

ENHANCING SUSTAINABILITY IN INDONESIAN DAM CONSTRUCTION: A LEAN OPTIMIZATION APPROACH

Ferdinand Napitupulu¹ & Edi Irtanto²

ABSTRACT

Dams represent critical infrastructure supporting Indonesia's food security, energy supply, flood control, and water resource management. Yet dam construction projects frequently experience time and cost overruns due to process inefficiencies, rework, and inadequate coordination among stakeholders. To enhance performance and sustainability, this study investigates the application of Lean Construction (LC) principles—particularly the Last Planner System (LPS)—as a systematic approach to waste reduction and process optimization in dam construction. Using an explanatory sequential mixed-method design (interviews, site observations, document analysis) on an ongoing dam project in Indonesia, the results show that LPS improves workflow reliability and reduces non-value-added activities, yielding measurable gains in schedule adherence, cost efficiency, productivity, and environmental sustainability through a 10–15% reduction in material waste. Key success factors include commitment-based planning, early constraint identification, and enhanced stakeholder collaboration. The study contributes a practical framework for integrating LC tools to achieve sustainable performance outcomes in complex project environments aligned with national infrastructure goals and optimize resource utilization.

KEYWORDS

Last Planner System, lean construction, waste reduction, dam construction, sustainable infrastructure.

INTRODUCTION

As an archipelagic state spanning over 17,000 islands, Indonesia is characterized by acute spatiotemporal disparities in water resource distribution, which expose different regions to conflicting risks of severe flooding and prolonged drought (World Bank, 2021). To address these challenges, the government prioritizes water infrastructure, especially dam construction, within National Strategic Projects (PSN) to strengthen water security, food resilience, renewable energy, flood control, and climate adaptation in line with the SDGs (PUPR, 2022; ADB, 2021). Despite an ambitious program (e.g., >65 new dams targeted for 2015–2024) (PUPR, 2022), many projects still encounter schedule delays and cost overruns driven by fragmented delivery, reactive planning, and coordination gaps (A. Edwards, 2021; C. Petheram and T.A. McMahon, 2019; I. Subagyo and M. Isradi, 2025). Lean Construction (LC) responds to these systemic issues by eliminating waste, stabilizing flow, and improving predictability

¹ Project Manager, Infrastructure 2 & Building Division, PT. Wijaya Karya (Persero) Tbk., Jakarta, Indonesia. ferdinand.napitupulu@wikamail.id, orcid.org/0009-0007-3089-7671

² Project Engineering Manager, Infrastructure 2 & Building Division, PT. Wijaya Karya (Persero) Tbk., Jakarta, Indonesia. edi.irtanto@wikamail.id, orcid.org/0009-0004-1522-4717

through collaborative planning and continuous improvement (M. E. A. M. Ahmed, 2022; G. Garces et al., 2025). Operating within the Lean framework, the Last Planner System (LPS) functions as a production control mechanism anchored in reliable commitments.

By systematically managing constraints and ensuring execution predictability, the system is proven to significantly bolster schedule compliance and optimize resource utilization (S. A. M. Hussain et al., 2015; R. Wibowo, 2023; E. Khoirunnisa et al., 2019). This paper empirically assesses LPS implementation in Indonesian dam construction—focusing on Jenelata Dam—to quantify effects on time, cost, quality, and productivity, and to identify adoption challenges and success factors in Indonesia's infrastructure context (B. D. Kussumardianadewi et al., 2024; M. Abduh and G. Shang, 2025).

LITERATURE REVIEW

The pursuit of sustainable dam infrastructure demands a holistic harmonization of ecological integrity, economic efficiency, and social equity throughout the project's entire lifecycle. This comprehensive approach not only safeguards ecosystems and optimizes resource utilization but also directly aligns with the United Nations' Sustainable Development Goals, specifically regarding water security (SDG 6), clean energy (SDG 7), and climate resilience (SDG 13). (UNDP, 2021). Conventional delivery often struggles with resource inefficiency, waste generation, and limited stakeholder engagement (ADB, 2021; W. Anggraini et al., 2022). Improving process efficiency is therefore pivotal. LC offers a pathway by minimizing waste, optimizing flow, and maximizing value; in practice, this involves combining engineered and nature-based solutions, optimizing water/energy use, and engaging communities to strengthen long-term resilience (W. Anggraini et al., 2022; E. Khoirunnisa et al., 2019; A.D. Ilmi, 2025).

Lean Construction (LC) adapts the efficiency principles of the Toyota Production System to the construction sector, prioritizing the reduction of non-value-adding activities while enhancing value delivery. In this framework, waste is defined broadly to include inefficiencies like rework and latency that consume resources without enhancing the product. By harmonizing process flows across the project lifecycle—from design to construction—LC fosters superior stakeholder collaboration and schedule adherence. Its operational success relies on five fundamental principles: defining client value, mapping value streams, establishing continuous flow, implementing pull systems, and committing to iterative improvement (World Bank, 2021). Empirical studies indicate that LC adoption significantly enhances productivity, reduces waste, and improves overall project performance (PUPR, 2022). However, in developing countries, including Indonesia, lean adoption is hampered by limited understanding of lean concepts, inadequate management commitment, and fragmented supply chains (UNDP, 2021). Despite these barriers, LC offers a structured framework for aligning efficiency, sustainability, and value creation, especially in large-scale infrastructure projects such as dams. While Lean Construction establishes the overarching philosophy of waste reduction and value generation, its practical execution on the field requires a specialized production control mechanism.

To address planning uncertainty, the Last Planner System (LPS) provides a robust framework widely recognized for improving project reliability (ADB, 2021). This system leverages collaborative, commitment-based planning by frontline supervisors rather than top-down mandates. Through a tiered planning cycle (master to weekly levels), LPS progressively shields production from constraints, ensuring that only tasks with all prerequisites met are scheduled. This 'screening' process is proven to bolster productivity and stakeholder communication (A. Edwards, 2021). However, the transition to LPS demands significant cultural shifts and continuous training. Notably, the application of LPS in the high-stakes environment of Indonesian dam projects is under-researched. Bridging this gap offers a strategic pathway to reduce process inefficiencies and optimize resource utilization.

Furthermore, the effectiveness of Lean principles, particularly LPS, can be significantly amplified when integrated with digital tools like Building Information Modeling (BIM). BIM facilitates visual planning, clash detection, and constructability reviews prior to execution. This digital integration aligns perfectly with Lean's waste reduction goals by proactively preventing rework, optimizing material use, and enhancing workflow reliability (Sbiti et al., 2021; Yang et al., 2025).

RESEARCH METHODOLOGY

RESEARCH CONTEXT

As a pivotal asset in Indonesia's national infrastructure roadmap, the Jenelata Dam is engineered to deliver multifaceted benefits, ranging from bolstering water resilience and flood mitigation to supporting hydroelectric power generation. The project's execution environment is characterized by high complexity, involving a dense network of contractors and intricate phasing that demands rigorous stakeholder alignment. This challenging context renders it an exemplary setting for stress-testing the Last Planner System (LPS). To quantify the efficacy of these LPS interventions, the study systematically tracked improvements across four critical vectors: schedule adherence, cost efficiency, operational productivity, and build quality.

1. **Schedule Adherence:** Evaluated by tracking the weekly Percent Plan Complete (PPC) metric and calculating the overall schedule variance against the baseline master schedule.
2. **Cost Efficiency:** Measured indirectly through material optimization, specifically by calculating the percentage reduction in concrete and rebar waste (comparing actual field consumption versus initial design volumes).
3. **Operational Productivity:** Assessed by tracking the daily execution rates (e.g., cubic meters of concrete poured or earthwork volume moved per day) before and after the full integration of daily huddles and make-ready planning.
4. **Build Quality:** Quantified by monitoring the frequency of rework incidents and non-conformance reports (NCRs), which were mitigated through BIM-based clash detection and joint field inspections.

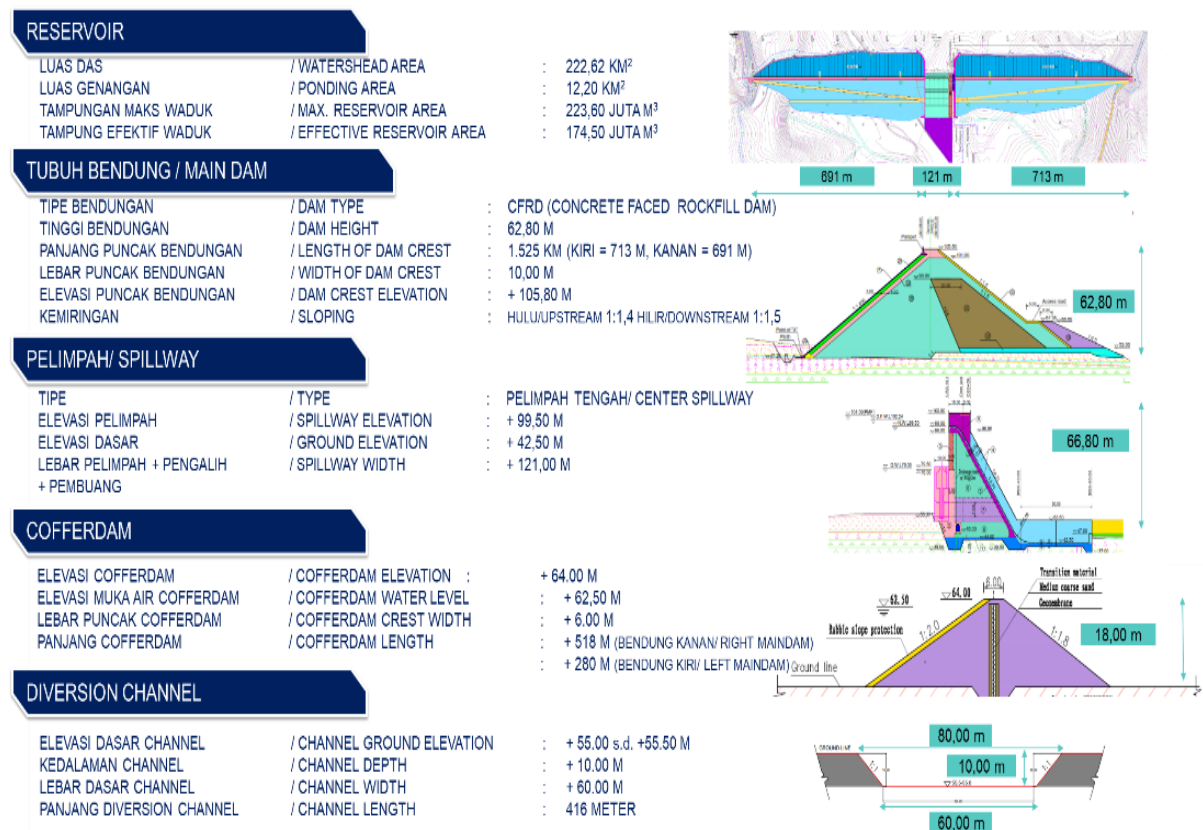


Figure 1: Jenelata Dam Technical Data

RESEARCH DESIGN

This study adopted an explanatory mixed-method design to explore strategies for achieving sustainable infrastructure through LPS implementation in an ongoing dam project in Indonesia. The research began with qualitative data collection, including semi-structured interviews, site observations, and document analysis, to gain insights into current practices, challenges, and opportunities for implementing lean principles in sustainable construction.

These qualitative results served as a framework for interpreting the connection between Lean practices and sustainability outcomes. The reliability of the study was reinforced through the triangulation of data from multiple streams, a widely validated approach in mixed-methods research to enhance construct validity and corroborate findings (Creswell & Creswell, 2018). By selecting this approach, the research effectively captured the dual dimensions of Lean implementation—technical operationalization and contextual adaptation—offering a comprehensive perspective on its role in advancing Indonesia's sustainable infrastructure goals.

DATA COLLECTION AND ANALYSIS

The research employed a triangulation strategy to validate findings, merging measurable project metrics with in-depth qualitative evidence. This approach was designed to elucidate how LPS drives waste reduction and sustainable delivery within the Jenelata Dam context. Qualitative data collection was conducted over a 6 month observation period during the main dam construction phase. The process involved direct observation of 24 weekly planning meetings and over 180 daily huddle meetings. Furthermore, semi-structured interviews were conducted with 11 key project personnel, comprising 2 Project Managers, 1 Site Manager, 1 Project Engineering Manager, 1 Site Engineer, and 6 foremen/subcontractors. This purposive sampling ensured a comprehensive understanding of LPS implementation from both strategic and operational viewpoints. Furthermore, project documentation served as a secondary data source.

By applying thematic coding to this qualitative dataset, the study identified key patterns in LPS adoption. Integrating these soft and hard data points provides a comprehensive explanation of the system's efficacy, capturing both the statistical improvements and the lived experiences of the project team. To explicitly capture sustainability outcomes, the study systematically monitored environmental indicators by comparing actual material consumption (e.g., rebar, formwork, and concrete) against baseline volume estimates to calculate waste reduction percentages. Social sustainability was qualitatively observed through improved communication and worker safety alignment during daily huddles. Additionally, the study documented the project's BIM workflow; 3D models were utilized to conduct clash detection across structural and civil disciplines prior to weekly planning meetings. The resulting clash reports directly informed the LPS make-ready process, ensuring that only constructible, clash-free tasks were committed to the weekly work plan.

RESULTS AND DISCUSSION

LEAN IMPLEMENTATION PRACTICES IN JENELATA DAM PROJECT

The primary objective of implementing LPS in this project was to mitigate waste and enhance the reliability of construction flows by systematically embedding the Last Planner System (LPS) across all project phases. The framework encompassed a full spectrum of coordination tools, ranging from high-level master and pull planning to granular on-site mechanisms like daily huddles and weekly scheduling (Hussain et al., 2015; Khoirunnisa et al., 2019). To further optimize execution, the team employed specific technical controls, including joint inspections and surveys to prevent rework, alongside material waste management and concrete mock-ups to ensure constructability. This holistic approach facilitated a seamless transition from planning to field execution.

While the master schedule harmonized the broader design, procurement, and construction targets, pull planning introduced a downstream-driven approach to task sequencing. To enforce daily accountability and constraint management, the team relied on daily huddles, a practice that directly contributed to raising the Percent Plan Complete (PPC) score from 65% to >85%. This increased reliability directly contributed to a significant schedule acceleration of 159 days against the baseline master schedule as illustrated in the schedule comparison in Fig. 2. Specifically, this acceleration was accumulated by mitigating rework and optimizing heavy equipment cycles on critical path tasks. In parallel, the make-ready planning phase utilized biweekly readiness checklists to preemptively identify barriers, thereby ensuring that tasks were fully prepared for execution and reducing the incidence of schedule delays.

Task Name	Duration	Baseline Start	Baseline Finish	Start	Finish
Jenelata Dam Project	1706 days	Mon 16/10/23	Fri 16/06/28	Mon 16/10/23	Fri 16/06/28
Left Bank Work (ADHI-WIKA)	1363 days	Mon 16/10/23	Fri 09/07/27	Mon 16/10/23	Fri 09/07/27
Commencement Letter	0 days	Mon 16/10/23	Mon 16/10/23	Mon 16/10/23	Mon 16/10/23
Mobilisasi	3 days	Mon 16/10/23	Wed 18/10/23	Mon 16/10/23	Wed 18/10/23
Preparation Works	248 days	Thu 19/10/23	Sat 22/06/24	Thu 19/10/23	Sat 22/06/24
Additional Investigation	1360 days	Thu 19/10/23	Fri 09/07/27	Thu 19/10/23	Fri 09/07/27
Access Road and Resettlement Road Works	362 days	Thu 19/10/23	Mon 14/10/24	Thu 19/10/23	Mon 14/10/24
River Diversion Works	897 days	Wed 24/01/24	Wed 08/07/26	Wed 24/01/24	Wed 08/07/26
CFRD Dam and Instrumentation	1262 days	Wed 24/01/24	Thu 08/07/27	Wed 24/01/24	Thu 08/07/27
Spillway	916 days	Wed 24/01/24	Mon 27/07/26	Wed 24/01/24	Mon 27/07/26
Batching Plan/ Bridge Workshop	165 days	Sat 18/11/23	Tue 30/04/24	Sat 18/11/23	Tue 30/04/24
Building Facilities	300 days	Sun 23/08/26	Fri 18/06/27	Sun 23/08/26	Fri 18/06/27
Soil And Water Consercation	240 days	Sun 23/08/26	Mon 19/04/27	Sun 23/08/26	Mon 19/04/27
HSE Implementation	1360 days	Thu 19/10/23	Fri 09/07/27	Thu 19/10/23	Fri 09/07/27
Left Bank Finish	0 days	Fri 09/07/27	Fri 09/07/27	Fri 09/07/27	Fri 09/07/27

Task Name	Duration	Start	Finish	Baseline Start	Baseline Finish
Jenelata CFRD Dam Project	1547 days	Mon 16/10/23	Sun 09/01/28	Mon 16/10/23	Sun 09/01/28
Left Bank Work (ADHI-WIKA)	1547 days	Mon 16/10/23	Sun 09/01/28	Mon 16/10/23	Sun 09/01/28
Mobilization and Demobilization of equipment, man power etc	1547 days	Mon 16/10/23	Sun 09/01/28	Mon 16/10/23	Sun 09/01/28
Preparation Works	1547 days	Mon 16/10/23	Sun 09/01/28	Mon 16/10/23	Sun 09/01/28
Access Road and Resettlement Road Works	1019 days	Mon 16/10/23	Thu 30/07/26	Mon 16/10/23	Sun 18/10/26
River Diversion Works	76 days	Mon 27/10/25	Sat 10/01/26	Fri 05/09/25	Wed 15/10/25
Left CFRD Dam and Instrumentation	1339 days	Thu 14/03/24	Fri 12/11/27	Thu 14/03/24	Fri 12/11/27
Spillway & Water Diversion Works	453 days	Thu 07/11/24	Mon 02/02/26	Thu 07/11/24	Mon 02/02/26
Building Facilities	908 days	Mon 14/07/25	Fri 07/01/28	Mon 14/07/25	Fri 07/01/28
Soil And Water Conservation	105 days	Mon 14/12/26	Sun 28/03/27	Mon 14/12/26	Sun 28/03/27
HSE Implementation	1547 days	Mon 16/10/23	Sun 09/01/28	Mon 16/10/23	Sun 09/01/28
LEFT BANK FINISH	0 days	Sun 09/01/28	Sun 09/01/28	Sun 09/01/28	Sun 09/01/28

Figure 2: Comparison of master schedule and pull planning demonstrating a 159-day acceleration.

The implementation was anchored operationally by weekly planning meetings, which drove accountability and continuous improvement through the rigorous assessment of planned versus actual progress. Collaboration across the project hierarchy—involving owners, consultants, and contractors—was strengthened through joint surveys and inspection routines. This shared oversight mechanism was critical for maintaining quality compliance and preventing rework. Additionally, the project adopted Lean strategies for material optimization. Technical accuracy and quality were further bolstered by conducting concrete mock-up tests, which allowed for precise volume calibration and standardized execution methods.

In summary, the collective deployment of these Lean methodologies yielded significant improvements in project coordination, successfully mitigated operational variability, and bolstered overall sustainability metrics (evidenced by a 10-15% reduction in material waste). A detailed synopsis of the specific Lean instruments utilized—including their strategic objectives, execution modalities, and quantifiable performance impacts—is presented in Table 1.

Table 1: Lean Construction Implementations and Outcomes

Lean Phase	Objective	Implementation	Observed Outcomes
Master Schedule & Milestone Planning	Establish overall project roadmap and align key deliverables.	Developed integrated schedule covering design, procurement, and construction milestones.	Improved coordination among disciplines; minimized schedule slippage.
Pull Planning & Rolling Schedule	Enhance workflow reliability through backward planning from milestones.	Conducted collaborative planning workshops to define interdependencies and weekly rolling updates.	Reduced waiting time and rework; improved sequencing efficiency.
Daily Huddle Meetings (Daily Work Plan, Constraint Management, PPC)	Improve communication, monitor progress, and manage constraints daily.	Short morning meetings with foremen and engineers to discuss safety, tasks, and barriers.	Increased transparency; PPC improved from ~65% to >85% over implementation period.
Make-Ready Planning (Biweekly Work Plan & Checklist Readiness)	Ensure task readiness and prevent disruptions.	Used readiness checklist for materials, manpower, equipment, and design clearance.	Minimized stoppages; enhanced productivity through proactive preparation.
Weekly Planning (LPS Core Cycle)	Commit to achievable work packages and foster accountability.	Weekly coordination meetings integrating PPC results and short-term planning.	Improved plan reliability and learning culture among field teams.
Joint Survey	Verify geometric accuracy and prevent rework.	Conducted joint verification with contractor, consultant, and owner teams.	Reduced measurement errors; enhanced trust among stakeholders.
Control of Waste Materials	Reduce material waste and optimize resource utilization.	Implemented monitoring system for rebar, formwork, and concrete usage.	Achieved measurable reduction in material wastage (up to 10–15%).
Mock-Up & Concrete Volume Optimization	Standardize methods and test constructability before execution.	Prepared mock-ups for key structural elements to calibrate volume and pouring methods.	Increased accuracy of volume estimation; improved quality consistency.
Joint Inspection	Assure quality compliance and continuous improvement.	Conducted inspections with joint teams at key stages; feedback integrated into next planning cycle.	Enhanced quality assurance; strengthened learning and collaboration culture.

OPTIMIZING RESOURCE EFFICIENCY THROUGH THE CONVERGENCE OF LPS AND BIM

Significant reductions in waste—particularly regarding waiting periods, rework, and material overuse—were achieved through the project's LPS implementation. Central to optimizing these results was the incorporation of BIM-based clash detection as a control mechanism (Fig. 3). This technology enabled the proactive discovery of interface clashes across structural, mechanical, and civil disciplines, allowing for schedule and workflow adjustments before physical construction began. In terms of build quality, the integration of BIM-based clash detection successfully identified and preemptively resolved 498 hard clashes across structural and civil interfaces (as detailed in Fig. 3). This proactive resolution drastically minimized rework and reduced the issuance of Non-Conformance Reports (NCRs) to near zero during the execution phase. Furthermore, operational productivity experienced a notable increase; for instance, the implementation of daily huddles and make-ready planning significantly optimized heavy equipment utilization and improved the daily concrete pouring execution rate. Qualitative data from project manager interviews and observation of planning meetings support the conclusion that BIM facilitated superior constraint management, thereby enhancing commitment reliability and reducing avoidable rework. This integration aligns with prior studies highlighting the efficacy of combining Lean Construction with digital technologies to visualize production flows, control variability, and systematically drive down non-value-added waste (C. Petheram and T.A. McMahon, 2019; B.D. Kussumardianadewi et al., 2024).

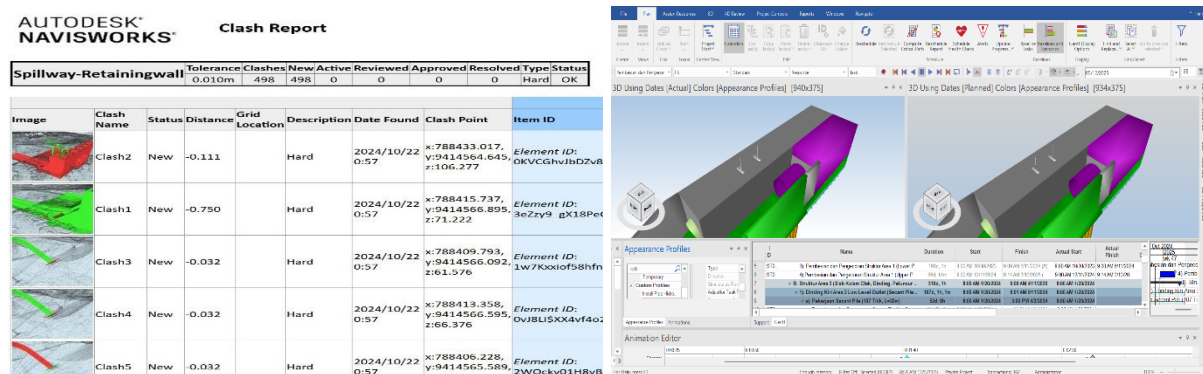


Figure 3: The convergence of digital modeling and lean methodologies

CONCLUSION

This research substantiates that the synergistic application of the Last Planner System (LPS) alongside BIM-enabled clash detection, yields substantial performance improvements in Indonesia's large-scale dam projects. Operationally, LPS was instrumental in streamlining constraint management and enhancing stakeholder coordination, thereby leading to optimized resource use, accelerated schedules, and waste minimization. Concurrently, on the technical front, BIM-based clash detection enhanced planning rigor by resolving design conflicts pre-construction, a step that directly contributed to superior quality and outcome predictability. Findings from the Jenelata Dam Project indicate measurable performance gains, enhanced cost efficiency, increased productivity, and compliance with design specifications, collectively achieving On-Time, On-Budget, and On-Spec outcomes. Beyond operational improvements, the adoption of Lean Construction and digital technologies contributed to sustainable infrastructure outcomes. Specifically, the verified 10–15% reduction in material waste and optimized resource utilization served as a direct proxy for environmental sustainability. Concurrently, schedule acceleration and cost efficiency drove economic sustainability, while enhanced stakeholder coordination and daily safety huddles fostered improved social

conditions on site. For future large-scale infrastructure developments in Indonesia and similar emerging markets, it is imperative to embed LPS and BIM protocols starting from the conceptual design phase. Successful adoption further requires institutionalizing structured stakeholder training, fostering decisive leadership, and maintaining rigorous performance tracking to uphold sustainability goals. It is important to acknowledge the limitations of this study. The findings are derived from a single-case study of the Jenelata Dam, which may limit the generalizability of the results to other types of infrastructure or different regional contexts. Furthermore, the quantitative assessment of sustainability was primarily constrained by data availability, relying on material waste proxies and schedule performance rather than comprehensive lifecycle analyses. Future research should encompass multiple case studies across diverse project scales and incorporate broader sustainability metrics to validate these findings. Ultimately, this inquiry offers robust empirical validation that the convergence of Lean methodologies and digital construction tools serves as a potent blueprint for achieving high-performance, sustainable outcomes within resource-scarce and complex engineering environments.

REFERENCES

- Abduh, M., & Shang, G. (2025). Lean construction adoption in Indonesia and Australia: Based on TOE framework. In *Proceedings of the 33rd Annual Conference of the International Group for Lean Construction (IGLC 33)*. Osaka and Kyoto.
- Agustin, N., & Koestoer, R. H. (2025). Achieving sustainable construction through the integration of lean construction and ESG: A critical review. *Journal of Placemaking and Streetscape Design*, 3(7), 23–38.
- Ahmed, M. E. A. M. (2022). A critical review on the strategies of lean planning to reduce construction wastes at the construction sits. *Academic Journal of Engineering Studies*, 3(2).
- Anggraini, W., Harpito, Siska, M., & Novitri, D. (2022). Implementation of lean construction to eliminate waste: A case study construction project in Indonesia. *Jurnal Teknik Industri*, 23(1), 1–16.
- Asian Development Bank. (2021). *Mainstreaming water resilience in Asia and the Pacific: Technical assistance report*.
- Bigwanto, A., Widayati, N., Wibowo, M. A., & Sari, E. M. (2024). Lean construction: A sustainability operation for government projects. *Sustainability*, 16(8), 1–16.
- Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). SAGE Publications.
- Edwards, A. (2021). Cost overruns in infrastructure projects: Evidence and implications. *Journal of Economics Library*, 8(1), 22–44.
- Garcés, G., Forcael, E., Osorio, C., Castañeda, K., & Sánchez, O. (2025). Systematic review of lean construction: An approach to sustainability and efficiency in construction management. *Journal of Infrastructure Preservation and Resilience*, 6(6), 1–28.
- Hussain, S. A. M., Sekhar, D., & Fatima, A. (2015). A systematic approach of construction management based on Last Planner System and its implementation in the construction industry. *Journal of Construction Engineering and Project Management*, 5(2), 11–15.
- Ibrahim, A., Zayed, T., & Lafhaj, Z. (2025). Bridging barriers to lean construction adoption in megaprojects: A data-driven contribution to sustainable development using SEM. *Environment, Development and Sustainability*.
- Ilmi, A. D. (2025). Sustainable dam development: Balancing hydropower, water management, and environmental conservation in a changing climate. *Journal of Sustainable Infrastructure*, 4(1), 40–49.

- Khoirunnisa, E., Toyfur, M. F., & Susanti, B. (2019). Implementation of Last Planner System in a project in Palembang (Case study: The Jakabaring Rusunami project). *Jurnal Rekayasa Sipil*, 15(1), 43–56.
- Kussumardianadewi, B. D., Husin, A. E., & Susianti, A. (2024). Analysis of key factors for successful implementation of the Last Planner System to improve time performance on dam projects. *Media Komunikasi Teknik Sipil*, 29(2), 163–172.
- Ministry of Public Works and Housing (PUPR). (2022). Indonesia national strategic projects report. Jakarta.
- Petheram, C., & McMahon, T. A. (2019). Dams, dam costs and damnable cost overruns. *Journal of Hydrology X*, 3, 100021.
- Riyanti, E., Kurniawan, P., Haryani, S., Haffiyan, Q., & Rizal. (2025). Evaluation of the impact of lean construction implementation on efficiency and waste management in large-scale infrastructure projects. *International Research Journal of Management, IT and Social Sciences*, 12(3), 127–134.
- Sbiti, M., Beddiar, K., & Beladjine, D. (2021). Toward BIM and LPS data integration for lean site project management: A state-of-the-art review and recommendations. *Buildings*, 11(5), 196.
- Setiono, Rifai, M., & Wibawa, L. A. (2023). Waste identification in lean construction implementation (Case study: Tower X construction project, Central Jakarta). *Jurnal Matriks Teknik Sipil*, 11(3), 262–269.
- Subagyo, I., & Isradi, M. (2025). Analysis of multi-project resources in dam construction on Java Island affecting contractor performance. *Eduvest - Journal of Universal Studies*, 5(9), 10998–11013.
- Syafrimaini, & Husin, A. E. (2021). Study of key success factors for Lean Six Sigma and Last Planner System in basement work on high-rise residential building projects, Jakarta Indonesia. *International Journal of Engineering Research and Advanced Technology (IJERAT)*, 7(4), 1–12.
- United Nations Development Programme. (2021). The sustainable development goals report 2021. New York.
- Wibowo, R. (2023). Implementasi Last Planner System pada proyek Tol Kayu Agung – Palembang – Betung paket II seksi 3. *Jurnal Profesi Insinyur Universitas Lampung*, 4(1), 25–29.
- World Bank. (2021). Planning for an uncertain future: Strengthening the resilience of Indonesian water utilities.
- Yang, Y., Chen, C., Liu, X., & Zhang, Z. (2025). Integration of lean construction and BIM in sustainable built environment: A review and future research directions. *Buildings*, 15(14), 2411.