Journal of Construction in Developing Countries, 25(2), 237–255, 2020

Analytic Hierarchy Process-Based Decision-Making Framework for Formwork System Selection by Contractors

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First submission: 21 January 2020; **Accepted:** 17 June 2020; **Published:** 15 December 2020

To cite this article: Seng Hansen, Pratama HR Siregar and Jevica (2020). Analytic hierarchy process-based decision-making framework for formwork system selection by contractors. *Journal of Construction in Developing Countries*, 25(2): 237–255. https://doi.org/10.21315/jcdc2020.25.2.10.

To link to this article: https://doi.org/10.21315/jcdc2020.25.2.10

Abstract: This article presents a study of the contractors' preference for formwork system selection in Indonesian context. As decision makers, contractors are faced with challenges in choosing the formwork system for a particular project. While conventional timber formwork has been the most used formwork system in Indonesia, aluminium formwork is present although it has not been widely used. Thus, this research investigates the current practices of available formwork systems and its selection criteria in Indonesia. A decision-making framework (DMF) is developed by considering the appropriate assessment criteria for formwork system selection. This framework is then implemented through analytic hierarchy process technique. The result shows that contractors tend to choose aluminium formwork with a preference at 79% compared to conventional timber formwork with a preference at 21%. These findings can be used as considerations for contractors to start using aluminium formwork due to its excellence compared to conventional timber formwork. This study also proves that the proposed DMF can be applied and provides a sound decision related to formwork system selection.

Keywords: Analytic hierarchy process, Contractors, Decision-making framework, Formwork system selection, Indonesia

INTRODUCTION

Conventional timber formwork has been the most used formwork system in Indonesia. However, timber as a construction material used especially for formwork system has become significantly scarce (Budisuwanda, 2011). Indonesian forests as the source of raw material for timber formwork is rapidly decreasing while the demand continues to increase. In fact, the use of timber has been recorded to exceed the limit of the wood supply amount set by the Ministry of Forestry (Forest Trends and Anti Forest-Mafia Coalition, 2015).

Due to this fact, Supriyatna (2016) argued that construction innovations which focus on environmental protection must be encouraged. One of these innovations is the use of aluminium formwork system as an alternative to conventional timber formwork. While aluminium formwork has been widely used in other Asian countries such as South Korea, Japan, Singapore and Malaysia, there are limited records of its usage in Indonesia. The aluminium formwork supplier has just entered to Indonesian market in 2016 and only some projects have used this system. An obstacle from the lack of aluminium formwork usage is related to the process for deciding

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priorities for formwork system. Therefore, this article aims to develop a decision-making framework (DMF) for the selection of formwork system by contractors. This framework was developed using analytic hierarchy process (AHP) technique based on multiple selection criteria. AHP is a flexible multi-criteria decision-making (MCDM) technique that deals with qualitative variables. It allows decision makers to make decisions in a hierarchical and logical manner. Finally, this framework has been implemented and evaluated through expert judgement.

LITERATURE REVIEW

Formwork Systems

Formwork is a temporary structure that is installed to hold the load of concrete at the time of pouring and released for reuse in the future (Nemati, 2007). It serves to provide shape to the concrete material, obtain the desired concrete surface structure and provide support until the concrete is hard enough to carry its own load.

Nawy (2008) describes three aspects in formwork planning, i.e. quality, safety and economy. Quality aspect of formwork is characterised by its stiffness and accuracy, including the shape, size and position in accordance with the plan, as well as the density of the formwork to produce a smooth concrete surface. Safety aspect refers to safety considerations when formwork is planned so that it does not collapse or cause danger. Here, formwork's stability and robustness are required so that it can rigidly withstanding the load without shifting from its original position. Economy aspect can be achieved with efficient use of formwork that save time and cost. Three main factors in optimising the cost-effectiveness of formwork planning are maximum reuse, economical form of assembly, and efficient formwork installation and dismantling.

Formwork was first made with timber and is still extensively used in construction projects. Formwork that used timber and plywood is also called as conventional formwork system. Due to its nature, timber formwork has a relatively short lifespan. The development of formwork system has introduced the use of metal frame (usually aluminium) as the main formwork material. Compared to conventional timber formwork, aluminium formwork has several advantages including the speed of installation/dismantling, lower life cycle costs, and higher safety considerations. This research focuses on comparing these two systems.

Formwork is the biggest cost component in concrete structural work. It costs about 40% to 60% of concrete work and 10% of overall construction work (Hanna, 1998). On the other hand, aluminium formwork has higher initial investment cost rather than conventional timber formwork. However, 80% of aluminium formwork panel can be reused for next projects with approximately 120 to 250 times usage while timber formwork can only be reused for 4 to 5 times. A Hong Kong study found that the aluminium formwork cost could be reduced up to 40% when reuse for 100 times compared with reuse for 50 times (Poon, Yu and Ng, 2003). Thus, aluminium formwork may provide lower life cycle cost compared to conventional timber formwork.

Table 1. Comparison of Conventional Timber Formwork and Aluminium Formwork

Conventional Timber Formwork	**Aluminium Formwork**
Mainly made from timber and plywood (Pratama et al., 2017).	The panels and all accessories are mainly made of aluminium which is environmentally friendly (Poon, Yu and Ng, 2003).
May use crane to move the formwork system (Gazali, 2018).	The panels are light weighted and designed to be carried by workers so it does not need a crane (Poon, Yu and Ng, 2003).
70 to 80 people per 1,000 m^2 and there must be carpenters (Gazali, 2018).	40 to 50 people per 1,000 m^2 and there is no specific skill required (Gazali, 2018).
Floor to floor duration usually reaches 12 days (Dong, 2016).	It is possible to reach floor to floor duration in 4 days (Jayasinghe and Fernando, 2017).
Low costs (Pratama et al., 2017).	Initial investment costs are relatively high but become cheaper with reuse (Poon, Yu and Ng, 2003).
The connection between beam and column is visible (Samant, 2014).	Smooth concrete surface without visible connection (Samant, 2014).
Need plastering and/or finishing coat (Jayasinghe and Fernando, 2017).	Seldomly need plastering work (Jayasinghe and Fernando, 2017).
Supports must be removed when dismantling the formwork (Jayasinghe and Fernando, 2017).	Formwork may be dismantled without need to remove the support (Jayasinghe and Fernando, 2017).
Produce a lot timber waste (Gazali, 2018).	Formwork material does not produce waste, and slurry and concrete waste could be minimised (Poon, Yu and Ng, 2003).
Timber material is not durable for repeated use (Pratama et al., 2017).	Could be reuse until 120 to 150 times with good maintenance (Poon, Yu and Ng, 2003).
More flexible (Gazali, 2018).	Less flexible (Gazali, 2018).
No need for detailed planning/drawing (Gazali, 2018).	Need for detailed planning (Poon, Yu and Ng, 2003).

Regarding time aspect, aluminium formwork enables structural work to be completed in 4 days per floor compared with conventional timber formwork which needs up to 12 days (Dong, 2016). Since aluminium formwork is an engineered system, it can be dismantled without removing the falsework (supporting components). Since it provides smooth concrete surface, duration for finishing works such as plastering and coating can be eliminated (Samant, 2014). Gazali (2018) argued that the number of carpenters needed for formwork activities was 70 to 80 people per 1,000 m^2 (for conventional timber formwork) and 40 to 45 people per 1,000 m^2 (for aluminium formwork).

In quality aspect, aluminium formwork has two main advantages, i.e. consistency and accuracy. It is common in Indonesian projects to face several challenges related to concrete quality such as honeycombing in concrete, crazing, dusting, curling, scaling, cracking and unsmooth connections which are characterised as a non-conformance. These problems may occur due to poor formwork system. To overcome these problems, Gazali (2018) in his report provided the benefits in using aluminium formwork including consistent panel connections, smoothness of concrete surface and high accuracy of dimensions.

AHP

AHP is a MCDM technique used to assist decision makers in achieving at a sound decision. It is a framework of logic and problem resolving by organising decision makers' judgements into a hierarchy (Saaty, 1994). The hierarchy structure of an AHP model follows an inverted tree (Widianta et al., 2018).

The application of AHP in the field of construction management has been widely observed. For instance, Skibniewski and Chao (1992) demonstrate the viability of AHP technique in evaluating tower cranes technology. Li et al. (2013) develop an improved AHP to identify risks during an open-cut subway construction. Meanwhile, Darko et al. (2018) review the AHP application in construction management research using 77 articles published in 8 peer-reviewed construction management journals. Their findings indicated that the most popular topic were risk management and sustainable construction.

While there are other MCDM methods such as preference ranking organisation method for enrichment of evaluations (PROMETHEE) (Yu et al., 2019), non-structural fuzzy decision support system (NSFDSS) (Lau et al., 2018), simple additive weighting (SAW) (Akcan and Guldes, 2019), technique for order of preference by similarity to ideal solution/TOPSIS (Cunha et al., 2019) and fuzzy group decision-making model based on Eckenrode's criteria rating method (Turskis et al., 2019), this article has chosen AHP as the main technique to solve the formwork system selection problem because:

1. it is the most common MCDM technique in Indonesia,
2. it is recognised as a systematic approach for decision-making and
3. it measures decision makers' preference towards each decision criterion.

METHODS

This study mainly adopts a quantitative approach with two stages (as shown in Figure 1). First is the development stage which employed relative importance index (RII) technique, followed by the implementation stage which employed AHP technique. The first stage focused on developing a DMF for formwork system selection. It started with a desktop study to identify influencing factors in formwork system selection (as shown in Table 2). RII technique (Questionnaire 1) was then employed to reduce the factors so that only key selection criteria will be used. Next, a DMF was developed in accordance with AHP principles. Finally, at the second stage this DMF was implemented by experts (Questionnaire 2).

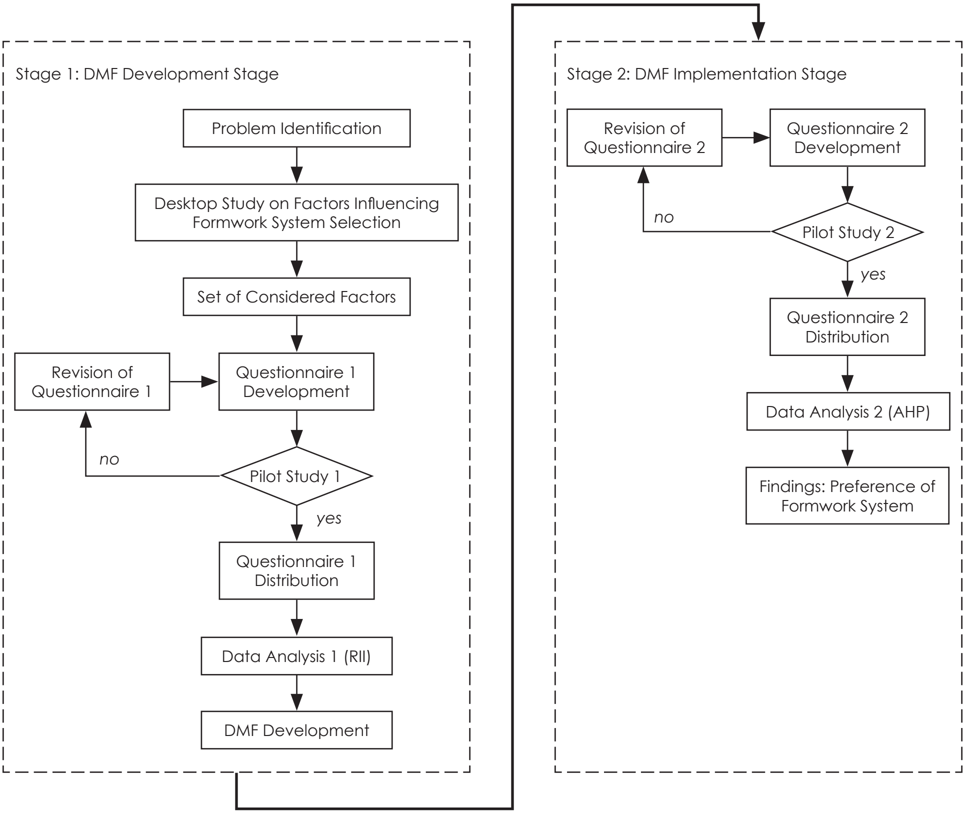

Figure 1. Methods Adopted in This Study

Table 2. Factors Influencing Formwork System Selection (Based on Desktop Study)

No.	**Factors**	**References**
A	Material characteristics	
1	Weight	Poon, Yu and Ng (2003)
2	Assembly	Poon, Yu and Ng (2003)
3	Reuse	Samant (2014)
4	Waste	Poon, Yu and Ng (2003)
5	Recyclable	Gazali (2018)
B	Cost aspects	
1	Material price	Pratama et al. (2017)
2	Rental cost	Pratama et al. (2017)
3	Labour cost	Dong (2016)

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Table 2. (*continued*)

No.	Factors	References
4	Project financing cost and site overhead	Dong (2016)
5	Finishing work costs	Poon, Yu and Ng (2003)
C	Quality aspects	
1	Accuracy and precision	Gazali (2018)
2	Concrete surface	Gazali (2018)
3	Beam-column connection results	Gazali (2018)
4	Rework	Gazali (2018)
5	Practicality to do quality control	Dong (2016)
6	Tidiness of the work	Gazali (2018)
D	Time aspects	
1	Floor to floor duration	Samant (2014)
2	Finishing work duration	Dong (2016)
3	Staircase work duration	Samant (2014)
E	Human resources	
1	Number of workers	Gazali (2018)
2	Skilled workers needed	Samant (2014)
F	Planning	
1	Planning readiness	Gazali (2018)
G	Occupational safety and health and environment	
1	Dismantling method	Dong (2016)
2	Waste produce	Poon, Yu and Ng (2003)
H	Technology	
1	Method application	Dong (2016)

Questionnaire 1: RII Technique

Questionnaire 1 was conducted to reduce the number of factors as results of desktop study. Pilot Study 1 (on 25th February 2019) was done to test the considered factors in formwork system selection. Feedbacks from the Pilot Study 1 were used to revise Questionnaire 1 so that it contained 8 factors and 31 sub-factors. The survey was carried out in a cross-sectional method. RII technique was used to rank these 31 sub-factors. These factors are sorted based on the largest RII value to the smallest value. Top 8 factors with the largest RII value are considered as the most influential factors to proceed to the next analysis. This was done to simplify the considered factors to be used in AHP technique – a method of determining choices by conducting pairwise comparisons and producing priority scale (Saaty, 2008).

To avoid biased answers, six points Likert scale was used in which respondents might choose the middle point. It started with 1 for "No Influence" to 6 for "Very Influential". Questionnaire 1 was distributed to targeted respondents which meet the following criteria: (1) professional working in a construction company in Indonesia which meet the qualification as a large contractor in accordance with Ministry Regulation No. 08/PRT/M/2011, (2) has been involved in an apartment project and (3) member of project team with at least an engineering staff.

All valid responses were analysed using RII formula based on Holt (2014) as follows:

$$\text{RII} = \frac{\Sigma W}{AN} \qquad \text{Eq. 1}$$

where ΣW is the total weight from all respondents, A is the maximum weight and N is number of respondents.

In case of factors having the same RII value, standard deviation value was used to rank the importance. Factor with smaller standard deviation value is considered more important than the other. The formula to calculate standard deviation value is:

$$\text{SD} = \sqrt{\frac{\Sigma(W - \overline{W})^2}{N - 1}} \qquad \text{Eq. 2}$$

where W is the weight from each respondent, $\overline{W}$ is average weight and N is number of respondents. The result of RII analysis was used as input selection criteria in the DMF developed.

Questionnaire 2: AHP Technique

After DMF has been developed, Questionnaire 2 was conducted to implement and validate the proposed DMF. It employed AHP technique to determine the preference in selecting formwork system alternatives. Pilot Study 2 (on 16th April 2019) was done to test whether the questions or factors asked in the questionnaires are appropriate and understandable by respondents. Here, purposive sampling was used in which experts have become the targeted respondents. They were those who had experienced in comparing conventional timber formwork and aluminium formwork system so that they indeed understood and could provide definitive answers regarding their preferences in choosing the system of formwork system.

Questionnaire 2 was distributed to experts which meet five criteria, i.e. (1) professional working in a construction company in Indonesia which meet the qualification as a large contractor in accordance with Ministry Regulation No. 08/PRT/M/2011, (2) has been involved in an apartment project, (3) has authority in making decisions on project (serves as project manager, site engineering manager, site operational manager, etc.), (4) has construction related educational background and (5) has at least two years of experience.

The steps in conducting AHP analysis according to Mu and Pereyra-Rojas (2017) are:

1. Develop a decision hierarchical structure (problem decomposition).

   There are at least three levels of hierarchy in AHP, i.e. the goal, the criteria and the alternatives. The first level describes the goal to be achieved, namely choosing the most appropriate formwork system. The second includes all selection criteria necessary for assessment and evaluation, namely the eight highest factors from RII analysis. The last level considers the possible alternatives for the problem, namely conventional timber formwork and aluminium formwork system. Figure 2 illustrates the decision hierarchical structure used in this study.

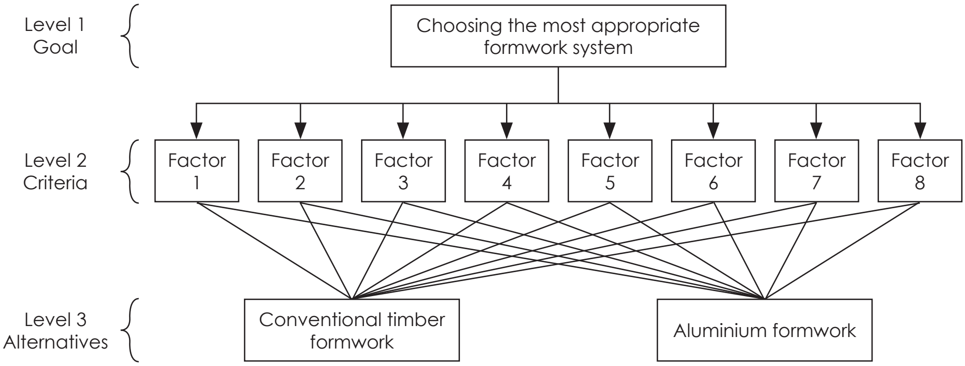

Figure 2. Decision Hierarchical Structure Representing the Multi Criteria Problem in This Study

2. Calculate the priority scale for each criterion.

   Each factor or criterion was compared in pairwise system against the study's objective: the most appropriate formwork system. With 8 factors as selection criteria, there were a total of 45 pairwise comparisons conducted. Semantic differential scale was used with 1 (Equal Importance), 3 (Moderate Importance), 5 (Essential or Strong), 7 (Very Strong Importance), 9 (Extreme Importance), and 2, 4, 6, 8 serve as intermediate values between two adjacent points.

3. Determine the consistency ratio.

   After conducting pairwise comparison, data consistency must be calculated. This can be done by calculating the eigenvector and the maximum Eigenvalue. The consistency index (CI) follows the Equation 3:

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n - 1} \qquad \text{Eq. 3}$$

where CI is consistency index, λ_{max} is the largest Eigenvalue and n is number of alternatives in the set. From this, the ratio of consistency in pairwise comparison can be calculated using the following formula:

$$CR = \frac{CI}{RI} \qquad \text{Eq. 4}$$

where CR is consistency ratio, CI is consistency index and RI is random index. CR value is preferably less than 10% (0.1), meaning the inconsistency is minor and can be accepted.

4. Determine the weight of alternatives and criteria.

   Here, the relative importance for each row of alternatives and criteria was calculated. Afterwards, normalisation was conducted to determine the weights of alternatives and criteria.

5. Calculate overall scores.

   To calculate the final scores, results from both alternatives and criteria should be combined. Thus, matrix of alternatives' weights was multiplied with matrix of criteria's weights. The maximum value provides the best solution.

ANALYSIS AND RESULTS

Reduction of Selection Criteria

Reduction of considered factors (from 31 factors) was done by selecting top 8 factors with the highest RII value. Questionnaire 1 was distributed from 14th March to 2nd April 2019 directly to on-site contractors operating around Jadetabek area (covering Jakarta, Depok, Tangerang and Bekasi cities). Out of 248 distributed questionnaires, only 115 returned. Due to invalid and incomplete response, only 77 responses could be gathered for data analysis. Table 3 presents the results of RII analysis.

Table 3. Results of RII Analysis

Codes	Factors	RII	SD	Rank
B1	Accuracy and precision	0.86	1.03	1
B2	Concrete surface smoothness	0.85	0.98	2
B6	Tidiness of the work	0.85	1.04	3
D2	Skilled workers needed	0.85	0.92	4
E1	Planning readiness	0.85	1.08	5

(*Continued on next page*)

Table 3. (*continued*)

Codes	Factors	RII	SD	Rank
B3	Beam-column connections results	0.85	0.84	6
C1	Floor to floor duration	0.85	1.08	7
A1	Installed formwork price	0.84	0.96	8
E2	Building design	0.84	1.02	9
H1	Formwork durability (reuse)	0.83	1.10	10
G2	Formwork installation/assembly	0.83	0.82	11
G6	Material stocks	0.83	0.99	12
F1	Dismantling method	0.82	0.96	13
F3	Safety perimeter of formwork system	0.82	0.99	14
F2	Easiness of work access	0.81	0.94	15
D1	Number of workers	0.81	1.05	16
B4	Rework needed	0.81	1.13	17
H2	Formwork repair	0.80	0.95	18
B5	Practicality to do quality control	0.80	1.07	19
A2	Project financing cost and site overhead	0.80	0.99	20
A3	Finishing work costs	0.80	1.17	21
H3	Waste produce	0.79	1.27	22
C2	Finishing work duration	0.79	1.12	23
G5	Load work of tower crane (TC)	0.79	1.17	24
G3	Building structure	0.77	1.10	25
G4	Practicality for surveying	0.77	1.15	26
G1	Formwork weight	0.77	1.28	27
C3	Staircase work duration	0.76	1.21	28
H4	Material recycling	0.75	1.08	29
A4	Waste management costs	0.71	1.49	30
C4	Mechanical, electrical and plumbing (MEP) work costs	0.69	1.25	31

Note: SD = Standard deviation.

From RII analysis, factors related to quality aspects rank as top three factors namely accuracy and precision, concrete surface smoothness, and tidiness of the work. These are followed by skilled workers needed, planning readiness, beam-column connections results, floor to floor duration and installed formwork price as top eight factors influencing formwork system selection.

Proposed DMF

DMF is a vital managerial tool in assisting contractors to make decisions regarding formwork system selection. In this study, the development of DMF for formwork system selection follows a systematic approach which integrates multiple techniques including RII and AHP techniques. First, this DMF consists of three main sections of input, process and output. The input section contains two major inputs namely formwork selection criteria and formwork system alternatives. Formwork selection criteria derived from the previous desktop study and RII analysis. It consists of top eight factors influencing formwork system selection. These factors are considered essential to be included in this proposed DMF. Meanwhile, the alternatives consist of two system of formwork systems, i.e. conventional timber formwork as the most commonly used system in Indonesia and aluminium formwork as a new innovation in Indonesian construction industry.

The process section follows AHP principles. It has two phases, i.e. design and implementation phase. Problem decomposition becomes the main focus in design phase. Here, goal is identified to a particular decision problem. It is then decomposed into a hierarchical structure and shortlist the inputs to be processed. Next, expert criteria need to be established before pairwise comparison could be performed. Meanwhile in the implementation phase, comparative judgement is performed and consistency ratio is checked. Finally, the weight of alternatives and criteria are determined and evaluated to obtain the final comparison scores. Alternatives with the highest value serves as the most appropriate formwork system to be selected. Figure 3 presents this proposed DMF.

While in this study, the DMF was developed specifically for formwork system selection by contractors in Indonesian context, the DMF itself is designed to be simple and flexible so that it can be adaptive to changing situation and context. Thus, it allows others to use and modify this framework, particularly regarding the input section.

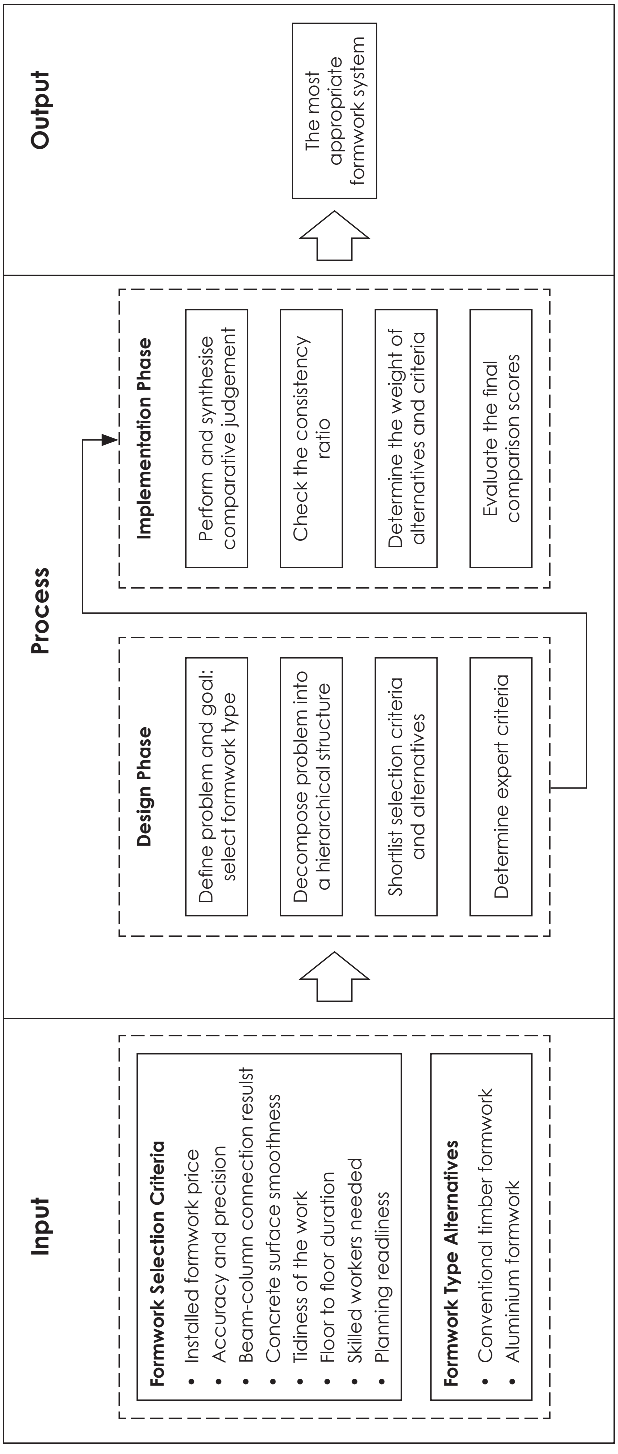

Figure 3. DMF for Formwork System Selection by Contractors

Implementation of DMF for Formwork System Selection

The proposed DMF was implemented using AHP technique. Here, researchers designed and distributed Questionnaire 2 for collecting expert opinions in pairwise comparison format. Out of 48 directly distributed questionnaires from 2nd May to 7th June 2019, only 26 returned with 5 forms are invalid. Thus, a total of 21 pairwise comparisons were obtained from expert respondents. Geometric mean was used to combine their responses and obtain data for matrix analysis.

The implementation of DMF for formwork system selection started with a pairwise comparison between two alternatives (i.e. conventional timber formwork and aluminium formwork) under various selection criteria. The input matrix is shown in Table 4 while the normalisation matrix is shown in Table 5.

Table 4. Input Matrix for Formwork System Selection

Criteria	B1	B2	B6	D2	E1	B3	C1	A1
B1	**1.00**	2.90	2.42	1.61	0.69	0.88	0.39	0.80
B2	0.34	**1.00**	1.06	1.03	0.80	0.62	0.35	0.58
B6	0.41	0.94	**1.00**	1.33	0.91	0.40	0.29	0.77
D2	0.61	0.96	0.74	**1.00**	0.58	0.53	0.34	0.39
E1	1.43	1.24	1.09	1.71	**1.00**	0.75	0.64	0.55
B3	1.12	1.60	2.46	1.88	1.31	**1.00**	0.40	0.57
C1	2.50	2.85	3.33	2.89	1.55	2.44	**1.00**	1.92
A1	1.24	1.72	1.28	2.52	1.80	1.75	0.52	**1.00**
Total	8.68	13.23	13.43	14.01	8.67	8.40	3.96	6.60

Table 5. Normalised Data

Criteria	B1	B2	B6	D2	E1	B3	C1	A1	Weight
B1	0.11	0.21	0.18	0.11	0.08	0.10	0.10	0.12	0.12
B2	0.03	0.07	0.07	0.07	0.09	0.07	0.08	0.08	0.07
B6	0.04	0.07	0.07	0.09	0.10	0.04	0.07	0.11	0.07
D2	0.07	0.07	0.05	0.07	0.06	0.06	0.08	0.05	0.06
E1	0.16	0.09	0.08	0.12	0.11	0.09	0.16	0.08	0.11
B3	0.12	0.12	0.18	0.13	0.15	0.11	0.10	0.08	0.12
C1	0.28	0.21	0.24	0.20	0.17	0.29	0.25	0.29	0.24
A1	0.14	0.13	0.09	0.18	0.20	0.20	0.13	0.15	0.15

The weight of normalised data was then sorted to provide better presentation as presented in Table 6. During the process, all critical values including the maximum Eigenvalue (as shown in Table 7), the CI and the CR were calculated. It is found that the consistency ratio in this study fall within the acceptable limit (less than 0.1).

Table 6. Weights of Selection Criteria

Rank	Codes	Weight	Factor
1	C1	24.66%	Floor to floor duration
2	A1	15.62%	Installed formwork price
3	B1	12.99%	Accuracy and precision
4	B3	12.87%	Beam-column connections results
5	E1	11.43%	Planning readiness
6	B6	7.93%	Tidiness of the work
7	B2	7.64%	Concrete surface smoothness
8	D2	6.86%	Skilled workers needed

Table 7. Calculation of Eigenvalue

Criteria	B1	B2	B6	D2	E1	B3	C1	A1	Weighted Sum Value	λ
B1	0.12	0.22	0.19	0.11	0.07	0.11	0.09	0.12	1.07	8.26
B2	0.04	0.07	0.08	0.07	0.09	0.08	0.08	0.09	0.62	8.18
B6	0.05	0.07	0.07	0.09	0.10	0.05	0.07	0.12	0.64	8.16
D2	0.08	0.07	0.05	0.06	0.06	0.06	0.08	0.06	0.56	8.22
E1	0.18	0.09	0.08	0.11	0.11	0.09	0.15	0.08	0.94	8.24
B3	0.14	0.12	0.19	0.12	0.15	0.12	0.10	0.08	1.06	8.26
C1	0.32	0.21	0.26	0.19	0.17	0.31	0.24	0.30	2.04	8.29
A1	0.16	0.13	0.10	0.17	0.20	0.22	0.12	0.15	1.28	8.23
λ max.										8.23

$$CI = \frac{8.2349 - 8}{7} = 0.03$$

$$CR = \frac{0.0336}{1.41} = 0.02$$

Afterwards, local priority weights could be calculated as shown in Table 8. Local priority weights refer to respondents' preference in choosing the two alternatives against each selection criteria. These values were combined with the weight of criteria to obtain the overall priority scores as shown in Table 9.

Table 8. Local Priority Weights

Codes	Alternatives Priority Score Based on	Conventional Formwork	Aluminium Formwork
B1	Accuracy and precision	13.69%	86.31%
B2	Concrete surface smoothness	16.69%	83.31%
B6	Tidiness of the work	17.32%	82.68%
D2	Skilled workers needed	19.37%	80.63%
E1	Planning readiness	19.88%	80.12%
B3	Beam-column connections results	14.28%	85.72%
C1	Floor to floor duration	18.68%	81.32%
A1	Installed formwork price	41.70%	58.30%

Table 9. Overall Priority Scores

	B1	B2	B6	D2	E1	B3	C1	A1	Overall Priority
Weight of criteria	0.12	0.07	0.07	0.06	0.11	0.12	0.2	0.15	*
Conventional formwork	0.01	0.01	0.01	0.01	0.02	0.01	0.04	0.06	0.21
Aluminium formwork	0.11	0.06	0.06	0.05	0.09	0.11	0.20	0.09	0.79

The result of AHP analysis found that the contractors' preference in choosing formwork system favoured aluminium formwork (with a weight of 79.01%) rather than conventional timber formwork (with a weight of 20.99%). Alternative with a higher priority score means that it is more desirable than the other one if considered based on the eight selection criteria provided.

DISCUSSION

In general, the proposed DMF can be applied in the decision-making process related to formwork system selection by contractors. The DMF is simple and can be implemented to provide a sound decision. Based on the analysis, the most dominant factors influencing contractors in choosing formwork system are floor to floor duration, installed formwork price, and the level of accuracy and precision of work.

This finding is in accordance with the three most important aspects in construction industry, namely cost, quality and time. In addition, the DMF implementation showed that after considering the top 8 selection criteria, the contractors' preference in choosing the formwork system was aluminium formwork at 79% compared to conventional formwork at 21%.

Contractors can consider the benefits of aluminium formwork in terms of work duration (floor to floor duration) as their main consideration. According to one respondent, the speed of aluminium formwork is due to its systemised technology. However, without careful planning these benefits may not be immediately obtained by its users. As the initial investment cost is higher than conventional timber formwork, planning issues such as design, cost, schedule and manpower planning must be ready and complete.

On the other hand, none of the factors related to safety and environmental aspects are included in the top eight influencing factors that serve as selection criteria. This shows that in practice, the Indonesian construction industry has not yet prioritised safety and environmental aspects as major considerations in the planning and execution of construction work. This is in line with the Ministry of Public Works and Housing data which shows that the biggest work accident cases in Indonesia come from construction sector with an average incidence of 32% annually (BPSDM [Badan Pengembangan Sumber Daya Manusia], 2018). Furthermore, Dewi (2015) also found that there are at least 14 obstacles in the implementation of green construction in Indonesia.

In fact, formwork activities produce the most waste (28%) in construction projects compared to other activities (Poon, Yu and Ng, 2003). Therefore, the use of aluminium formwork should be encouraged as the main choice due to its advantages. The concept of minimal waste technology is found in aluminium formwork system where it uses durable materials and most of its elements are prefabricated. As much as 60% of these panels can be reused in other similar projects, while broken panels can be recycled by melting it back into new raw materials.

CONCLUSION

The selection of formwork system by contractors in Indonesia has not been done strategically. This is due to no proper guidance available based on the MCDM approach. Thus, this research focuses on developing a DMF that can assist contractors in selecting the most appropriate formwork system. The development of this DMF integrates AHP technique and principles in the context of Indonesian construction industry. The application which enables calculation of the judgement consistency ensures that the decision maker's judgements are consistent.

The proposed DMF is expected to be a tool for contractors to make decisions regarding the selection of formwork systems. This DMF provides alternatives and selection criteria that have been analysed in depth. These are critical as inputs for the decision-making process to produce a sound decision. It is also important to highlight that the proposed DMF is designed to be flexible so that decision makers can assert or eliminate the input factors which they consider suitable for a particular problem.

The results of this study can be used as considerations for contractors in selecting formwork system used in apartment construction projects. The findings can be subject to discussion between project teams regarding the advantages of aluminium formwork compared to conventional timber formwork when judged from various factors.

Further research can be done by comparing other formwork systems such as permanent insulated formwork and stay-in-place structural formwork systems. The proposed DMF can be applied by considering changes in the input section related to formwork selection criteria and system alternatives. In addition, research can also be done by changing the study object from apartment buildings (which are typical) to infrastructure projects (which are less typical design).

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to RMIT University, Universitas Agung Podomoro and Lembaga Pengelola Dana Pendidikan (LPDP), Republik Indonesia for supporting this research.

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