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Optimizing Time and Cost Efficiency in Housing Construction using a Lean Construction Approach

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Abstract

Efficient time and cost control is critical in housing construction, particularly where workflow disruptions and non-value-added activities reduce project performance. This study examines the Green Royal Housing Project in Jakarta, Indonesia, to evaluate how Lean Construction can improve delivery through waste identification, activity classification, and workflow planning. Project documents, site observations, and interviews with five key stakeholders were used to classify 87 construction activities into value-added, essential non-value-added, and non-value-added categories. The analysis identified 21 non-value-added activities, mainly related to waiting, unnecessary processes, transportation inefficiencies, and inventory problems. Their elimination reduced the projected duration from 83 to 74 weeks. An LPS-informed planning framework was then used to support lookahead planning, constraint screening, and weekly work commitments. Because a four-week delay remained, a CPM-based crashing scenario was evaluated separately as a post-lean acceleration option, reducing the duration to 66 weeks. The findings clarify Lean Construction's role in improving housing project efficiency.

INTRODUCTION

Housing construction projects often face challenges related to delays, cost overruns, and inefficient resource utilization due to poor planning, wasteful activities, and ineffective coordination [1,2]. As a result, developers and contractors seek strategies that improve project performance while maintaining quality and minimizing costs.

Lean Construction (LC) provides a systematic approach to improving construction efficiency by eliminating non-value-added (NVA) activities, optimizing workflows, and improving coordination [3]. Originally derived from Lean Manufacturing, LC principles such as the Last Planner System (LPS), Just-in-Time (JIT), Prefabrication, and Standardization have been applied in various infrastructure projects to reduce delays, improve productivity, and control costs [4]. However, its application in housing projects in Indonesia remains underexplored.

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This study aims to evaluate how Lean Construction improves time and cost efficiency in housing construction through three sequential mechanisms: identifying and eliminating non-value-added activities, strengthening workflow reliability through LPS-informed lookahead and weekly work planning, and mapping appropriate Lean tools to preparation, procurement, and execution work packages. A CPM-based crashing scenario is examined only as a post-lean acceleration option to recover the remaining delay after Lean-based waste reduction has been applied. By making this distinction, the study clarifies the contribution of Lean Construction to housing project performance while avoiding the misclassification of schedule crashing as a Lean tool.

The contribution of this study lies in its sequential treatment of Lean Construction and schedule acceleration. First, the study quantifies the effect of Lean-based waste elimination by comparing the delayed condition with the NVA-elimination scenario. Second, it clarifies how LPS-informed planning can be used to translate remaining VA and ENVA work packages into lookahead constraints and weekly work commitments. Third, it separates Lean Construction from CPM-based crashing, positioning crashing only as a complementary recovery scenario after Lean-based workflow improvement has been evaluated.

Accordingly, the study addresses two research questions: which construction activities generate time and cost inefficiencies in the Green Royal Housing Project, and how can Lean Construction, through NVA elimination, LPS-informed planning, and Lean tool mapping, improve project time and cost performance while being distinguished from a separate post-lean crashing scenario?

The findings offer practical insights for developers and contractors aiming to improve project performance, policymakers seeking more efficient housing delivery, and researchers exploring the broader application of LC in Indonesia's construction sector.

LITERATURE STUDY

Lean Construction Practices

Lean Construction (LC) emerged as an innovative approach to project management, rooted in the principles of Lean Manufacturing developed by Toyota through the Toyota Production System (TPS). TPS initially aimed to optimize production processes in manufacturing by continuously eliminating waste and maximizing value-added activities, thus achieving significant cost savings, productivity enhancement, and quality improvement [5].

The fundamental principles of Lean, which are highly applicable to the construction industry, involve defining customer value, identifying and mapping value streams, creating flow by minimizing interruptions, implementing pull systems to ensure work is demand-driven, and striving for continuous improvement [6]. Unlike traditional construction management approaches that tend to be reactive, LC emphasizes proactive planning, collaborative workflows, and systematic waste elimination from the earliest planning stages [4,7].

In construction, LC seeks to enhance project efficiency by systematically addressing wasteful activities, streamlining coordination, and improving stakeholder communication [3]. This strategic focus on workflow efficiency, resource optimization, and continuous improvement distinguishes LC from conventional project management approaches, which often suffer from fragmented planning and inefficient resource allocation [8]. Consequently, LC has gained attention globally, offering significant benefits such as reduced project duration, lowered construction costs, increased productivity, and improved overall project quality.

Several international studies have demonstrated the benefits of LC, especially within residential construction projects. Fauzan & Sunindijo [8] examined LC implementation in Australian housing projects, highlighting a 20% reduction in project delays and significant workflow improvements through the application of Last Planner System (LPS) and Just-in-Time (JIT). Cairampoma-Caro et al. [9] found similar benefits in Latin America: productivity gains up to 50% and yearly construction-time reductions around 20% due to Prefabrication and Standardization. Additionally, Xing et al. [4] documented significant economic benefits in Chinese residential construction, including an 8% reduction in overall construction costs and approximately 13% savings in transportation expenses, largely driven by Prefabrication, 5S, and JIT practices.

In developing countries, LC has also shown encouraging results. Elmalky et al. [10] concluded that Prefabrication and Standardization effectively reduced waste generation and mitigated project delays across multiple housing projects. Similarly, after applying LC principles, Babalola et al. [11] observed tangible improvements in cost efficiency and reliable project delivery timelines in Nigerian housing projects.

Recent studies have further highlighted the relevance of construction method selection and scheduling risk to project performance. Chandler and Sunindijo [12] reported that prefabrication can influence work conditions and construction process outcomes, while Djohim et al. [13] demonstrated the value of probabilistic scheduling analysis for identifying delay risks in modest housing projects. Together, these findings reinforce the need to connect Lean-based workflow improvement with housing project scheduling and production reliability.

Lean Construction in the Context of Indonesia's Housing Industry

Despite the proven global benefits of Lean Construction (LC), its adoption in Indonesia's housing sector remains limited. Several structural and operational barriers hinder implementation, including fragmented project planning, inadequate stakeholder coordination, inconsistent supply chains, and insufficient training in Lean methodologies. These challenges are compounded by a lack of awareness, cultural resistance to change, and the absence of frameworks tailored to local construction practices [7,8].

Indonesia's housing construction industry is particularly affected by inefficiencies stemming from rapid urbanization and traditional management approaches [14]. Nurlaelah and Jayady [15] identified key productivity issues such as poor material handling, labor shortages, and weak contractor-subcontractor coordination. Furthermore, regulatory complexities and reactive project planning often exacerbate delays and cost overruns [3]. As a result, many residential projects suffer from low performance and missed quality benchmarks.

LC brings an alternative through collaborative planning, continuous improvement, and waste elimination [16]. However, its application requires contextual adaptation to Indonesia's regulatory, cultural, and operational environment. Local implementation also demands leadership commitment, stakeholder buy-in, and skill development across project teams [17].

This study responds to these challenges by examining the integration of LC tools within the Green Royal Housing project in Jakarta. It aims to provide empirical evidence on how targeted Lean strategies, such as Last Planner System (LPS), Just-in-Time (JIT), Standardization, and Prefabrication, can be effectively applied to reduce inefficiencies and improve project outcomes in Indonesia's residential construction sector.

Waste in Construction

Waste in construction refers to any activity that consumes resources without adding value to the final product. Koskela et al. [6] as well as Ohno & Bodek [5] classified waste into seven categories: overproduction, waiting, transportation, over-processing, inventory, motion, and defects. Identifying and eliminating these inefficiencies is crucial for achieving time and cost efficiency in housing projects [18].

Construction activities can be categorized into Value-Added (VA), Non-Value-Added (NVA), and Essential Non-Value-Added (ENVA) activities [19]. VA activities directly contribute to the final product and generate customer value, such as foundation work and structural assembly. NVA activities, such as unnecessary inspections, material handling delays, and inefficient coordination, do not add value and should be eliminated. ENVA activities, such as regulatory approvals and site safety checks, do not add direct value but are necessary for project completion.

Recent studies have examined the implementation of LC principles to reduce waste in housing projects across various countries. Elmalky et al. [10] evaluate this implementation to reduce construction waste in building projects in developing countries. Their research found that adopting LC principles can reduce waste and improve efficiency in building projects in developing countries. In Nigeria, Babalola et al. [11] found that LC helped reduce cost overruns and improved project delivery without compromising quality. These findings highlight the effectiveness of Lean practices in reducing waste, yet their application in Indonesia's housing sector remains underexplored.

Despite the advantages, adopting LC in Indonesian housing projects faces several challenges, including limited awareness, a lack of stakeholder commitment, and inadequate training on Lean methodologies. This study aims to bridge this gap by evaluating the impact of LC on housing projects in Jakarta, providing a framework for improving efficiency and reducing construction waste.

METHODS

Project Case Study

This research aims to (1) identify activities that cause time and cost inefficiencies in housing construction, (2) evaluate the effect of Lean-based NVA elimination on project duration and cost performance, and (3) develop an LPS-informed workflow planning strategy supported by relevant Lean tools. The study assesses Lean Construction primarily as a waste-reduction and production-control approach, including the use of LPS, JIT, Standardization, Coordination, Collaboration, Prefabrication, and Five S. A CPM-based crashing scenario is analyzed separately as a post-lean schedule recovery option, not as a Lean Construction tool.

To achieve these objectives, this study focuses on the Green Royal housing project in Jakarta, Indonesia, a three-hectare residential development with 236 units. The project includes foundation work, structural assembly, and finishing stages, with a planned duration of 70 weeks. Inefficiencies in workflow and resource management have led to delays and cost overruns.

Data Collection Method

The study adopts a structured data collection approach to ensure alignment with the research objectives. It integrates qualitative and quantitative data from three primary sources: project documentation, interviews, and site observations.

Baseline schedules, cost breakdowns, and construction progress reports were collected to compare planned vs. actual performance and identify time, cost, and resource utilization deviations. Semi-structured interviews were conducted with project managers, site engineers, and contractors to gather insights into waste sources, workflow disruptions, and LC challenges. Five (5) interviews focused on decision-making constraints, coordination issues, and the feasibility of LC tools. Weekly progress reports were also reviewed to reconstruct short-term work commitments and verify whether planned work packages were completed within the corresponding reporting period. These records were used to support the Percent Plan Complete (PPC) assessment under the LPS framework.

The interview process was organized in two stages. In this study, the Work Breakdown Structure (WBS) refers to the project’s hierarchical decomposition of scope into manageable work items used for planning and control. In Stage I, respondents assessed the list of WBS work items (treated as an activity list extracted from project documentation) and classified each as value-adding (VA), essential non-value-adding (ENVA), or non-value-adding (NVA). This classification served as an analytical overlay to identify waste and improvement opportunities, rather than as an inherent WBS categorization. In Stage II, the same respondents evaluated the VA and ENVA work items and recommended Lean Construction (LC) tools to improve execution efficiency, selected based on task relevance and field constraints. During the second interview stage, respondents were not only asked to recommend Lean tools but also to validate the readiness constraints affecting each work package. This validation supported the construction of the lookahead plan and the weekly work planning logic.

In addition to interviews and documentations, direct site observations over a 22-week period were conducted to capture real-time inefficiencies in construction activities. The study identified inefficiencies that were not always evident in documentation or interviews by analyzing on-site construction activities.

Respondents and Interview Stages

This study's qualitative component involved in-depth interviews with key project stakeholders to identify inefficiencies and evaluate the applicability of Lean Construction tools in the Green Royal Housing Project. A total of five respondents participated in the interviews, each representing a critical role in the project's management and execution:

1. One project manager is responsible for overall project delivery and decision-making.
2. Two site engineers are directly involved in daily coordination and technical supervision.
3. One procurement supervisor oversees material supply chains and logistics.
4. One contractor’s representative oversees on-site execution and workforce allocation.

All respondents had more than five years of experience in housing construction, with professional backgrounds in civil engineering or construction management. Their involvement in the Green Royal Housing Project ensured that the insights gathered reflected both strategic and operational perspectives.

The interview process was conducted in two stages over a period of six weeks. Each session lasted approximately 60–90 minutes and was conducted in a private setting to encourage open discussion. In Stage I, respondents reviewed the project's WBS work items and classified them as VA, ENVA, or NVA to identify sources of inefficiency and waste. In Stage II, they recommended appropriate Lean Construction tools for each remaining (VA/ENVA) work item, discussing implementation feasibility and potential impact. All interviews were audio-recorded, transcribed, and thematically analyzed to ensure reliability and validity. Direct site observations complemented interview findings, triangulating the data and documenting workflow inefficiencies not captured in project reports or interviews. For LPS operationalization, respondents reviewed each remaining VA and ENVA work package using three questions: whether the activity should be performed according to the revised schedule, whether it could be performed after constraints were removed, and whether it could be committed to the weekly work plan. This procedure allowed the study to distinguish scheduled activities from executable and committed activities.

Data Analysis Method

The data analysis followed a staged approach that started with classifying construction activities into VA, NVA, and ENVA to identify inefficiencies that caused project delays and cost overruns. A review of baseline schedules, cost reports, and site observations provided quantitative data on time, cost, and resource utilization deviations. Interview responses from project managers, site engineers, and contractors were analyzed to gain qualitative insights into workflow disruptions, coordination issues, and stakeholder challenges.

Second, the study assessed the potential of LPS, JIT, Prefabrication, Standardization, Coordination, Collaboration, Right at First Time, Five S, and Overlap in reducing workflow unreliability. NVA activities identified through the waste classification framework were removed, while the remaining VA and ENVA activities were mapped to Lean tools based on their dominant constraints. CPM-based crashing was analyzed separately as a post-lean schedule recovery scenario and was not classified as a Lean Construction tool.

Last, the study measured the impact of LC on time and cost efficiency by comparing planned vs. actual project performance metrics. Deviations in schedule, work progress rates, and cost variations were analyzed to quantify improvements. A cost-benefit analysis determined whether the efficiency gains from LC outweighed the additional investments required. This structured approach ensured that the findings provided empirical evidence supporting LC as a viable strategy for improving housing project efficiency. Figure 1 shows the research workflow.

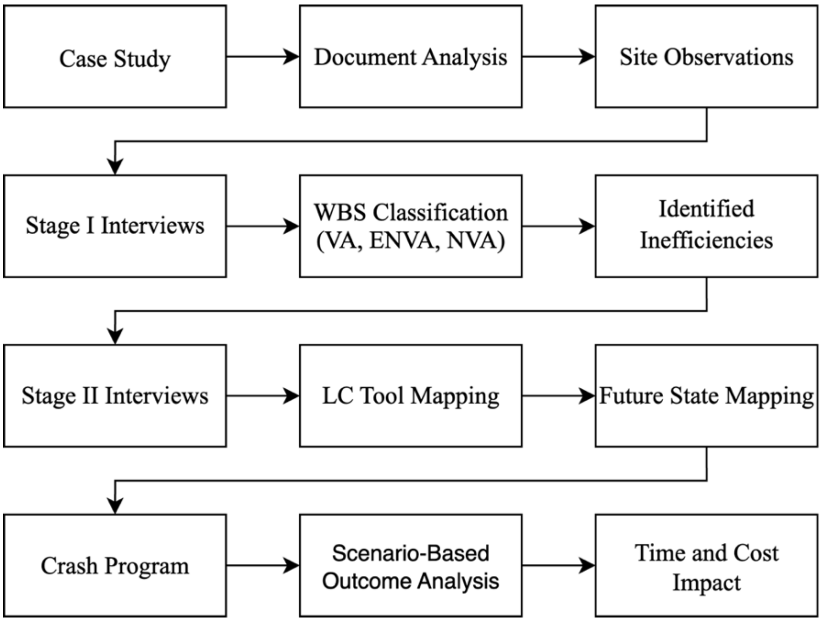

Figure 1. Research Workflow

Operationalization of the Last Planner System

To clarify the role of the Last Planner System (LPS) in this study, LPS was operationalized as a planning and production-control framework rather than as a schedule acceleration technique. This distinction was necessary because the study also evaluated a CPM-based crashing scenario as a separate post-lean acceleration option. The LPS procedure was applied to the remaining work packages after the VA-NVA-ENVA classification and NVA elimination stages.

The LPS-based procedure was implemented through four sequential steps, as summarized in Table 1. The first step involved classifying the remaining VA and ENVA work packages into three main project phases: preparation, procurement/delivery, and execution. The second step was the development of a lookahead planning framework by mapping the prerequisites and constraints associated with each work package, such as drawing readiness, material approval, supplier preparedness, equipment availability, work permit status, site access, and labor availability. In the third step, the work packages were evaluated using the should-can-will logic. In this context, "should" denoted the required activities under the baseline or revised schedule, "can" referred to activities that were executable after the relevant constraints had been cleared, and "will" represented activities formally committed to in the weekly plan by the responsible project participants. Finally, weekly work planning was applied to convert constraint-free work packages into short-term execution commitments on site.

PPC was used as a planning reliability indicator within the LPS framework. It was calculated as the proportion of weekly commitments completed as planned relative to the total number of weekly commitments. Because the project did not originally maintain a formal LPS-based PPC log, the PPC assessment was reconstructed from weekly progress reports, work-package readiness checks, and interview validation with project stakeholders. Therefore, PPC was used as a supporting indicator to evaluate planning reliability, while the main quantitative impact was assessed through duration reduction, NVA elimination, and time-cost scenario comparison.

The PPC value was calculated as:

$$PPC = \frac{\text{Number of weekly commitments completed as planned}}{\text{Total number of weekly commitments planned}} \times 100\% \tag{1}$$

In this study, a commitment was considered completed when the planned work package was executed within the relevant weekly reporting period and did not require deferral due to unresolved constraints.

Table 1. LPS Procedure used for Lookahead Planning, WWP, and PPC Assessment

LPS Step	Procedure Used in This Study	Data Source	Output
Work package screening	Remaining work items were classified into VA, ENVA, and NVA. NVA activities were removed from the workflow.	WBS, project schedule, interviews, site observations	List of VA/ENVA work packages for further planning
Lookahead planning	Upcoming work packages were reviewed based on drawing readiness, material approval, supplier readiness, work permit, equipment availability, site access, and labor availability.	Baseline schedule, weekly reports, procurement records, interviews	Constraint list and work-package readiness status
Should-can-will screening	'Should' activities were taken from the revised schedule; 'can' activities were those with constraints removed; 'will' activities were converted into weekly commitments.	Revised schedule, stakeholder validation, field observation	Weekly work plan commitments
Weekly work planning	Constraint-free work packages were assigned to responsible actors for short-term execution.	Weekly coordination records and stakeholder interviews	Weekly work plan/WWP
PPC assessment	Weekly commitments were compared with completed work packages.	Weekly progress reports and interview validation	PPC value as planning reliability indicator

RESULTS AND DISCUSSION

Identifying Activities Causing Inefficiencies

The first result of the Lean Construction analysis was the identification of workflow inefficiencies through VA-NVA-ENVA classification. This classification was not treated merely as an activity-labeling exercise, but as a diagnostic step to distinguish work packages that created customer value, work packages that were necessary but did not directly create value, and work packages that generated avoidable waste. This step was central to the Lean-based improvement process because it determined which activities could be eliminated, simplified, or controlled through Lean planning tools.

From 87 construction activities analyzed in the Green Royal Housing Project, 21 activities were classified as non-value-added (NVA), representing 24% of the total activities. VA and ENVA activities each accounted for 38%. The

NVA activities were distributed across preparation, procurement/delivery, and execution phases, indicating that inefficiency was not limited to field production but also emerged from information flow, approval procedures, material logistics, and coordination practices. This confirms that the project delay was not only a scheduling problem but also a workflow reliability problem.

In addition to process inefficiencies, deviations in actual construction performance further confirmed operational challenges. By week 22, the project recorded a 0.8% delay from the planned schedule, with actual progress at 23.47% instead of 24.27%. The pile driving process for 25x25 cm piles showed a 0.907% deviation, as actual progress reached 2.13% compared to the target of 3.037%. These delays extended the project duration from 70 weeks to 83 weeks and increased the risk of penalties and cost overruns (see Figure 2). This delay introduced risks of penalties and additional costs.

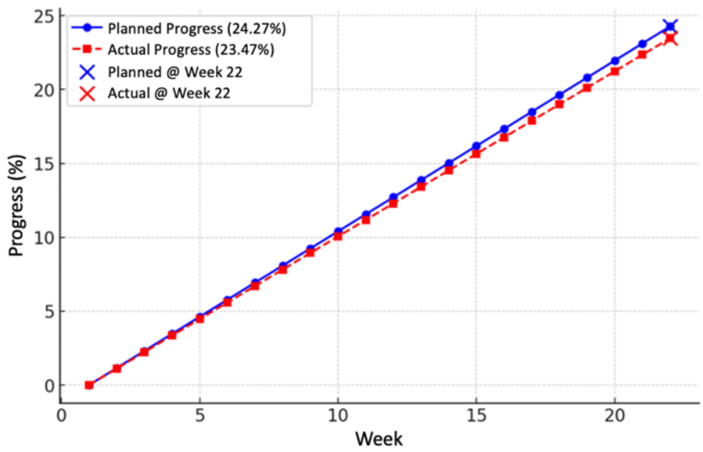

Figure 2. Project Timeline Deviation at Week 22

The dominant NVA categories were waiting, unnecessary processing, transportation inefficiency, and inventory-related waste. Nine NVA activities were associated with waiting, seven with unnecessary processes, three with transportation inefficiencies, and two with inventory mismanagement. In practical terms, these wastes appeared in delayed shop drawing circulation, repeated approval procedures, unclear supplier coordination, material handling inefficiencies, and storage-related disruptions. These results support the need for Lean Construction interventions that address process reliability before applying any schedule acceleration technique.

Lean-Based Waste Elimination and Workflow Recovery

The second result concerns the effect of eliminating NVA activities on project duration. Under the delayed condition, the project duration was projected to increase from the planned 70 weeks to 83 weeks. After removing the 21 NVA activities, the projected duration decreased to 74 weeks. This nine-week recovery represents the direct contribution of Lean-based waste elimination. It shows that a substantial portion of the delay originated from avoidable process inefficiencies rather than from unavoidable technical constraints.

However, the NVA elimination scenario still left a four-week gap compared with the original 70-week plan. This finding is important because it shows both the strength and the limitation of Lean-based waste elimination in the studied project. Lean analysis substantially reduced the delay, but additional production-control measures were still needed to improve the reliability of the remaining VA and ENVA work packages. For this reason, the study proceeded to Lean tool mapping and LPS-informed planning before evaluating any post-lean schedule acceleration option.

Results of LPS-Informed Lookahead Planning and Weekly Work Planning

The LPS-informed planning analysis was applied to convert the remaining VA and ENVA work packages into more dependable short-term commitments for site execution. Within this process, lookahead planning was used to identify the constraints that hindered scheduled activities from becoming ready-to-execute work packages, as shown in Table 2. The key constraints included drawing readiness, material approval, supplier preparedness, equipment availability, work permit status, storage readiness, work-front access, and labor availability. These constraint categories were then used to differentiate between activities that “should” be carried out based on the revised schedule and those that “can” be executed once the relevant constraints had been resolved.

Weekly work planning was developed from work packages that satisfied the 'can' condition. In other words, activities were not directly transferred from the master schedule into weekly commitments unless the required drawings, materials, permits, equipment, and work-front access were available. This reflects the LPS principle of shifting from push-based scheduling to pull-based production control. The approach follows the should-can-will logic, where 'will' activities represent commitments that can reasonably be executed within the weekly planning period.

PPC was used as a supporting planning reliability indicator. Since the project did not originally maintain a formal LPS-based PPC log, the PPC assessment was reconstructed from weekly progress reports, work-package readiness checks, and validation from project stakeholders. Therefore, PPC is presented as a reconstructed reliability assessment rather than as a continuous formal LPS implementation record. This limitation is acknowledged to avoid overstating the level of LPS maturity in the project.

Table 2. LPS-informed Planning Results for Key Work Pack

Work package	Main constraints identified	Lookahead planning action	Weekly work planning commitment	PPC assessment basis
Shop drawing	Drawing revision, approval circulation, and document distribution delays	Standardize drawing checklist and clarify approval responsibility	Complete and distribute controlled shop drawings to field team	Weekly completion status of drawing-related commitments
Material approval	Incomplete material list and delayed technical approval	Prepare BoQ-based material list and verify specifications before submission	Submit and obtain approval for priority materials	Completion of committed approval tasks
Supplier/subcontractor coordination	Unclear supplier capacity and delivery sequence	Confirm supplier/subcontractor readiness and delivery schedule	Issue PO and confirm delivery dates for priority materials	Procurement commitment completion
Workshop and storage	Storage congestion, poor FIFO control, and fabrication readiness problems	Arrange storage layout, apply FIFO, and prepare reinforcement workshop	Complete storage readiness and workshop preparation	Completion of readiness checklist
Pile driving and structural works	Equipment condition, material readiness, work-front access, and labor allocation	Verify pile availability, equipment readiness, work permits, and access	Execute planned weekly pile driving/structural work packages	Weekly comparison between committed and completed work

The reconstructed PPC assessment revealed an overall planning reliability of 54.9% across the 22-week observation period, as shown in Table 3. This value indicates that approximately 45% of weekly work package commitments were deferred at least once due to unresolved constraints, consistent with the project's eventual schedule overrun from 70 to 83 weeks. The phase-level results show a progressive improvement in planning reliability: PPC was lowest in the preparation phase (44.0%), where unnecessary process activities such as repeated approval loops and documentation reviews prevented timely commitment completion. PPC improved in the procurement/delivery phase (56.0%), where transportation inefficiencies and inventory-related problems delayed material availability. The highest PPC was recorded in the early execution phase (62.5%), where the primary constraint had shifted to waiting associated with material readiness and work-front access rather than information or approval failures.

Table 3. Reconstructed PPC by Project Phase (22-week Observation Period)

Phase	Weeks	Work packages planned	Completed as planned	PPC (%)	Primary NVA constraint category
Preparation	1-7	25	11	44.0	Unnecessary processes; waiting (approval and permit delays)
Procurement/ Delivery	8-14	25	14	56.0	Transportation inefficiency; inventory mismanagement; waiting (supplier delays)
Early Execution	15-22	32	20	62.5	Waiting (material readiness, work-front access)
Overall	1-22	82	45	54.9	-

The rising PPC trend across phases reflects the gradual resolution of upstream constraints as the project progressed from information-intensive preparation activities to field execution. Nevertheless, the overall PPC of approximately

55% remained below the benchmark values typically observed in projects with mature LPS implementation, which commonly achieve PPC values of 70–80% or higher. This gap confirms that the project had significant unreliability in its planning process, particularly in the preparation and procurement phases where NVA activities were most concentrated. The LPS-informed planning framework developed in this study, including constraint screening, should-can-will logic, and weekly work plan commitments, was designed to address precisely these sources of planning unreliability by preventing work packages from entering weekly commitments before their prerequisites were cleared.

Evaluating Project Improvement Strategies Through Waste Elimination and Lean Tools

Lean Tools and Their Application

LC employs specific tools and techniques designed to eliminate waste and systematically enhance productivity in construction projects. Among the most prominent tools are the LPS, JIT, Prefabrication, Standardization, and the Five S method. The LPS improves planning reliability by involving multiple project stakeholders in schedule development and daily coordination. Through this approach, teams anticipate issues earlier and adjust activities before disruptions occur. Compared to reactive scheduling, LPS supports more consistent task execution and helps reduce delays [8]. JIT targets inventory efficiency by ensuring that materials arrive at the construction site when required. This method reduces the risk of material damage, lowers storage costs, and prevents unnecessary material movement [4].

Prefabrication shifts the production of components off-site. This method improves dimensional accuracy, reduces site congestion, and supports faster installation. Projects that use prefabricated elements experience less rework and shortened timelines [10]. On the other hand, standardization creates consistency in methods, materials, and procedures. It simplifies coordination, reduces variability, and minimizes errors. Consistent application of standardized processes also makes training easier and promotes safer working conditions.

The 5S method consists of Sort, Set in Order, Shine, Standardize, and Sustain. It improves site organization by promoting a clean and orderly workspace where tools and materials follow a logical arrangement. This structure helps reduce wasted movement and avoids delays caused by disorganized or unsafe workspaces. These five tools formed the basis for the improvement strategy in this study. Their selection was based on the types of inefficiencies found in the project and the need to improve specific phases of execution.

Mapping Lean Tools

This study began by evaluating current project conditions to identify inefficiencies before selecting appropriate LC tools. Given that the Green Royal Housing project was already in progress, a future state mapping approach was adopted. This method relied on current state analysis to define process improvements that could reduce delays and improve efficiency. It also supported the long-term objective of establishing consistent improvement practices across the construction stages.

The waste classification process was conducted through Stage I interviews with site engineers, supervisors, and project managers. Respondents reviewed the WBS work items and categorized them into VA, ENVA, and NVA as a value-based screening. Based on this classification, 21 NVA work items were removed. The remaining 66 work items consisted of 33 VA and 33 ENVA tasks, with a combined duration of 191.5 calendar days. The project contract, however, only allocated 90 days for this stage. This revealed a critical gap and emphasized the need to apply additional measures to increase efficiency.

To avoid ambiguity between WBS and schedule outputs, this study distinguishes (i) WBS work items (work packages) used for scope decomposition and interview-based waste screening, and (ii) schedule activities used in the baseline CPM programme and weekly progress reporting. In the project documents, schedule activities were coded under their corresponding WBS work items; therefore, the S-curve represents cumulative planned and actual progress aggregated from schedule activities (using the project's planned weights) and summarized at the WBS level. Accordingly, WBS work items and the S-curve refer to the same underlying scope, but the S-curve is a time-phased representation of progress rather than a list of WBS work items.

Although removing NVA activities improved the schedule, projections still indicated a four-week delay. To address this, the study proceeded to Stage II interviews. The same group of respondents evaluated the 66 remaining VA and

ENVA activities and selected applicable Lean tools for each work category. Nine Lean Construction tools were considered: (LC1) Standardization, (LC2) Last Planner System (LPS), (LC3) Right at First Time, (LC4) Coordination, (LC5) Just-in-Time (JIT), (LC6) Collaboration, (LC7) Five S, (LC8) Prefabrication, and (LC10) Overlap. In addition, a CPM-based schedule acceleration technique (LC9, schedule crashing) was evaluated separately as a post-lean option to recover remaining delay; it is not treated as a Lean tool.

Because Lean Construction tools such as the Last Planner System (LPS) are not yet standard practice in Indonesia's housing projects, a short tool-briefing sheet was provided before the Stage II mapping exercise. The briefing summarized each candidate LC tool using consistent definitions and practical examples aligned with the studied project (e.g., weekly commitment planning and constraint removal for LPS). During the interview, the facilitator confirmed respondents' understanding and allowed clarification questions to minimize terminology bias. Respondents were senior site and project managers (9–22 years of experience), which supported informed judgments on the feasibility of applying each tool in the project context.

To map LC tools to work categories, respondents were asked to (i) review the remaining VA/ENVA work items grouped by project phase (preparation, procurement, execution) and by activity type, (ii) identify the dominant source of unreliability or waste for each group (e.g., information/coordination gaps, material flow variability, workspace congestion, rework risk), and (iii) select the most applicable LC tool(s) from the predefined list based on feasibility in the Green Royal Housing context. For planning-related work, the Last Planner System (LC2) was operationalized as collaborative phase planning and pull-based lookahead/weekly work planning, including constraint removal and weekly commitment tracking (e.g., Percent Plan Complete). This operational definition follows the original LPS formulation [20].

Following the elimination of NVA activities and the LPS-informed screening of constraints, the remaining VA and ENVA work packages were linked to relevant Lean Construction tools according to the primary source of waste or workflow unreliability. This mapping was intended not to shorten activity durations through additional resources, but to enhance workflow reliability, reduce process variability, minimize unnecessary waiting time, and strengthen coordination among project participants. For this reason, the Lean tool mapping table includes only Lean Construction tools, as presented in Table 4. CPM-based crashing was deliberately excluded from this table and is instead presented separately as a post-Lean schedule recovery scenario.

Table 4. Lean Tool Mapping for VA and ENVA Work Packages

Work category	Subcategory	Recommended Lean tools
Preparation work	Shop drawing	Standardization, Coordination, Collaboration
Preparation work	Material approval	Standardization, Right at First Time, Coordination, Collaboration
Preparation work	Lookahead and weekly work planning	Last Planner System, Coordination, Collaboration
Delivery/procurement	Supplier/subcontractor	Coordination, Collaboration
Delivery/procurement	Purchasing order	Standardization, Coordination, Collaboration
Delivery/procurement	Administration	Standardization, Coordination
Delivery/procurement	Workshop	Coordination, Just-in-Time
Execution work	Pile driving	Standardization, Coordination, Collaboration
Execution work	Reinforcement and concrete works	Coordination, Just-in-Time, Five S, Overlap
Execution work	Wall construction	Coordination, Just-in-Time, Five S, Overlap
Execution work	Roof construction	Coordination, Just-in-Time, Five S, Overlap
Execution work	Ceiling works	Coordination, Just-in-Time
Execution work	Flooring	Coordination, Just-in-Time
Execution work	Door and window installation	Coordination, Just-in-Time
Execution work	Painting	Coordination, Just-in-Time

Note: CPM-based crashing is excluded from the Lean tool mapping because it is not classified as a Lean Construction tool in this study. It is evaluated separately as a post-lean schedule acceleration scenario.

It is important to distinguish between pull-based production planning and traditional push-based schedule optimization. In this study, LPS (LC2) is positioned as a pull-oriented planning and production control layer (phase planning, lookahead and weekly work planning, constraint removal, and commitment tracking) that improves workflow reliability, whereas CPM and its crashing technique are used as baseline schedule control and an analytical acceleration scenario, respectively. Therefore, schedule crashing is reported as a post-lean mitigation measure rather than evidence that crashing is a Lean tool.

Future State Mapping as Lean Workflow Redesign

The Future State Mapping (FSM) translated the Lean tool mapping into a revised workflow strategy for the preparation, delivery, and execution phases. In the preparation phase, Standardization, LPS, Coordination, and Collaboration were used to reduce information-flow variability, particularly in shop drawing preparation, material approval, and work planning. In the procurement/delivery phase, Standardization, JIT, Coordination, and Collaboration were used to reduce supplier uncertainty, material waiting time, and storage-related waste. In the execution phase, Coordination, JIT, Five S, and Overlap were used to improve work-front readiness, reduce unnecessary movement, and support smoother transitions among structural, wall, roofing, ceiling, flooring, door/window, and painting works.

The FSM result confirms that the Lean contribution of the study lies in redesigning the production flow rather than merely compressing the schedule. By removing NVA activities and improving the reliability of remaining VA and ENVA activities, the project duration was reduced from 83 weeks to 74 weeks before any crashing scenario was introduced. This result demonstrates that Lean Construction functioned as the primary improvement framework, while crashing served only as a supplementary recovery measure.

Post-Lean Schedule Recovery Scenario

After the Lean-based waste elimination and workflow redesign stages, the project still showed a four-week delay compared with the original 70-week plan. At this stage, a CPM-based crashing scenario was evaluated as a post-lean recovery option. This scenario was not treated as a Lean Construction tool. Instead, it was used to test whether the remaining delay could be recovered after Lean interventions had already reduced avoidable waste and improved workflow reliability.

The crashing scenario focused only on selected critical-path activities, mainly formwork, reinforcement, and structural slab works. The acceleration was achieved by adding 22 workers to these activities without extending working hours. This reduced the duration from 74 weeks to 66 weeks. Therefore, the total improvement to 66 weeks should be interpreted as a sequential result: first, Lean-based waste elimination reduced the delay from 83 to 74 weeks; second, CPM-based crashing recovered the remaining delay and produced a four-week gain against the original 70-week plan.

Scenario Analysis and Time-Cost Impacts

The scenario analysis was structured to distinguish Lean-based improvement from post-lean schedule acceleration. Condition I represents the original 70-week plan. Condition II represents the delayed condition, in which workflow inefficiencies extended the projected duration to 83 weeks. Condition III represents the Lean-based NVA elimination scenario, which reduced the duration to 74 weeks. Condition IV represents the post-lean CPM-based crashing scenario, which further reduced the duration to 66 weeks.

The most important Lean result is the transition from Condition II to Condition III. The reduction from 83 to 74 weeks indicates that eliminating NVA activities recovered nine weeks of delay without relying on resource-intensive crashing. This finding demonstrates that Lean Construction improved project performance by removing avoidable waste and improving workflow reliability. The transition from Condition III to Condition IV should be interpreted separately as a post-lean recovery scenario, not as evidence that crashing is a Lean tool.

Figure 3 presents the S-curve comparison of the planned schedule, delayed condition, Lean-based NVA-elimination scenario, and post-lean recovery scenario. The comparison shows that Lean-based waste elimination first recovered nine weeks of delay by reducing the projected duration from 83 weeks to 74 weeks. The subsequent CPM-based crashing scenario then reduced the remaining duration to 66 weeks. This sequencing clarifies that the final accelerated duration was achieved through a combination of Lean-based workflow improvement and a separate post-lean schedule recovery scenario.

The post-lean recovery scenario focused on selected activities including foundation formwork, reinforcement, and structural slab works. Each targeted task achieved an approximate one-week reduction, contributing to an eight-week reduction from the Lean-improved 74-week scenario.

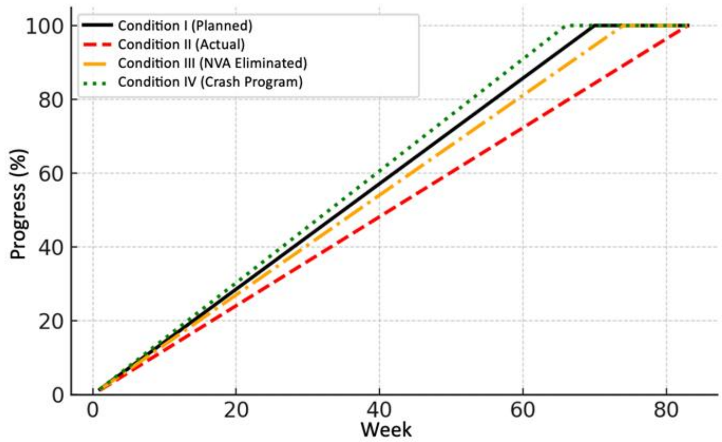

Figure 3. S-Curve Comparison of Planned, Actual, and Crash Program Durations

The post-lean crashing scenario added approximately IDR 201.5 million in labor and equipment costs. However, because the acceleration avoided penalties and reduced indirect costs, the project achieved a net cost saving of approximately IDR 544.6 million. The financial result should therefore be interpreted as the effect of a sequential improvement strategy: Lean-based delay recovery followed by targeted critical-path acceleration.

Figure 4 illustrates the comparison of cost percentages and profit margins across the main project scenarios. The comparison shows that Lean-based waste elimination improved the delayed condition before any additional schedule acceleration was introduced. The post-lean crashing scenario then increased direct costs slightly but improved the overall profit margin because it avoided penalties and reduced indirect costs.

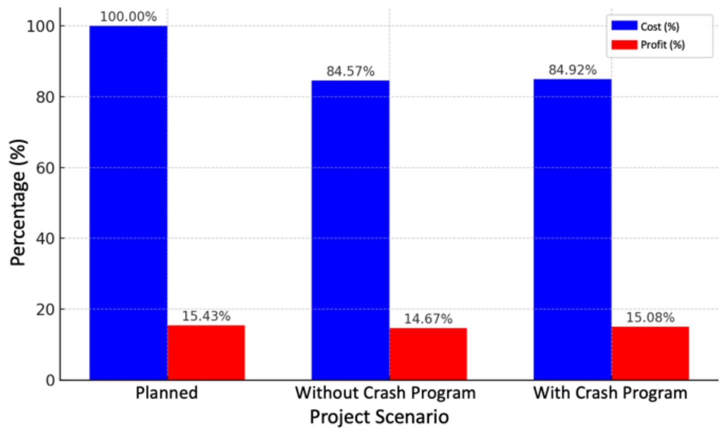

Figure 4. Relation of Contract Value, Costs Before, and After the Crash Program

Each scenario affected not only project duration but also financial outcomes. In Condition II, the extended duration increased overhead, equipment costs, and penalty exposure, causing COGS to rise and the profit margin to decline. Condition III improved the outcome by removing NVA activities and recovering nine weeks of delay through Lean-based waste elimination. Condition IV added a targeted CPM-based crashing scenario after the Lean intervention; although this increased labor costs, the resulting penalty avoidance and indirect-cost reduction improved the profit margin to 15.08%, as shown in Table 5.

Table 5. Project Scenario Comparison by Intervention Type

Condition	Description	Main intervention	Duration	Interpretation
I	Original plan	Baseline schedule	70 weeks	Contractual/planned duration
II	Delayed condition	No Lean intervention	83 weeks	Delay caused by workflow inefficiencies
III	Lean-based improvement	NVA elimination and Lean workflow redesign	74 weeks	Lean contribution: nine-week recovery
IV	Post-lean recovery	CPM-based crashing after Lean improvement	66 weeks	Additional recovery after Lean intervention

This structure prevents the misinterpretation that the 66-week duration was produced by crashing alone. The Lean Construction contribution occurred before crashing, through the identification and elimination of NVA activities and the development of LPS-informed workflow planning. The crashing scenario was only introduced after the Lean analysis showed that a four-week delay still remained.

Time-Cost Impacts

The findings show that Lean Construction contributed to project improvement in three ways. First, the VA-NVA-ENVA classification made waste visible and provided a basis for eliminating activities that did not contribute to project value. Second, LPS-informed planning shifted the analysis from schedule compliance to work readiness by distinguishing activities that should be done, could be done, and would be committed for weekly execution. Third, Lean tool mapping and FSM provided a structured mechanism to address different sources of workflow unreliability across preparation, delivery, and execution phases.

These results are aligned with previous studies in other contexts. Erol et al. [21] reported that LC improved project workflows and reduced delays in the Turkish residential construction. Hei et al. [22] demonstrated that the integration of LC with Building Information Modeling (BIM) in China shortened the construction period by 11 days. LC practices led to labor productivity improvements of 3.4% and overall productivity gains of 12.9%. Similarly, Shang and Chan [23] observed that LC minimized cost overruns and improved delivery outcomes in Chinese residential developments by reducing construction costs by 8.07% and transportation costs by 12.5%.

This distinction is methodologically important. If the analysis focused only on crashing, the improvement strategy would remain within conventional schedule compression. By contrast, the Lean-based analysis explains why delays occurred, which activities generated avoidable waste, and how workflow reliability could be improved before resource-intensive acceleration was considered. Therefore, the study supports the title's emphasis on Lean Construction while acknowledging that the final recovery to 66 weeks required an additional CPM-based acceleration scenario.

Implications and Limitations

This study acknowledges several limitations that may affect the generalizability and robustness of its findings. First, the research focuses exclusively on a single housing project (the Green Royal Housing Project) in Jakarta. The outcomes may be shaped by factors such as organizational structure, stakeholder experience, and site conditions, and thus may not fully represent the broader Indonesian housing construction sector. Second, the qualitative findings are based on interviews with a limited number of respondents (five key stakeholders), which may introduce respondent bias or limit the diversity of perspectives. While the participants held critical roles, their views might not capture the entire spectrum of challenges present in different projects.

A specific limitation concerns the maturity of LPS implementation. The project did not originally maintain a formal PPC log as part of a fully institutionalized LPS process. Therefore, the PPC values reported in this study were reconstructed from weekly progress reports, work-package readiness checks, and stakeholder interview validation. The reconstructed overall PPC of 54.9% should be interpreted as an approximate planning reliability indicator rather than a continuously monitored LPS metric. Future studies should implement LPS prospectively from the outset of the project and maintain continuous PPC records to enable more rigorous evaluation of planning reliability across the full project lifecycle.

CONCLUSIONS

This study demonstrates that Lean Construction can improve housing project performance primarily through waste identification, NVA elimination, and workflow reliability improvement. In the Green Royal Housing Project, 21 NVA activities were identified from 87 construction activities. Their elimination reduced the projected project duration from 83 weeks to 74 weeks, indicating that Lean-based waste reduction produced a substantial schedule recovery before any acceleration scenario was introduced. The LPS-informed planning framework further clarified how remaining VA and ENVA activities should be screened through lookahead planning, constraint removal, and weekly work commitments. The CPM-based crashing scenario was used only after the Lean analysis showed that a four-week delay remained. By adding 22 workers to selected critical activities, the project duration could be reduced from 74 weeks to 66 weeks. Thus, the study distinguishes between Lean Construction as a waste-reduction and workflow-control approach and crashing as a post-lean schedule acceleration measure. This distinction strengthens the methodological contribution of the study and prevents the misclassification of crashing as a Lean tool.

DISCLAIMER

The authors declare no conflict of interest.

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