Wiguna, I. P. A., Adi, T. J. W., Waliulu,Y. E. P. R., & Prastyo, S. A. A. (2026). A decision-support framework for prioritising lean construction techniques in the planning stage of Indonesian construction projects. In F. Hamzeh, M. Poshdar, N. P. Garcia-Lopez, & V. Gan (Eds.), *Proceedings of the 34th Annual Conference of the International Group for Lean Construction* (IGLC34) (pp. 533–546). https://doi.org/10.24928/2026/0260

A DECISION-SUPPORT FRAMEWORK FOR PRIORITISING LEAN CONSTRUCTION TECHNIQUES IN THE PLANNING STAGE OF INDONESIAN CONSTRUCTION PROJECTS

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ABSTRACT

Lean construction has gained increasing attention as a strategy to enhance project performance; however, its effectiveness is largely determined by decisions made during the planning stage, where workflow reliability and resource efficiency are established. In developing countries such as Indonesia, weak planning practices often lead to material waste, rework, and schedule variability, highlighting the need for structured decision-support in selecting appropriate lean techniques. This study develops a decision-support framework to prioritise critical success factors (CSFs) and lean construction techniques for improving planning reliability and reducing planning-related waste. A two-stage quantitative approach is employed, integrating the Relative Importance Index (RII) and the Analytic Hierarchy Process (AHP). Data are obtained from ten experts with experience in construction planning and lean implementation. The results indicate that managerial readiness—particularly top management commitment, financial transparency, responsibility assignment, and effective use of improvement tools—plays a dominant role. Among the evaluated lean construction techniques, Building Information Modelling (BIM) is identified as the most suitable for the planning stage, followed by the Last Planner System (LPS) and Value Stream Mapping (VSM). The proposed framework provides a structured basis for selecting context-appropriate lean techniques and improving planning reliability while contributing to waste reduction and more sustainable construction practices.

KEYWORDS

Lean construction, planning reliability, decision-support framework, construction planning, waste reduction, BIM, last planner system

INTRODUCTION

Lean construction, rooted in production theory, provides a structured approach to improving construction planning by reducing variability, enhancing information flow, and increasing workflow reliability (Womack & Jones, 1997). Planning-oriented lean tools such as the Last Planner System (LPS) and Building Information Modelling (BIM) enable collaborative decision-making, early constraint identification, and improved coordination among project

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stakeholders (Ballard and Tommelein, 2020; Sacks et al., 2020). From a lean perspective, effective planning is not solely determined by tool adoption but by the presence of enabling conditions that support reliable flow, structured planning control, and continuous improvement.

In developing countries, these enabling conditions are often constrained by fragmented project structures, conventional management practices, and limited adoption of lean and digital technologies (Ismail et al., 2013). In Indonesia, despite regulatory support for lean construction, significant inefficiencies persist. Material waste has been reported to reach approximately 25% of project costs, while project delays range from 30–40% (Irfandi & Rachmawati, 2023). These issues are largely associated with weak planning practices, poor coordination, and insufficient managerial commitment. Beyond performance implications, such inefficiencies contribute to avoidable rework, excessive material consumption, and increased environmental impact. In this study, the "green" dimension is framed as the ability of planning-stage decisions to reduce material waste and resource inefficiencies. From a lean–green perspective, these techniques contribute indirectly to sustainability through reduced material waste, minimised rework, and more efficient resource utilisation enabled by improved planning control. This reduction is achieved through early coordination, constraint identification, and improved workflow reliability, which minimise design conflicts, avoidable rework, and inefficient use of materials during project execution

Previous studies have highlighted the importance of aligning lean techniques with critical success factors (CSFs) to enhance planning reliability. Techniques such as BIM, LPS, and Value Stream Mapping (VSM) have been shown to improve coordination, workflow stability, and waste identification when supported by strong managerial and organisational conditions (Noorzai, 2023b). However, not all lean techniques are equally applicable across project contexts, and their effectiveness depends on how well they align with underlying CSFs.

Despite these advances, existing research remains limited in systematically prioritising lean construction techniques based on their contribution to CSFs, particularly in the context of construction planning in developing countries. This study addresses this gap by developing a decision-support framework to prioritise CSFs and lean construction techniques for improving planning reliability and reducing planning-related waste in Indonesian construction projects.

LITERATURE REVIEW

LEAN CONSTRUCTION AND THE ROLE OF THE PLANNING PHASE IN CONSTRUCTION

Lean construction is rooted in production theory and focuses on eliminating waste, reducing variability, and maximizing value throughout the project lifecycle (Koskela et al., 1992.; Womack & Jones, 1997). Within the construction phase, planning plays a critical role in translating project objectives into reliable site execution and workable schedules. Weak planning at this stage often leads to workflow disruptions, rework, material waste, and schedule delays. (Ballard and Tommelein: 2020 ; Ballard, 2000).

These problems are more pronounced in developing countries, where fragmented project structures, conventional management practices, and limited stakeholder coordination remain dominant. (Ismail et al., 2013b; Koohestani et al., 2020). In Indonesia, empirical studies report persistent project delays and material waste reaching approximately 25% of total project costs, reflecting systemic weaknesses in construction-phase planning (Irfandi & Rachmawati, 2023). This condition underscores the need for lean-oriented planning approaches that enhance coordination, information flow, and decision-making reliability during construction execution.

CRITICAL SUCCESS FACTORS FOR LEAN PLANNING

The successful implementation of lean planning during the construction phase depends on several interrelated CSFs. Previous studies consistently identify top management commitment

as a key driver, as leadership support influences strategic direction, resource allocation, and the continuity of lean practices on site. (Alinaitwe et al., 2009; Belhadi et al., 2019). Financial management also plays an essential role, as accurate cost control and reliable funding support realistic scheduling and reduce uncertainty during execution.(Issa, 2013).

In addition, workforce capability, quality improvement efforts, waste reduction, and the effective use of improvement tools contribute significantly to stabilizing construction workflows. Health, safety, and environmental management further supports lean planning by minimizing disruptions caused by accidents and unsafe site conditions. Based on the literature, the CSFs considered in this study are summarized in Table 1.

Table 1: Planning stage Critical Success Factors (CSFs)

No	Critical Success Factors	References									
		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
1	Top Management Commitment	*	*	*	*	*	*	*			
2	Financial Management	*	*	*	*	*	*	*			
3	Task Planning Based on Scope of Work	*	*	*	*	*	*	*			
4	Workforce Capability			*	*	*	*				
5	Quality Improvement			*	*	*	*				
6	Waste Reduction				*	*	*				
7	Improvement Tools								*	*	*
8	Health, Safety, and Environment										*

References: R1.(Negi et al., 2024), R2.(Romo et al., 2024), R3. (Moradi & Sormunen, 2023), R4.(Noorzai, 2023) R5.(Pedrosa et al., 2023), R6.(Likita et al., 2022), R7. (Arnaiz et al., 2021), R8. (Koskela et al., 1998), R9.(Tezel et al., 2018), R10. (Choudhry, 2017; Dixit et al., 2019; Princy & Shanmugapriya, 2017)

LEAN-BASED PLANNING TECHNIQUES IN THE CONSTRUCTION PHASE

Lean construction introduces several planning-oriented techniques designed to improve workflow reliability and reduce variability during construction. Techniques such as value stream mapping and the last planner system emphasise collaborative planning, early identification of constraints, and commitment-based scheduling, allowing project teams to better align work sequences with available resources and site conditions. (Ballard, 1995; Salem et al., 2005). Empirical studies demonstrate that these techniques improve coordination, reduce rework, and enhance schedule performance when systematically applied during construction. (Karatas & Budak, 2023; Noorzai, 2023a). Based on the literature, the lean planning techniques considered in this study are presented in Table 2.

Table 2: Lean technique in planning stages

No	**Lean Technique in Planning Stages**	**References**				
		R1	**R2**	**R3**	**R4**	**R5**
1	Value Stream Mapping (VSM)	*	*	*	*	*
2	Last Planner System (LPS)	*	*	*	*	*
3	Building Information Modelling (BIM)	*	*	*	*	*

References: R1. (Noorzai, 2023a) R2. (Ramani & KSD, 2021) R3. (Tavakolan & Nikoukar, 2025) R4.(Karatas & Budak, 2023) R5.(Michalski et al., 2021)

RESEARCH METHOD

This study adopts a quantitative research design to develop a decision-support framework for prioritising critical success factors (CSFs) and lean construction techniques for the planning

stage of construction projects in Indonesia. A structured two-stage analytical approach is employed to ensure systematic and transparent expert-based decision-making under limited and qualitative information conditions typical of early project planning. In the first stage, CSFs influencing planning-stage lean implementation are identified and ranked using the Relative Importance Index (RII). In the second stage, the prioritised CSFs are structured into a hierarchical decision model consisting of criteria, sub-criteria, and alternative lean construction techniques, which are then evaluated using the Analytic Hierarchy Process (AHP)

EXPERT SELECTION AND DATA COLLECTION

Primary data are collected through a structured questionnaire administered to ten domain experts selected using purposive sampling. To ensure the credibility of expert judgement and mitigate bias associated with small sample sizes, explicit selection criteria are defined. Experts are required to (i) have a minimum of five years of professional experience, (ii) be directly involved in construction planning or project management, and (iii) possess prior exposure to lean construction or BIM-based planning practices. The selected experts represent diverse institutional backgrounds, including private companies, state-owned enterprises, and academia, and occupy roles such as project managers, site managers, and engineering experts. This diversity is intended to reduce single-source bias and improve the robustness of aggregated judgments. A summary of respondent characteristics is presented in Table 3.

Table 3: Profile of expert respondents

Aspect	Description (Number of Respondents)
Number of experts	10 experts
Institution types	Private companies (2), state-owned enterprises (6), and universities (2)
Positions/roles	Project managers (5), site managers (3), and experts/lecturers (2)
Project divisions	Water structures (2), housing (2), highway (3), and building works (3)
Educational background	Bachelor's degree (3), Professional Engineer qualification (3), and Master's degree (4)
Years of experience	5-10 years (5) 11-15 years (5)

QUESTIONNAIRE DESIGN AND RII ANALYSIS

The questionnaire is designed to capture expert judgments in a structured and reproducible manner and consists of three sections. The first section collects respondent profile information. The second section evaluates the importance of CSFs using a five-point Likert scale for RII analysis. The third section includes pairwise comparison matrices following the AHP procedure, where respondents assess the relative importance between two elements using Saaty's 1–9 scale. To improve transparency and replicability, respondents are provided with clear instructions and examples of pairwise comparisons, ensuring consistent interpretation of the scale across all participants. The Relative Importance Index (RII) is used to rank CSFs based on expert perception. It is calculated as:

$$\mathrm{RII} = \frac{\sum \mathrm{W}}{\mathrm{A} \times \mathrm{N}}$$

where Wrepresents the weight assigned by respondents (1–5), $A$is the highest possible weight (5), and $N$is the number of respondents. RII values range from 0 to 1, with higher values indicating greater importance. This method is widely adopted in construction management studies to prioritise influencing factors under expert-based evaluation.

AHP MODELLING

To prioritise lean construction techniques, a structured multi-criteria decision-making approach based on AHP is employed (Saaty, 2008). The decision problem is decomposed into a hierarchical structure consisting of (i) the overall goal, (ii) CSFs as criteria, (iii) associated sub-

criteria, and (iv) alternative lean construction techniques (BIM, LPS, and VSM). The hierarchy is illustrated in Figure 1.

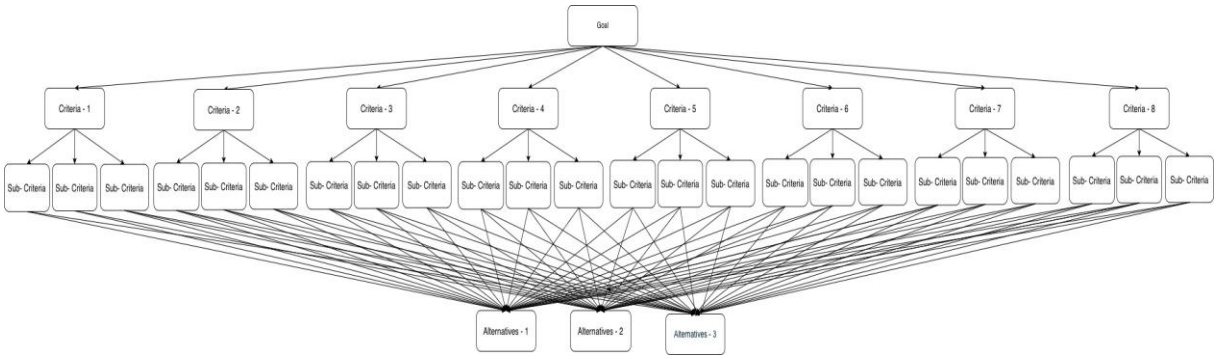


Figure 1: The Analytical Hierarchy Process framework for prioritizing

Experts conduct pairwise comparisons at each level using Saaty's 1–9 scale. Individual matrices are aggregated using the geometric mean, then normalised to derive priority weights through eigenvector computation. The Consistency Ratio (CR) is calculated for each matrix to ensure judgment reliability, with values below 0.10 indicating acceptable consistency. The analysis produces both local weights (criteria and sub-criteria) and global weights, which represent the overall priority of each lean technique. These global priorities provide a quantitative basis for identifying the most suitable techniques to enhance planning reliability and reduce planning-related waste. All calculated CR values are below 0.10, confirming the consistency of the aggregated expert judgments. The detailed results are presented in Table 4.

Table 4: Consistency Ratio (CR) results for AHP Matrices

Matrix Level	Number of Elements	CR Value	Consistency Status
Criteria	4	0.062	Acceptable
Sub-criteria (Managerial)	5	0.083	Acceptable
Sub-criteria (Operational)	4	0.071	Acceptable
Alternatives (BIM, LPS, VSM)	3	0.054	Acceptable

RESULT AND DISCUSSION

RANKING OF CRITICAL SUCCESS FACTORS AT THE PLANNING STAGE

The analysis aims to identify and prioritise the most influential CSFs affecting planning-stage lean implementation. Table 5 presents the RII values for all CSFs considered in this study.

Table 5: RII results for planning stage critical success factors

Code	Influencing Factor	ΣW (Total Score)	RII	Interpretation
P1	Top Management	45	0.90	Very Important
P2	Financial Management	45	0.90	Very Important
P3	Task Planning Based on Scope of Work	45	0.90	Very Important
P4	Workforce Capability	38	0.76	Important
P5	Quality Improvement	36	0.72	Important
P6	Waste Reduction	36	0.72	Important
P7	Improvement Tools	45	0.90	Very Important
P8	Health, Safety, and Environment	36	0.72	Important

The results show that Top Management, Financial Management, Task Planning Based on Scope of Work, and Improvement Tools achieve the highest RII values (0.90), indicating strong expert consensus on their critical role. These factors act as key enabling conditions that support planning reliability, structured decision-making, and effective coordination. In contrast, Workforce Capability, Quality Improvement, Waste Reduction, and Health, Safety, and Environment (HSE) are ranked slightly lower (0.72–0.76) but remain important, functioning as operational enablers that sustain planning effectiveness during execution. These findings confirm that lean implementation is primarily driven by managerial commitment and structured planning, rather than tool adoption alone, consistent with prior studies (Tezel et al., 2018). This aligns with existing literature emphasising the role of organisational readiness and leadership as key enablers of lean implementation (Belhadi et al., 2019; Koohestani et al., 2020). From a lean perspective, planning reliability is shaped more by upstream organisational conditions than downstream activities. The inclusion of waste reduction and HSE further highlights the link between planning decisions and environmental performance, particularly in reducing material waste and avoidable rework. Overall, the identified CSFs provide a robust foundation for subsequent AHP-based prioritisation of lean construction techniques.

ANALYSIS OF LEAN CONSTRUCTION TECHNIQUE IMPLEMENTATION FOR THE PLANNING STAGE IN INDONESIA

The implementation of lean construction techniques was analysed using questionnaire data to assess their perceived importance and applicability in the planning stage of construction projects in Indonesia. Respondents evaluated each technique using a five-point Likert scale. The RII results are presented in Table 6.

Table 6: RII results for planning stage lean construction technique implementation

Code	Influencing Factor	ΣW (Total Score)	RII	Interpretation
P1	Last Planner System (LPS)	45	0.9	Very Important
P2	Value Stream Mapping (VSM)	45	0.9	Very Important
P3	Building Information Modelling (BIM)	45	0.9	Very Important

The results show that all three techniques—Last Planner System (LPS), Value Stream Mapping (VSM), and Building Information Modelling (BIM)—achieve identical RII values (0.90), indicating strong consensus among experts regarding their importance in planning-stage lean implementation. This finding suggests that, from a practitioner perspective, these techniques are not viewed as competing alternatives but as complementary tools that collectively support planning effectiveness. BIM contributes to early coordination and information integration, LPS enhances commitment-based planning and workflow reliability, while VSM supports the identification of process inefficiencies. Therefore, their equally high ratings reflect the need for integrated application rather than isolated use, particularly in improving planning reliability and reducing planning-related waste in construction projects.

OVERVIEW AND HIERARCHICAL STRUCTURE

This section presents the results of the AHP analysis based on a structured hierarchical model consisting of the overall objective, critical success factors (CSFs) as criteria, associated sub-criteria, and lean construction techniques as alternatives. This hierarchical decomposition enables a systematic evaluation of the relationships between planning conditions and the suitability of lean techniques. The hierarchy and the corresponding synthesised priority weights for the planning stage are illustrated in Figure 2.

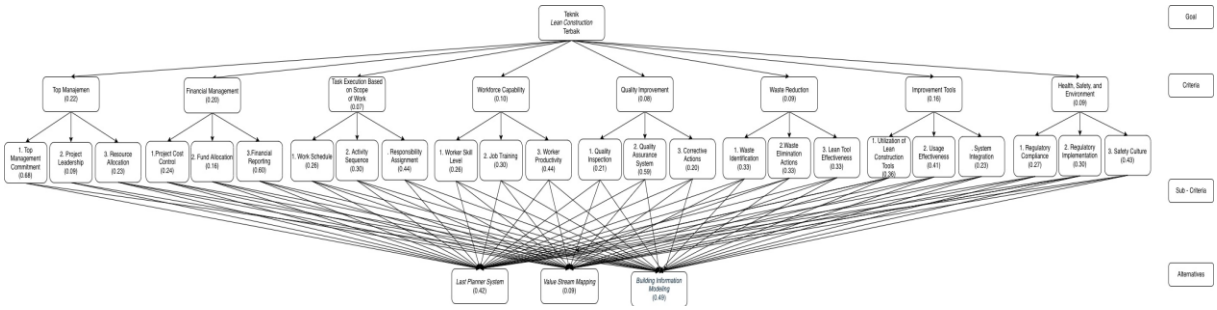


Figure 2: Hierarchy structure and synthesized priority weights in the planning stage

The resulting priority weights represent the relative contribution of each element to planning-stage performance, allowing clear comparison across criteria, sub-criteria, and techniques. This structure provides the analytical basis for identifying the most suitable lean construction techniques to enhance planning reliability and reduce planning-related waste.

RELATIVE PRIORITY OF CRITICAL PLANNING CRITERIA

The relative importance of planning-related criteria is evaluated using AHP based on expert pairwise comparisons across eight CSFs. Each expert assessed the relative dominance of criteria using Saaty's 1–9 scale. Individual judgments were aggregated using the geometric mean to obtain a group decision matrix, which was then normalised to derive priority weights through eigenvector computation. Consistency of the judgments was verified using the Consistency Ratio (CR), ensuring reliable and logically consistent comparisons. The resulting weights represent the relative contribution of each criterion to planning-stage lean performance. The pairwise comparison matrix and the derived priority weights are presented in Tables 7 and 8.

Table 7: Pairwise comparison for criteria level

CSF	Top Manag.	Financial Manag.	Task Planning	Workforce Capability	Quality Improve.	Waste Reduction	Improvement Tools	HSE
Top Management	1.00	1.29	2.10	2.52	3.74	2.78	1.35	2.66
Financial Management	0.78	1.00	3.01	2.36	3.35	1.97	1.89	2.00
Task Planning Based on Scope of Work	0.48	0.33	1.00	0.63	0.45	0.89	0.80	0.62
Workforce Capability	0.40	0.42	1.58	1.00	3.52	1.18	0.32	0.51
Quality Improvement	0.27	0.30	2.21	0.28	1.00	1.18	0.44	1.05
Waste Reduction	0.36	0.51	1.12	0.84	0.85	1.00	0.58	1.58
Improvement Tools	0.74	0.53	1.25	3.12	2.28	1.72	1.00	2.59
HSE	0.38	0.50	1.60	1.96	0.95	0.63	0.39	1.00

Table 8: Priority weights for criteria level

CSF	Top Manag	Financial Manag.	Task Plannin	Workforce	Quality Improve	Waste Reductio	Improvement Tools	HSE	Total	Priority
Top Management	0.23	0.26	0.15	0.20	0.23	0.25	0.20	0.22	1.74	0.22
Financial Management	0.18	0.20	0.22	0.19	0.21	0.17	0.28	0.17	1.61	0.20
Task Planning Based on Scope of Work	0.11	0.07	0.07	0.05	0.03	0.08	0.12	0.05	0.58	0.07
Workforce Capability	0.09	0.09	0.11	0.08	0.22	0.10	0.05	0.04	0.78	0.10

Quality Improvement	0.06	0.06	0.16	0.02	0.06	0.10	0.06	0.09	0.62	0.08
Waste Reduction	0.08	0.10	0.08	0.07	0.05	0.09	0.09	0.13	0.69	0.09
Improvement Tools	0.17	0.11	0.09	0.25	0.14	0.15	0.15	0.22	1.27	0.16
HSE	0.09	0.10	0.12	0.15	0.06	0.06	0.06	0.08	0.71	0.09

To enhance interpretability, the final priority weights are visualised in Figure 3, enabling clearer comparison of the relative dominance among criteria.

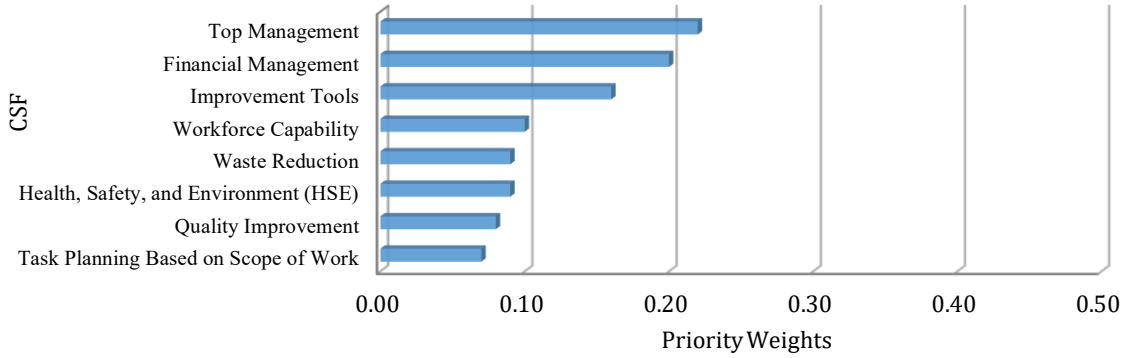


Figure 3: Priority weights for criteria level

The results show that Top Management (0.22) and Financial Management (0.20) have the highest priorities, followed by Improvement Tools (0.16). These findings indicate that planning reliability is primarily driven by managerial commitment, financial control, and structured improvement practices. In contrast, operational factors such as workforce capability, task planning, and quality improvement receive lower weights, suggesting that their effectiveness depends on upstream managerial conditions. From a lean construction perspective, these results highlight that reliable workflow (flow reliability) and effective planning control are primarily enabled by strong managerial commitment and stable resource allocation, which reduce variability and support continuous improvement. This pattern is consistent with previous studies highlighting the role of organisational readiness and leadership in enabling lean implementation (Belhadi et al., 2019; Koohestani et al., 2020; Moradi & Sormunen, 2023b).

PRIORITY STRUCTURE OF PLANNING SUB-CRITERIA

Following the criteria-level analysis, the AHP evaluation is extended to the sub-criteria level to capture more detailed planning attributes within each criterion. Sub-criteria represent specific managerial and operational factors that directly influence the effectiveness of lean-based planning. Expert judgments were obtained through pairwise comparisons and aggregated using the geometric mean to produce group decision matrices. The detailed pairwise comparison matrices are omitted for brevity, as the AHP procedure follows standard computation steps. To illustrate the analysis, the Top Management criterion consists of three sub-criteria: Top Management Commitment, Project Leadership, and Resource Allocation. The resulting priority weights are presented in Table 9. The results show that Top Management Commitment (0.68) is the dominant sub-criterion, followed by Resource Allocation (0.23), while Project Leadership (0.09) plays a supporting role. This indicates that sustained executive commitment is the primary driver of effective lean planning.

Table 9: Pairwise comparison of Top Management sub-criteria

Sub-Criteria	Top Management Commitment	Project Leadership	Resource Allocation
Top Management Commitment	1.00	6.04	3.81
Project Leadership	0.17	1.00	0.30
Resource Allocation	0.26	3.28	1.00

Applying the same procedure across all criteria (Figures 4–11), the results consistently highlight the dominance of key sub-criteria, including financial reporting, responsibility assignment, worker productivity, quality assurance systems, effective use of improvement tools, and safety culture. In contrast, operational and compliance-related sub-criteria tend to play supporting roles. Notably, the relatively balanced weights observed in waste-reduction sub-criteria suggest that effective waste control depends on integrated actions rather than a single dominant factor.

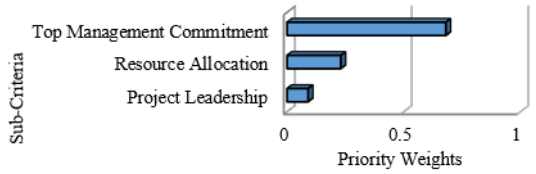


Figure 4: Top management sub-criteria

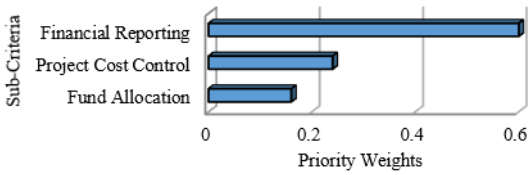


Figure 5: Financial management sub-criteria

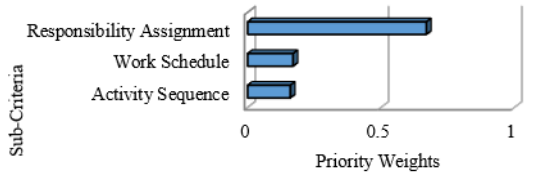


Figure 6: Task planning based on scope of-work sub-criteria

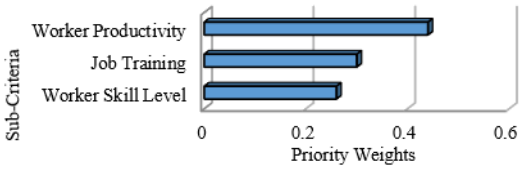


Figure 7: Workforce capability sub-criteria

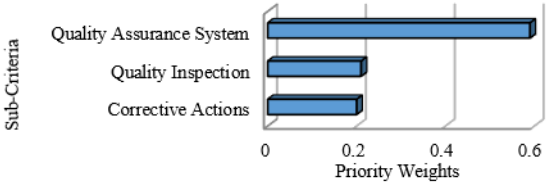


Figure 8: Quality improvement sub-criteria



Figure 9: waste reduction sub-criteria

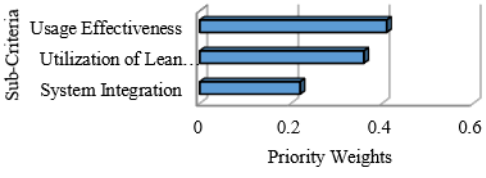


Figure 10: Improvement tools sub-criteria

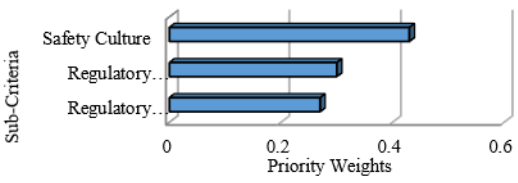


Figure 11: HSE sub-criteria

Overall, the results indicate that planning-stage lean performance is primarily driven by managerial commitment, accountability, and execution readiness, rather than by isolated technical factors. This finding reinforces previous studies that emphasise organisational readiness and structured control as key enablers of lean construction success (Belhadi et al., 2019; Tezel et al., 2018). From a lean perspective, these sub-criteria function as enabling

conditions that support planning reliability, reduce variability, and strengthen workflow control during project delivery.

PRIORITISED LEAN CONSTRUCTION TECHNIQUES FOR ENHANCING THE PLANNING STAGE

At the alternative level, AHP is applied to evaluate the relative importance of lean construction techniques in supporting planning-stage performance. Expert judgments are synthesised and normalised to derive priority weights, ensuring consistent and comparable evaluation across techniques. Table 10 presents the resulting priority weights of the evaluated techniques.

Table 10: Priority weights of alternatives at the planning stage

Alternatives	Last Planner System	Value Stream Mapping	Building Information Modelling	Total	Priority
Last Planner System	0.41	0.44	0.41	1.25	0.42
Value Stream Mapping	0.09	0.09	0.10	0.28	0.09
Building Information Modelling	0.50	0.47	0.50	1.47	0.49

The results indicate that Building Information Modelling (BIM) has the highest priority (0.49), followed by the Last Planner System (LPS) (0.42), while Value Stream Mapping (VSM) has the lowest priority (0.09), as illustrated in Figure 12.

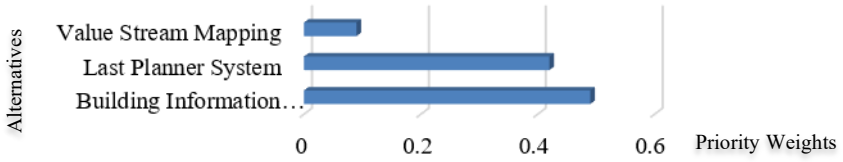


Figure 12 Priority weights of alternatives

The dominance of BIM reflects its strong capability in enhancing coordination, information transparency, and early decision-making, which are critical for reducing planning uncertainty. Previous studies confirm that BIM improves planning reliability through better integration of design information and stakeholder collaboration (Sacks et al., 2020; Michalski et al., 2021). From a planning-stage perspective, this capability is operationalised through key BIM deliverables, including coordinated 3D models at an appropriate Level of Development (LOD) to support design clarity, structured clash detection and resolution workflows to minimise design conflicts, and the integration of scheduling and cost information through 4D and 5D BIM. These deliverables enable early identification of constraints, improved coordination among stakeholders, and more reliable planning decisions. Within the scope of this study, these elements are discussed at a conceptual level to indicate the practical relevance of BIM in enhancing planning-stage performance.

LPS ranks second, indicating its effectiveness in supporting collaborative and commitment-based planning, particularly in improving workflow reliability (Ballard & Tommelein, 2020). In practical terms, its contribution to planning-stage performance is reflected in structured planning routines, including pull planning workshops, weekly work planning cycles, and short-cycle coordination meetings. These routines support commitment-based scheduling and constraint identification. In addition, LPS implementation is commonly monitored using reliability metrics such as Percent Plan Complete (PPC) and constraint removal lead time, while continuous improvement is supported through systematic learning routines such as reasons-for-variance analysis and A3-based problem solving.

In contrast, VSM has the lowest priority, suggesting its role primarily as a diagnostic tool for identifying inefficiencies rather than as a direct driver of planning performance (Ramani & KSD, 2021). Importantly, these findings indicate a complementary implementation logic rather than isolated application. BIM supports coordination and information integration, LPS strengthens planning reliability, and VSM facilitates continuous process improvement. In practice, these techniques can be deployed sequentially, where BIM establishes early coordination, LPS operationalises collaborative planning, and VSM supports continuous evaluation and improvement of planning processes.

From a theoretical perspective, these results can be interpreted through the Transformation–Flow–Value (TFV) theory of production (Koskela, 1992), which underpins lean construction. The transformation view is reflected in structured task planning and clear responsibility assignment, ensuring that work packages are well-defined and executable. The flow view is supported by BIM and LPS, which reduce variability and improve workflow continuity. Meanwhile, the value view is represented by quality assurance, stakeholder alignment, and continuous improvement, ensuring that project outcomes meet both client and sustainability expectations. This alignment confirms that the prioritised techniques are not merely operational preferences but represent mechanisms for improving planning reliability and flow efficiency within lean construction systems.

In the Indonesian context, the prominence of BIM is also aligned with national regulations promoting digital construction and sustainable practices (Kementerian PUPR, 2018; 2021). From a lean–green perspective, these techniques contribute indirectly to sustainability through reduced material waste, minimised rework, and more efficient resource utilisation enabled by improved planning control. Specifically, BIM supports early design coordination and clash detection, reducing design conflicts that would otherwise lead to rework and material waste. LPS enhances workflow reliability and commitment-based planning, thereby minimising variability and preventing inefficient resource use during execution. Meanwhile, VSM facilitates the identification and elimination of non-value-adding activities, enabling continuous process improvement and waste reduction. Although not directly quantified in this study, prior research indicates that improved planning coordination and reduced rework may lead to material waste reduction of up to 10–20% and associated reductions in embodied carbon emissions (Guerra et al., 2020).

To enhance practical applicability, the findings can be translated into a short-term implementation roadmap for Indonesian project teams during the planning stage (Table 11).

Table 11: Suggested 12-week lean planning implementation roadmap

Phase	Timeline	Key Actions	Expected Outcome
Phase 1: Coordination Setup	Weeks 1–2	Develop BIM-based 3D model, perform initial clash detection, align stakeholders	Improved design clarity and coordination
Phase 2: Collaborative Planning	Weeks 3–6	Conduct pull planning workshops, define work packages, assign responsibilities	Increased planning reliability
Phase 3: Planning Control	Weeks 7–10	Implement short-cycle planning (weekly planning), monitor constraints	Reduced variability and delays
Phase 4: Process Improvement	Weeks 11–12	Apply VSM to identify inefficiencies, evaluate workflow performance	Continuous improvement and waste reduction

This staged approach reflects a complementary deployment of BIM, LPS, and VSM, where digital coordination is established first, followed by collaborative planning and continuous process improvement.

CONCLUSION

This study demonstrates that managerial readiness—particularly top management commitment, financial transparency, and the effective use of improvement tools—constitutes the primary foundation for successful lean implementation at the planning stage. Operational factors such as workforce capability, quality improvement, waste reduction, and HSE remain important, but their effectiveness is contingent upon strong organisational support. At the sub-criteria level, top management commitment emerges as the dominant driver, supported by financial reporting, responsibility assignment, worker productivity, quality assurance systems, safety culture, and effective use of improvement tools. These factors collectively reflect the importance of leadership, accountability, and execution readiness in enabling reliable planning.

This study contributes a decision-support framework for prioritising CSFs and lean construction techniques, rather than proposing a standalone method. Within this framework, Building Information Modelling (BIM) is identified as the most suitable technique for the planning stage, followed by the Last Planner System (LPS) and Value Stream Mapping (VSM), highlighting the importance of digital integration and collaborative planning in enhancing planning reliability. However, this study is limited by the small number of experts (N = 10) and the focus on only three lean techniques, which may introduce subjectivity and limit generalisability. Future research is recommended to validate the framework through real project applications and to extend it by incorporating additional techniques and data-driven approaches.

Overall, planning-stage lean performance in Indonesia is shaped by the integration of leadership commitment, managerial discipline, digital capability, and continuous improvement practices. However, the findings should be interpreted with caution due to several limitations, including the limited number of experts, reliance on subjective judgment, and the focus on a restricted set of lean techniques. Future research is recommended to validate the proposed framework through project-based or longitudinal studies, extend the analysis to execution and monitoring stages, and incorporate hybrid or data-driven methods to better capture uncertainty.

ACKNOWLEDGMENT

The authors show acknowledgment to Department of Civil Engineering, Institut Teknologi Sepuluh Nopember, for it's conference funding support.

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