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Quantifying the ROI of Proactive Lean Workflows in High-Density Urban Sub-Structure Projects

Ashifa Sayed, Kranti Kumar Myneni

***Abstract:** The study evaluates the return on investment (ROI) benefits of transitioning from a traditional reactive construction workflow to a proactive hybrid geotechnical resilience workflow for high-density urban infrastructure projects. This paper addressed the complexities often seen in dense-urban environments characterised by high-moisture basins, hydraulic instability, and substructure compromised by environmental unpredictability, often leading to systemic delays, soil collapse, and material wastage. These complexities are addressed by implementing lean construction principles that focus on mitigating Muda (waste), Mura (unevenness), and Muri (overburden), and on enhancing the project's predictability and structural safety. The lean strategies to overcome the structural difficulties involved establishing a responsive feedback loop. Firstly, by achieving precise excavation using hydraulic machinery with 3D-GPS guidance kits synchronised with Digital Terrain Modelling (DTM). This helped eliminate the 10% standard manual over-dig typically encountered in traditional depth control. Thereby optimising excavation volumes and reducing redundant soil hauling. Secondly, a real-time monitoring network comprising vibrating-wire piezometers and inclinometers was used to monitor pore-water pressure and soil displacement. This sensor-driven approach enabled a Jidoka (built-in quality) protocol, in which automated alerts for pressure spikes triggered immediate stabilisation measures that helped prevent catastrophic failures that historically stall urban developments. In the study, a comparative performance analysis of a traditional workflow and a lean-integrated workflow demonstrates that the proactive lean-integrated workflow results in a quantifiable reduction in the construction timeline and labour volatility. Specifically, the excavation and the shoring durations were reduced by up to 40% through data-driven execution and Target Value Design (TVD). The findings validate that incorporating digital intelligence during the substructure phases helps achieve a net fiscal recovery of over ₹2.17 crores by preventing rework and resource wastage. By providing a scalable model for geotechnical resilience, this study helps optimise operations and improve ROI for projects in complex urban settings.*

***Keywords:** Cyber-Physical Systems (CPS), Geotechnical Resilience, Lean Construction, Target Value Design (TVD).*

Nomenclature:
ROI: Return on Investment
CPS: Cyber-Physical Systems
TVD: Target Value Design
DTC: Digital Twin Construction
DTM: Digital Terrain Modelling

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*Correspondence Author(s)

Ashifa Sayed, Department of Architecture, School of Planning and Architecture, Vijayawada (A.P.), India. Email ID: ar.ashifasayed@gmail.com

Dr. Kranti Kumar Myneni*, Department of Architecture, School of Planning and Architecture, Vijayawada (A.P.), India. Email ID: kranti.myneni@gmail.com, ORCID ID: 0000-0002-0753-5636

I. INTRODUCTION

In dense urban corridors with natural contextual complexities, particularly those near high-moisture basins, such as the Krishna River region in Vijayawada, India, substructure execution may be compromised by environmental unpredictability. To maintain structural viability, the fundamentals of soil mechanics and the hydraulic instability of fluvial strata must be understood.

Transitioning from reactive to proactive workflows is achieved by implementing lean construction principles to address Muda, Mura, and Muri systematically. This aligns with modern lean thinking for performance improvement [1]. The case in point for this study is a G+7, two-level basement residential structure in Vijayawada that experienced soil collapses due to a high-water table, necessitating reactive solutions. These solutions heavily impacted and derailed the project schedule. This research defines geotechnical resilience as the capacity of ground-contact systems to absorb and adapt to these adverse loads without structural failure. This strategy is achieved through Digital Twin Construction (DTC), which is a data-centric mode that extracts real-time data from the site and uses AI to proactively analyze and optimize the construction workflow based on real-time conditions [2].

A. Aim

To evaluate the integration of lean principles into the construction workflow, transforming it from reactive to proactive through a digital geotechnical monitoring system, thereby mitigating subsurface delays and systemic waste in high-density urban residential projects located near water basins.

B. Objective

i. To identify and quantify the primary forms of waste (Muda, Mura, and Muri) within the traditional sub-structure workflow of a G+7 with two-level basement residential project in Vijayawada, India.

ii. Implementing a hybrid framework of geotechnical resilience using digital terrain modelling (DTM) and real-time piezometric sensing.

iii. To perform a comparative cost-benefit analysis between traditional reactive engineering solutions and Lean-integrated workflows.

C. Scope

The study is strictly limited to the G+7 with a two-level residential project located on

MG Road, Vijayawada.

The research focuses exclusively on the **sub-structure phase** (site preparation, primary excavation, piling, and shoring).

The analysis centres on the application of lean principles and specific digital tools, such as GPS-guided excavation and AI-driven predictive analytics.

D. Limitations

The findings discussed in this paper, the soil behavior and hydraulic instability, are context-specific, and the solutions proposed may not apply to different geological strata without recalibration.

The costs are calculated based on current market rates for labour and materials in the Vijayawada region; inflation or supply chain disruptions were not factored into the baseline model.

II. TECHNICAL IMPLICATIONS

The transition from a reactive to a proactive workflow was achieved by integrating site operations with digital technologies, creating a responsive feedback loop.

A. Precision Excavation via Digital Terrain Modelling (DTM)

To eliminate the excess excavation of the earth (Muda of overproduction), retrofitting the hydraulic excavators with a 3D-GPS guidance kit can help in precise excavation [2]. Traditional manual depth checks often result in a 10% over-dig (6,452.33 cu. m.), which historically incurred ₹16.79 lakhs in unnecessary costs and added over 300 truck trips. By aligning excavation with a high-resolution 3D digital map, the volume was optimised to 58,070.96 cu.m., effectively eliminating the need for excess soil hauling and disposal.

B. Predictive Analytics in Piling Operations

Implementing the software to analyse the soil behaviour from historical site data and initial test piles, thereby mitigating the Muri (overburden) of machinery. The unexpected soil strata often cause rigs to overwork, leading to mechanical failure or piles that fail to reach bearing capacity. This proactive approach ensured rigs are operated at optimal torque and eliminated the standard practice of over-ordering concrete to compensate for unknown soil cavities, thereby reducing material waste [3].

C. Sensor-Driven Target Value Design (TVD) and Jidoka

Suppose the shoring operations are transitioned to a data-driven observational method. An array of vibrating-wire piezometers and inclinometers is installed along the 371 m perimeter to monitor pore-water pressure and soil displacement in real time. The system can trigger automated alerts to reinforce or evacuate, preventing the catastrophic slope failures that previously stalled the project. Enabling the **Jidoka (built-in quality)** protocol, if sensors detected a spike in pressure, the system triggered automated alerts.

III. COMPARATIVE PERFORMANCE AND FISCAL SYNTHESIS

The implementation of a lean, integrated workflow resulted in a quantifiable reduction in the construction timeline and a significant waste reduction. All cost estimates and material volumes were benchmarked against regional market rates and standard rate schedules. The outcomes are consistent with the documented challenges and the performance benefits of implementing lean strategies within the Indian construction sector [4]. The following tables illustrate the performance efficiency achieved by a proactive lean integration strategy as compared to the traditional workflow.

Table I: Volume of Material, Cost, and Duration Required Using the Traditional Workflow Method

Activity	Traditional Method				
	Current Volume	Unit	Cost	No. of Gangs	Total Duration (Days)
Excavation Volume	64,523.29	cu.m	1,67,95,412.00	174	88
Shoring	2,982.10	Sq.m	2,61,142.29	7	20
Piling (191 piles)	425	cu.m	10,31,60,477.75	1,895	53
GI Sheet enclosure	371	m	12,76,054.50	95	13

Table II: Volume of Material, Cost, and Duration Required Using the Lean Strategies Workflow Method

Implementing Lean Workflow					
Activity	New Volume	Unit	Cost	No. of Gangs	Total Duration (Days)
Excavation Volume	58,070.96	Cu.m	15,115,870.80	156.00	78.00
Shoring	2,683.89	Sq.m	235,028.06	6.00	12.00
Piling	382.50	Cu.m	82,528,382.20	1,705.50	48.00
GI Sheet enclosure	333.9	m	893,238.15	33.00	13.00

- Excavation: Using AI-powered digital terrain modelling to eliminate the standard 10% over-dig common in manual depth control. Duration was reduced from 88 days to 78 days through DTM precision.
- Piling: Time was compressed from 53 days to 48 days by eliminating waiting waste for concrete mixers and reducing rework by 20%.
- Shoring: Target Value Design; Integrating piezometric sensors to monitor real-time soil pressure, allowing for optimized nail density instead of fixed conservative spacing. The use of real-time sensors enabled faster, data-driven execution, reducing the duration from 20 days to 12 days. Considering that the shoring area and grout/steel volume are reduced by ~12.5%.
- GI Sheet Enclosure: A phased modular installation reduces labour and congestion by 30%.

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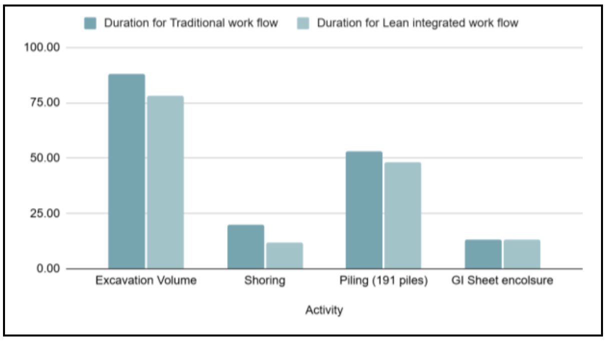
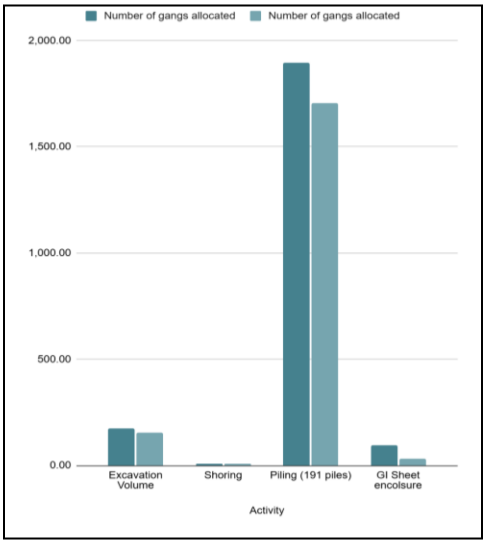


[Fig.1: Illustrates the Reduction in Duration by Integrating the Lean Integration Principles]

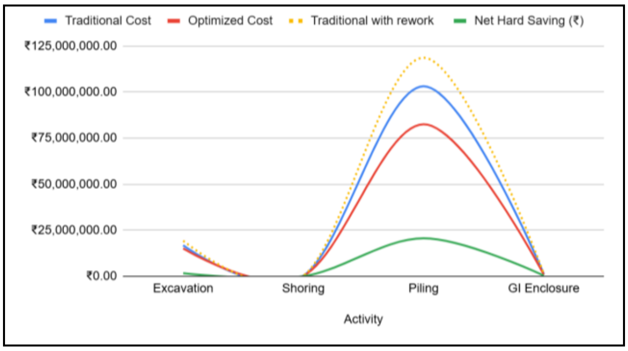
A. Labour Optimisation (Mura and Muri Mitigation)

A pull-based scheduling system effectively addressed systemic labour volatility. This resulted in a reduction of approximately 65% in high-density staffing for activities such as GI enclosures (from 95 to 33 gangs). The integration of JIT logistics ensured that materials arrived in synchronised phases, effectively mitigating the risks of site overcrowding and redundant material movement. This precision reduced the stress on site management and improved overall occupant health and safety protocols [5].



[Fig.2: Illustrates the Reduction in the Gang Size by Implementing the Lean Strategy]

B. Cost Recovery and Net Hard Savings



[Fig.3: Illustrates the Comparison of the Cost Using the Traditional Workflow, the Cost Involved if Rework is Done Using the Traditional Workflow, and the Cost of the Optimised Workflow]

The largest financial impact was identified by comparing the baseline cost to the optimised workflow cost. The comparison to hidden costs is often due to rework; in this case, the rework is caused by soil collapse and pile rework.

The total gross savings from optimised activities amounted to ₹22,720,567.33, as detailed in Table 3 below. The construction of foundation elements followed the required code of practice to ensure integrity in unstable urban strata.

Table III: The Fiscal Synthesis of Cost Using Traditional and Optimized Lean Integrated Workflow and the Net Hard Savings

Activity	Traditional Cost	Optimized Cost	Net Hard Saving (₹)
Excavation	₹16,795,412.00	₹15,115,870.80	₹1,679,541.20
Shoring	₹261,142.29	₹235,028.06	₹26,114.23
Piling	₹103,160,477.75	₹82,528,382.20	₹20,632,095.55
GI Enclosure	₹1,276,054.50	₹893,238.15	₹382,816.35
Total Savings	₹121,493,086.54	₹98,772,519.21	₹22,720,567.33

Table IV: The Fiscal Synthesis of Cost Using Traditional and Optimized Lean Integrated Workflow and the net Hard Savings

Item	Estimated Cost (₹)	Purpose
Piezometer Kit	250,000	Monitoring pore pressure to optimise shoring and dewatering operations.
GPS Excavator Kit	500000	Enabling 3D terrain modelling to prevent over-digging by 10%.
AI Software License	200,000	Real-time volume prediction and logistics modelling.
Specialized Admixtures	50,000	Reducing shotcrete rebound waste by 15%.
Total Investment	**1,000,000**	

Table V: The net Cost Savings

Net savings from optimized workflow	₹ 2,27,20,567.33
Cost of implementation	10,00,000
Total gain	**₹ 2,17,20,567.33**

IV. CONCLUSION

The optimisation of the construction workflow by adopting lean principles and transitioning from a traditional reactive system to a proactive workflow for a G+7 with a two-level basement residential project underscores a critical paradigm shift in the approach to substructure engineering. Using a proactive geotechnical resilience framework, the project could have mitigated risks such as hydraulic instability and soil collapse. The empirical data demonstrate that Lean integration is not merely a technical preference but a financial imperative. The systematic elimination of Muda, Mura, and Muri resulted in gross savings of ₹2.27 crore, as shown in the fiscal synthesis in Table 3. These savings were realized across every major activity, from excavation to the final piling operations. Even after accounting for a ₹10 lakh investment in digital infrastructure, as detailed in Table 4, the project still secured a net gain of 2.17 crore. This high return on investment confirms that using proactive monitoring and digital intelligence can stabilize both the structural integrity and the financial health of large-scale projects. Ultimately, this research concludes that geotechnical resilience must be integrated early; mismanagement can undermine both the structural integrity and financial viability of large-scale urban developments.

DECLARATION STATEMENT

As the article's author, I must verify the accuracy of the following information after aggregating input from all authors.

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- **Funding Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted objectively and without external influence.
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- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.

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AUTHORS' PROFILE

Ashifa Sayed is a dedicated Licensed Architect and a member of the Council of Architecture (CoA), India, who received her B.Arch. degree from Mahatma Gandhi University, Kottayam, Kerala, in 2022. Following two years of intensive professional experience in the architecture and construction industry, she is currently pursuing a Master of Building Engineering and Management (2024–2026) at the School of Planning and Architecture (SPA), Vijayawada. Her core research focuses on optimizing scheduling and proactive workflows for high-density urban infrastructure projects. Ashifa's academic pursuits delve into the influence of cognitive biases on project planning and the implementation of Digital Twin Construction (DTC) systems. She has successfully presented her findings at international conferences on urbanism and continues to develop data-driven strategies for risk management, procurement strategy, and quality control (QA/QC). Upon completing her graduate studies, she aims to specialise in commercial real estate strategy and professional business development.

Dr. Kranti Kumar Myneni is an accomplished academic who received his B.Arch degree from JNTU, Hyderabad, Telangana, in 2001. He furthered his expertise by pursuing an M.Sc. in Construction Management from South Bank University, London, in 2003, and subsequently earned his doctorate from the School of Planning and Architecture, Vijayawada. Currently serving as an Assistant Professor at the School of Planning and Architecture, Vijayawada, Dr. Myneni is a distinguished member of the Council of Architecture and a Fellow member of the Indian Institute of Architects. Throughout his career, he has published nearly 50 scholarly articles in reputed journals and has presented research papers at five major international conferences. His contributions to the field include three book chapters and the successful filing of four patents. His research interests remain centred on construction technology and advanced project management systems.