formwork and conventional formwork, the graph highlights the differences between the two types of formworks in terms of price and duration of execution.

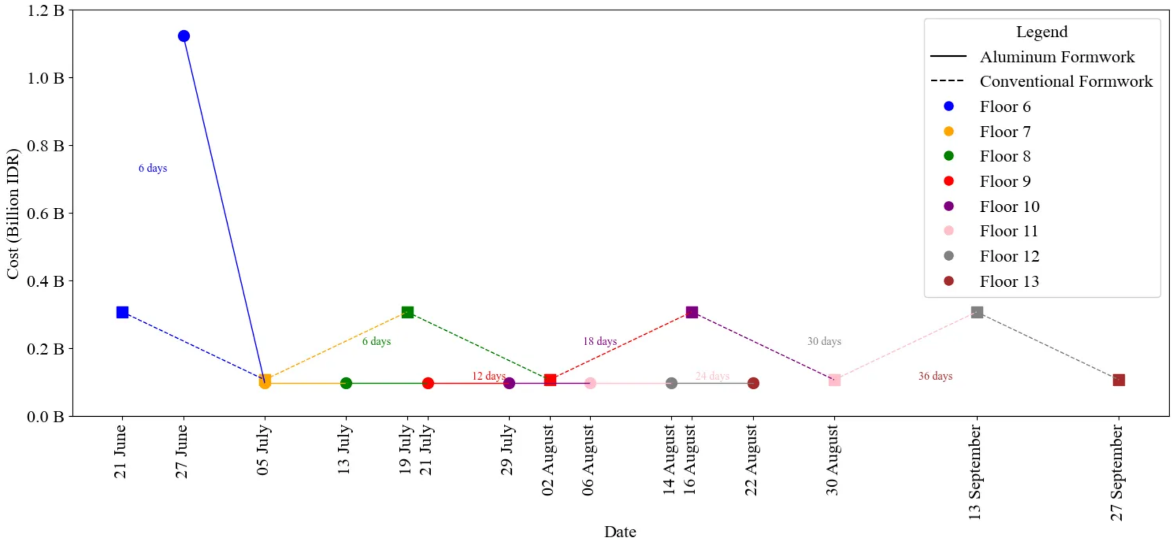

Figure 4. Comparison of Aluminum and Conventional Formworks by Floor Level

The installation of aluminum formwork on the 6th floor experienced delays compared to the conventional formwork. This was due to the dependency of the 6th-floor construction on the completion of supporting structural components, such as columns and shear walls, on the 5th floor. As a result, the aluminum formwork installation commenced on June 27, 2024, while the conventional formwork installation began earlier, on June 21, 2024. This delay was assumed because the previous floor primarily utilised conventional formwork. However, for subsequent floors, aluminum formwork consistently managed to start earlier than the conventional formwork. Figure 4 highlights the differences in costs and start times for formwork installations between aluminum and conventional systems across the project floors. On the 7th floor, aluminum formwork was installed 6 days earlier than the conventional system. This time difference increased on the 8th floor, where aluminum installation began 12 days earlier. The gap widened further on the 9th floor, with aluminum installation starting 18 days earlier. On the 10th and 11th floors, the difference extended to 24 days, and on the 12th floor, it grew to 30 days. By the 13th floor, aluminum formwork was installed 36 days earlier than the conventional system. In terms of costs, aluminum formwork required an initial cost of IDR 1.12 billion for the 6th floor, stabilising at IDR 0.0977 billion per floor for subsequent installations. Meanwhile, conventional formwork incurred an initial cost of IDR 0.307 billion, which decreased to IDR 0.107 billion for reuse on the following floors. Despite its higher initial cost, aluminum formwork demonstrated superior efficiency through earlier start times and consistent costs, making it an effective choice for large-scale construction projects that prioritise time and cost optimisation.

3.4. *Discussion*

The comparative analysis between conventional and aluminium formwork, particularly in terms of cost and time, aims to evaluate the efficiency of these two types of formwork. The analysis begins with calculating the required formwork volume for beams and slabs and then determining the unit cost of formwork installation. The next step involves calculating the total cost based on the volume and unit price of the work. The results indicate that the total beam formwork volume is 738.758 m², while the total slab formwork volume is 562.984 m². The calculated cost for formwork installation for slabs and beams from the 6th to the 13th floor using conventional formwork is IDR 1,965,450,621, whereas aluminum formwork costs IDR 1,805,910,198. This results in a cost difference of IDR 159,540,423 between conventional and aluminum formwork. The project duration was determined through interviews and literature studies and analysed using Microsoft Project. The duration required for conventional formwork was 112 days, while aluminum formwork was obtained as 60 days. Figure 4 illustrates the relationship between construction costs and the commencement of work on each floor, visually comparing aluminum and conventional formwork systems. Notably, the graph shows distinct differences in the initiation of work for each floor, with aluminum formwork facilitating faster progression due to its streamlined installation process. In the graph, the installation of aluminum formwork on the 6th floor experienced delays compared to conventional formwork. This delay was caused by the dependency of the 6th-floor construction on the completion of supporting structures, such as columns and shear walls on the 5th floor, which were assumed to have been constructed using conventional formwork.

These findings are consistent with previous research conducted by Ma'arif and Fauzi [1], highlighting aluminum formwork's cost-saving potential in large-scale projects. Furthermore, the detailed floor-by-floor analysis in this study builds upon the work of Radziejowska and Sobotka [2], who focused on general cost and time efficiency but did not delve into the dynamics of repetitive floor construction. By incorporating a granular perspective, this study extends prior research by demonstrating how aluminum formwork can optimize workflow in multi-story projects, providing actionable insights for practitioners. The findings demonstrate the potential of aluminum formwork as a sustainable solution in construction. Its reusability reduces material waste, enhances efficiency, and underscores the need for continuous innovation in formwork technology. Further exploration of alternatives, such as fibreglass, could improve efficiency while minimising environmental impact. Construction delays can also result from issues in the engineering drawing process, which often require agreement among the owner, main contractor, and subcontractor. On-site modifications cannot be made unilaterally, leading to potential disruptions in project timelines [26]. The analysis aligns with theoretical frameworks on sustainable construction, which advocate adopting innovative materials and methods to enhance efficiency and reduce environmental impacts. By demonstrating the benefits of aluminum formwork in repetitive floor construction, this study contributes to the ongoing discourse on sustainable construction practices, providing evidence for its practicality and long-term benefits. To build upon these findings, future studies could investigate additional factors, such as the impact of varying labour skill levels or alternative structural designs, to further optimise modern formwork systems.

4. **Conclusion**

Several conclusions can be drawn based on analysing the duration and cost of formwork work on the construction project for floors 6 through 13. The pattern of formwork usage indicates that aluminum formwork is more efficient in terms of time and cost in the long run. While conventional formwork may initially appear less expensive, its costs increase as the complexity of the floors rises. Therefore, aluminum formwork is more suitable for high-rise projects with efficiency-focused targets.

1. Using aluminum formwork demonstrates time efficiency compared to conventional formwork. Aluminum formwork requires 60 days, while conventional formwork takes 112 days, resulting in a duration efficiency of 52 days.
2. The total cost of aluminum formwork is IDR 1,805,910,198, while conventional formwork costs IDR 1,965,450,621, resulting in a cost savings of IDR 159,540,423. Although aluminum formwork is more

expensive, it offers superior time efficiency.

As mentioned, reusable aluminum formwork supports sustainability by reducing raw material use and improving efficiency. Evaluating its efficiency and environmental impact is crucial as the construction industry works towards sustainable practices. Future research could explore other sustainable formwork alternatives to optimise further cost, time, and environmental impact in construction projects.

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