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Selection of Scaffolding Materials Using AHP: Case Study of Puspem Gianyar

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ABSTRACT

The selection of scaffolding materials is a multi-criteria decision problem because safety, technical performance, cost, time, and operational considerations may lead to different preferences. This study evaluates wood, steel, and aluminum scaffolding for reinforced-concrete works in Building A of the Gianyar Government Center (Puspem Gianyar). A mixed-method design was applied using field observation, structured interviews, project documents, and pairwise-comparison questionnaires completed by 30 construction practitioners and experts. Respondents were selected purposively, and individual judgments were aggregated using the geometric mean before being processed with the Analytical Hierarchy Process (AHP). The revised reciprocal criteria matrix produced occupational safety as the highest-priority criterion (35.86%), followed by technical performance (27.09%), time (17.22%), cost (11.30%), and operational convenience (8.53%). The criteria matrix had a consistency ratio of 2.90%, while the sub-criteria matrices had a consistency ratio of 0.79%, both below the 10% acceptance threshold. After synthesizing criterion, sub-criterion, and alternative priorities, aluminum achieved the highest normalized final priority (41.77%), narrowly exceeding steel (40.88%), while wood obtained 17.35%. Aluminum performed strongly in durability, reuse, maintenance, installation efficiency, dismantling, and transportation, whereas steel remained superior in material strength, rigidity, and structural safety. The narrow difference between aluminum and steel indicates that the final decision remains sensitive to project-specific safety and technical requirements. The model offers a transparent decision-support framework rather than a universal material prescription.

Keywords: Analytical Hierarchy Process; scaffolding; material selection; construction safety; high-rise building.

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1. INTRODUCTION

Scaffolding is a temporary construction system that supports workers, materials, and construction loads during building activities. Its selection and use must satisfy structural capacity, access, stability, fall protection, and training requirements because failure or improper use can expose workers and adjacent activities to severe hazards [1]. Previous research has also shown that scaffold selection is not merely a cost decision; safety, installation speed, project quality, and operational constraints must be considered together [2].

Wood, steel, and aluminum offer different advantages. Wood is generally accessible and economical at the initial procurement stage, but its performance may vary because of moisture, deterioration, dimensional inconsistency, and limited reuse. Steel provides high strength and rigidity but increases handling loads and may require greater transport and maintenance effort. Aluminum is lighter and highly reusable, which can accelerate assembly and dismantling, although its initial cost may be higher. Therefore, selecting a material solely from one criterion can produce a decision that is technically or economically unbalanced.

The Analytic Hierarchy Process (AHP) provides a structured mechanism for decomposing such decisions into goals, criteria, sub-criteria, and alternatives [3]. AHP has been applied to construction safety prioritization [4], scaffold selection [2], temporary works assessment [5]-[8], and formwork-system selection [9]-[11]. Nevertheless, published evidence directly comparing wood, steel, and aluminum scaffolding for an Indonesian public-building project remains limited. Existing studies commonly focus on bamboo versus metal scaffolding, general scaffold safety, or formwork systems rather than the combined influence of technical performance, cost, time, occupational safety, and operational convenience in a local project context.

This study addresses that gap by developing and applying an AHP model to the Building A Construction Project of the Gianyar Government Center. The study aims to: (1) determine the relative importance of the five principal selection criteria; (2) identify the priority sub-criteria within each criterion; (3) calculate normalized final priorities for wood, steel, and aluminum; and (4) discuss the robustness and practical implications of the resulting ranking. The contribution of the study is a transparent and auditable decision-support framework that can be adapted by contractors to project-specific conditions.

1.2 Theoretical Framework

1.2.1 Scaffolding Safety and Performance

Scaffold safety depends on the interaction between structural, environmental, organizational, and human factors. Field assessments have identified deficiencies in bracing, anchorage, platforms, guardrails, access, and foundations as recurring concerns [5]. Lifecycle analyses of scaffolding further show that errors during design, element selection, assembly, use, inspection, and dismantling can contribute to unsafe conditions or structural failure [7]. Dynamic behavior is also relevant because worker movement may excite slender scaffold structures and reduce perceived stability [8]. These findings support the inclusion of material strength, rigidity, durability, structural safety, accident risk, and compliance with occupational safety and health requirements in the decision hierarchy.

1.2.2 Construction Material Selection

Construction material selection requires a balance between initial expenditure and long-term performance. For temporary construction systems, relevant factors include procurement cost, reuse potential, maintenance, installation and dismantling time, handling, transport, availability, and adaptability. Studies on formwork systems while not identical to scaffolding provide useful evidence because both are temporary construction systems supporting reinforced-concrete activities. Recent research identifies speed, initial cost, reuse, durability, safety, and project characteristics as important selection criteria [9]-[11].

1.2.3 Analytical Hierarchy Process

AHP structures a complex decision into hierarchical levels and obtains priorities through pairwise comparisons. Each judgment uses Saaty's fundamental scale, and the resulting matrix must be reciprocal. Priority vectors are obtained from the normalized principal eigenvector, while judgment reliability is assessed using the Consistency Index (CI) and Consistency Ratio (CR). A matrix is generally accepted when $CR \leq 0.10$ [3]. AHP is particularly useful for construction decisions because it can combine quantitative and qualitative judgments while making trade-offs explicit [4], [12], [13].

2. RESEARCH METHOD

2.1 Research Design and Data Collection

The study employed a mixed-method design combining qualitative identification of criteria with quantitative AHP analysis. The case study was Building A of the Gianyar Government Center (Puspem Gianyar), Bali. Primary data were collected through field observations, structured interviews, and pairwise-comparison questionnaires. Secondary data included cost estimates, project schedules, shop drawings, and occupational safety documentation. Thirty respondents were selected purposively from contractors, consultants, academics, and public-sector stakeholders based on their involvement or expertise in construction planning, execution, safety, and temporary works. All respondents were assigned equal importance, and their pairwise judgments were aggregated using the geometric mean.

2.2 Decision Hierarchy

The hierarchy comprised one goal, five criteria, fifteen sub-criteria, and three alternatives. Figure 1 shows the relationship among these levels. The alternatives were wood, steel, and aluminum scaffolding.

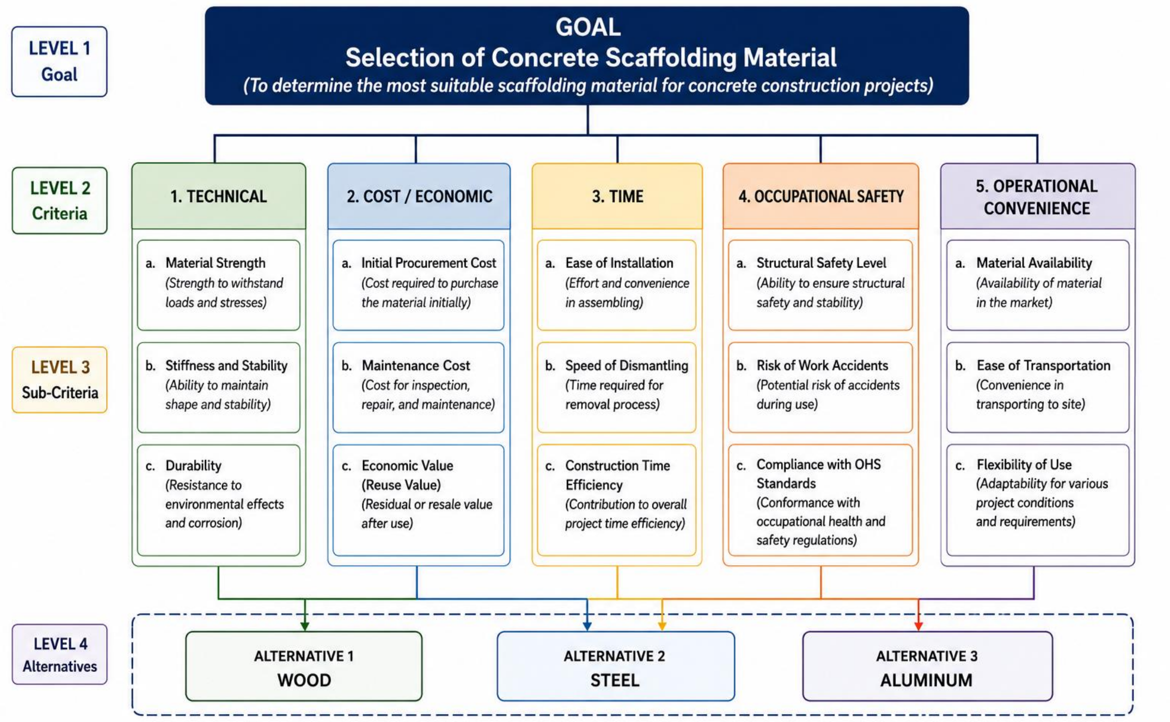

Figure 1. Hierarchical structure for the selection of concrete scaffolding material types

Table 1. Pairwise comparison scale

Intensity	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element
5	Strong importance	Experience and judgment strongly favor one element
7	Very strong importance	One element is strongly favored and demonstrated in practice
9	Extreme importance	Evidence favoring one element is of the highest order
2, 4, 6, 8	Intermediate values	Compromise values between adjacent judgments
Reciprocal	Reverse comparison	If $a_{ij} = x$, then $a_{ji} = 1/x$

2.3 AHP Calculation and Consistency

For m respondents, each aggregated comparison was calculated using the geometric mean: $a_{ij} = (\prod_{k=1}^{m} a_{ij}^{(k)})^{1/m}$. The criteria and sub-criteria matrices were then normalized to obtain priority vectors. The maximum eigenvalue was calculated from the weighted-sum vector, after which consistency was evaluated using $CI = (\lambda max - n)/(n - 1)$ and $CR = CI/RI$. The Random Index values used were 1.12 for a 5 × 5 matrix and 0.58 for a 3 × 3 matrix. Final alternative priority was calculated by multiplying each criterion weight, sub-criterion local weight, and alternative local priority, and then summing all contributions. All final alternative priorities were normalized so that their total equaled 1.00.

During data verification, reciprocal consistency was enforced in the displayed criteria matrix. In particular, because the cost-to-time judgment was 0.5, the time-to-cost entry was set to its reciprocal value of 2. This correction enabled a valid AHP consistency assessment without changing the intended direction of preference.

3. RESULTS AND DISCUSSION

3.1. Criteria Priorities

The aggregated and reciprocal criteria matrix is presented in Table 2. Occupational safety received the strongest judgments relative to the other criteria, followed by technical performance. The corrected matrix produced $\lambda max = 5.130$, $CI = 0.0325$, and $CR = 0.0290$, indicating acceptable consistency.

Table 2. Aggregated pairwise-comparison matrix for the criteria

Criterion	Technical	Cost	Time	Occupational safety	Operational convenience
Technical	1.000	3.000	2.000	0.500	3.000
Cost	0.333	1.000	0.500	0.333	2.000
Time	0.500	2.000	1.000	0.500	2.000

Criterion	Technical	Cost	Time	Occupational safety	Operational convenience
Occupational safety	2.000	3.000	2.000	1.000	3.000
Operational convenience	0.333	0.500	0.500	0.333	1.000

Table 3. Criteria priority weights and rankings

Rank	Criterion	Priority	Weight (%)
1	Occupational safety	0.3586	35.86
2	Technical	0.2709	27.09
3	Time	0.1722	17.22
4	Cost	0.1130	11.30
5	Operational convenience	0.0853	8.53

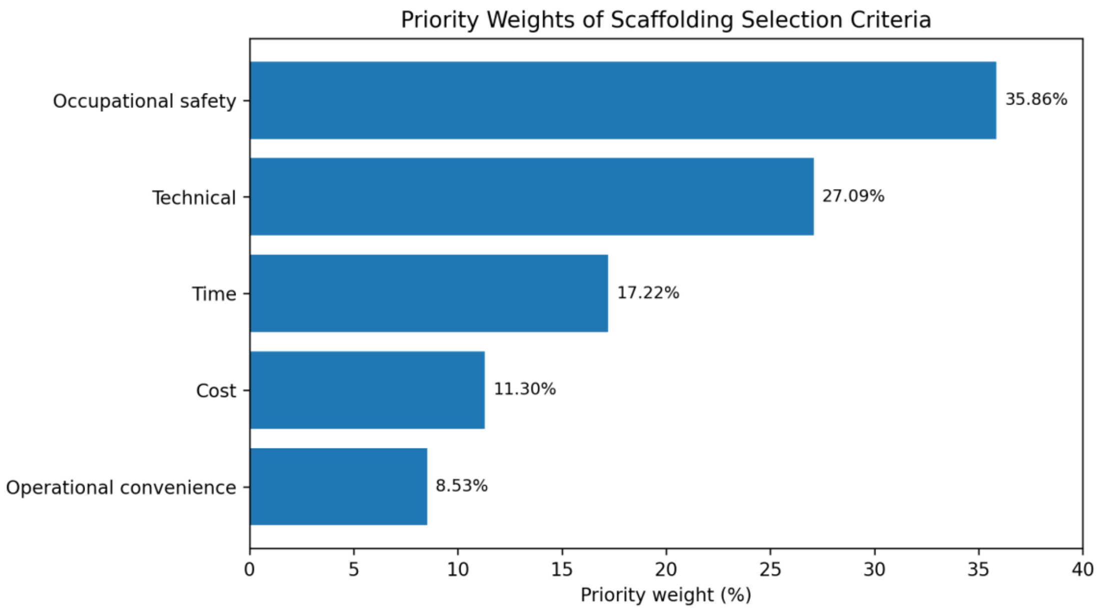

Figure 2. Priority weights of the five selection criteria

Occupational safety accounted for 35.86% of the decision, confirming that scaffold selection in a high-rise project is primarily a risk-control decision. This priority is consistent with scaffold regulations and research showing that structural integrity, fall prevention, access, training, and inspection are central to safe scaffold use [1], [5]-[8]. Technical performance ranked second because material strength and rigidity directly affect load resistance and stability. Time ranked above cost, indicating that respondents placed greater value on erection, use, and dismantling efficiency than on initial procurement alone.

3.2. Sub-Criteria Priorities

The five sub-criteria matrices produced the same local priority pattern: 0.5390 for the first-ranked sub-criterion, 0.2973 for the second, and 0.1638 for the third. This identical pattern resulted from the same aggregated comparison structure (1, 2, and 3 judgments) across the five groups. Each 3 × 3 matrix had λmax = 3.009, CI = 0.0046, and CR = 0.0079. Table 4 reports both local and global sub-criterion weights.

Table 4. Local and global weights of the sub-criteria

Criterion	Sub-criterion	Local weight	Global weight	Global (%)
Technical	Material strength	0.5390	0.1460	14.60
Technical	Rigidity and stability	0.2973	0.0805	8.05
Technical	Durability	0.1638	0.0444	4.44
Cost	Initial procurement cost	0.5390	0.0609	6.09
Cost	Reuse value	0.2973	0.0336	3.36
Cost	Maintenance cost	0.1638	0.0185	1.85
Time	Implementation time efficiency	0.5390	0.0928	9.28
Time	Ease of installation	0.2973	0.0512	5.12
Time	Dismantling speed	0.1638	0.0282	2.82
Occupational safety	Structural safety level	0.5390	0.1933	19.33
Occupational safety	Occupational accident risk	0.2973	0.1066	10.66
Occupational safety	OSH compliance	0.1638	0.0587	5.87
Operational convenience	Flexibility of use	0.5390	0.0460	4.60
Operational convenience	Material availability	0.2973	0.0254	2.54

Criterion	Sub-criterion	Local weight	Global weight	Global (%)
Operational convenience	Ease of transportation	0.1638	0.0140	1.40

Structural safety level had the largest global weight (19.33%), followed by material strength (14.60%) and occupational accident risk (10.66%). The result indicates that respondents evaluated scaffolding primarily as a temporary structural and safety system. Implementation time efficiency also obtained a substantial global weight (9.28%), supporting the practical importance of rapid construction cycles identified in temporary-works selection studies [9]-[11].

3.3. Alternative Evaluation and Final Synthesis

Table 5 presents the local priorities of wood, steel, and aluminum under each sub-criterion. All rows were normalized to a total of 1.00. A transcription inconsistency in the original structural-safety row was corrected so that steel remained the highest local alternative and the row total equaled 1.00.

Table 5. Local alternative priorities under each sub-criterion

Sub-criterion	Wood	Steel	Aluminum
Material strength	0.088	0.669	0.243
Rigidity and stability	0.088	0.669	0.243
Durability	0.074	0.283	0.643
Initial procurement cost	0.724	0.193	0.083
Reuse value	0.106	0.260	0.634
Maintenance cost	0.074	0.283	0.643
Implementation time efficiency	0.230	0.122	0.648
Ease of installation	0.239	0.137	0.624
Dismantling speed	0.106	0.260	0.634
Structural safety level	0.074	0.643	0.283
Occupational accident risk	0.074	0.283	0.643
OSH compliance	0.075	0.334	0.591
Flexibility of use	0.581	0.309	0.110
Material availability	0.309	0.110	0.581
Ease of transportation	0.252	0.159	0.589

Table 6. Normalized final priorities of scaffolding alternatives

Rank	Alternative	Normalized priority	Priority (%)
1	Aluminum	0.4177	41.77
2	Steel	0.4088	40.88
3	Wood	0.1735	17.35

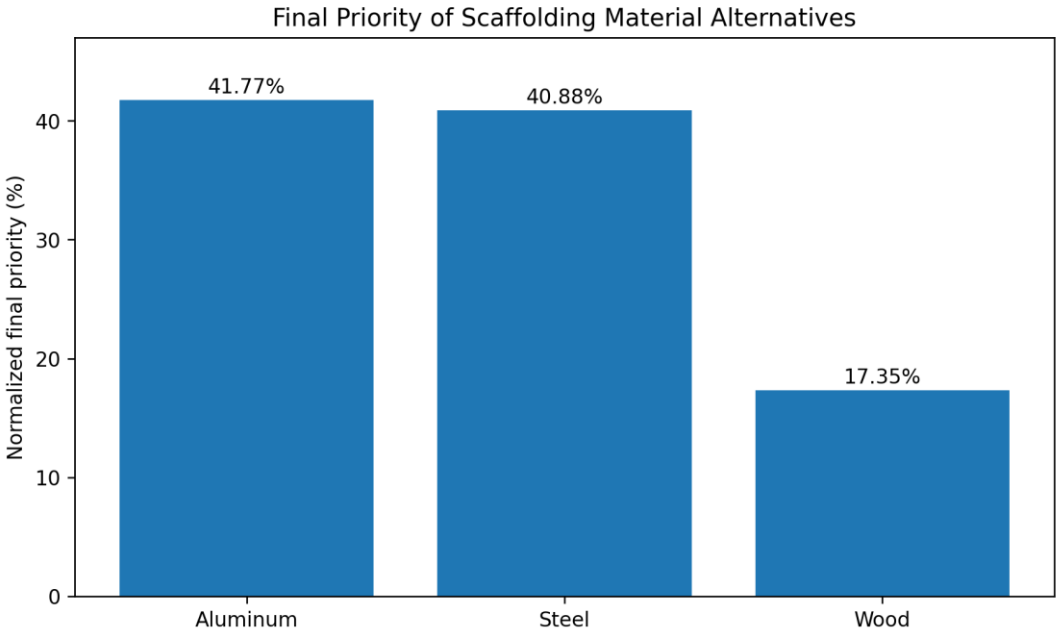

Figure 3. Normalized final priority of the scaffolding alternatives

Aluminum ranked first with 41.77%, followed closely by steel at 40.88%. Wood was substantially lower at 17.35%. Aluminum received strong local priorities for durability, reuse, maintenance, implementation

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efficiency, installation, dismantling, accident-risk reduction, OSH compliance, availability, and transportation. These advantages are consistent with recent temporary-system studies that identify aluminum as a high-performing option when speed, reuse, and lifecycle performance are emphasized [9]-[11].

Steel remained the strongest option for material strength, rigidity, and structural safety. Its final priority was only 0.89 percentage points below aluminum, meaning the ranking should not be interpreted as an absolute technical superiority of aluminum. A one-way sensitivity check showed that steel becomes the first-ranked option when the occupational-safety criterion increases from 35.86% to approximately 46.5%, while the relative proportions of the other criteria are maintained. Contractors should therefore verify project loads, scaffold geometry, manufacturer certification, inspection requirements, handling constraints, and procurement conditions before implementation.

Wood ranked highest only for initial procurement cost and flexibility. Its lower scores in strength, durability, maintenance, safety, and reuse reduced its final priority. This result broadly agrees with earlier scaffold-selection research, which found that lower-cost traditional materials may lose their advantage when safety and long-term performance are included [2]. The outcome also supports the broader construction-safety literature, which emphasizes that economic considerations should not displace structural and occupational risk controls [4], [12]-[15].

4. CONCLUSION

The revised AHP analysis indicates that occupational safety is the most influential criterion in scaffolding material selection for Building A of Puspem Gianyar, with a weight of 35.86%, followed by technical performance (27.09%), time (17.22%), cost (11.30%), and operational convenience (8.53%). Structural safety level, material strength, occupational accident risk, and implementation time efficiency were the most influential global sub-criteria. The criteria and sub-criteria matrices satisfied the AHP consistency requirement, with CR values of 2.90% and 0.79%, respectively.

After full normalization and synthesis, aluminum ranked first at 41.77%, steel second at 40.88%, and wood third at 17.35%. Aluminum offered the best overall balance of durability, reuse, time efficiency, maintenance, and handling, whereas steel was superior in strength, rigidity, and structural safety. Because the difference between aluminum and steel was small, the recommendation should be treated as project-specific rather than universal. The model can support transparent contractor decisions, but it does not replace scaffold engineering design, manufacturer requirements, inspection, or statutory safety compliance.

The study is limited to one project and relies on expert judgment with equal respondent weighting. It did not include detailed life-cycle cost, environmental impact, procurement uncertainty, or load-testing data. Future research should involve multiple building types and locations, apply sensitivity and uncertainty analysis, compare AHP with other MCDM methods, and integrate life-cycle cost and verified engineering-performance data.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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