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INTEGRATING LEAN CONSTRUCTION, LEAN OFFICE, AND BUSINESS INTELLIGENCE IN A PANAMANIAN SANITATION PROJECT

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ABSTRACT

In the construction sector, inefficiencies are high due to fragmented work, inadequate designs, and poor team coordination. In this way, this situation is also reflected in infrastructure projects. Lean Construction is a project management philosophy that significantly increases productivity in construction projects; however, there is limited literature on its implementation in sanitation projects. For this reason, the primary objective of the research was to jointly implement Lean Construction (LC), Lean Office (LO), and Business Intelligence (BI) to enhance the overall project productivity across design, fieldwork, and quality monitoring. The research method is primarily a case study in a US$60 m-plus sanitation megaproject in Panama with more than 45km of sanitation networks. The main results indicate significant improvements in design speed, sanitation pipeline execution, and error reduction. Finally, this LC, LO & BI framework can serve as a new framework of reference for the design/execution of projects, with greater transparency of information, execution capacity, and integration with the public sector and multilateral banks.

KEYWORDS

Lean construction, business intelligence, lean office, sanitation project.

INTRODUCTION

Construction is one of the main economic engines of countries. In some Latin American countries, it ranges from 5% to 7% (Cubeddu et al., 2012). In this way, large investments of economic, material, and logistical resources are made to put it into operation. However, due to various factors, construction projects can be less efficient and less productive than those in other industries (Barbosa et al., 2017). Some inefficiencies include material waste, cost overruns, delays, and safety issues (Pellicer et al., 2012).

In recent years, technological philosophies and methodologies have been developed to help improve productivity rates in construction projects. Thus, seeking synergy between the human factor and technologies to improve construction projects throughout their life cycle, from design to delivery and operation. One of the most recognized and widely implemented philosophies in the construction sector is Lean Construction (Koskela, 1992), which encompasses several fundamental principles, including continuous improvement, a focus on flow and efficiency,

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value from the customer's perspective, waste elimination, respect for people, and optimization of the entire process (González et al., 2022; Rischmoller et al., 2018). Furthermore, Lean principles align with digitalization processes, that companies in the AEC sector are gradually adopting to make their processes more efficient and reduce waste in the value chain (Pantazis et al., 2022). Therefore, these synergies between Lean Construction (LC) and Business Intelligence (BI) tools have shown positive effects for the companies that have implemented them (Dumrak & Zarghami, 2025). Likewise, in large infrastructure projects, there is too much information, too many procedures with government entities, and too many designs to meet citizens' needs (Halttula et al., 2020). Given the amount of information generated, it is necessary to implement strategies such as Lean Office (LO) to streamline administrative processes and reduce Lead Time to meet project rhythms (Freitas & Freitas, 2020). Although prior studies have discussed Lean Office in infrastructure and public-sector settings and recent research has explored Lean – Digital synergies, limited attention has been given to how Lean Construction (LC), Lean Office (LO), and Business Intelligence (BI) can be jointly implemented as an integrated managerial system in sanitation megaprojects, particularly in Latin America. This gap is relevant because such projects depend simultaneously on field production reliability, administrative flow stability, and rapid decision-making based on trustworthy information. Therefore, this study addresses the following research question: How can LC, LO, and BI be aligned as a complementary implementation framework to improve productivity and information reliability in a large-scale sanitation project? Beyond reporting a single case, the study contributes by proposing and empirically illustrating an LC – LO – BI integration logic for infrastructure projects under high coordination complexity.

APPROACH LEAN CONSTRUCTION (LC), OFFICE (LO), AND BUSINESS INTELLIGENCE (BI)

Lean Construction (LC) has had various definitions since its inception, as there has been no consensus on the matter (Mossman, 2018). However, many experts agree that LC is a philosophy with theories, principles, techniques, and ways of thinking that help people improve their processes (González et al., 2022; Koskela, 1992). Nonetheless, the objectives of a LC implementation are clear: to improve the continuous flow of value (Jacobides et al., 2006), reduce waste (Yang et al., 2018), increase value in the customer's eyes (Dai et al., 2025), reduce variability (Pellicer et al., 2012), and improve connection with the work group, all in a more transparent manner for stakeholders. Moreover, LC offers an implementation framework with clear principles and objectives based on a strategic vision (Hamdi & Leite, 2012). Nonetheless, to implement LC in construction projects, tools are also needed to ensure successful incorporation; taking this into account, Lean tools are required to incorporate these principles into the processes (Alizadehsalehi & Hadavi, 2023).

Construction projects encompass not only the construction procedures themselves, but also the entire process. According to Porter (2001), the value chain comprises primary and support activities that ensure the flow of value between processes and areas. Considering this situation, it is not enough to optimize construction processes; the administrative processes that support them must also be optimized (Osorio-Gómez et al., 2023). For this reason, a technique like Lean Office (LO) has considerable potential for implementation. According to a Neo-Tayloristic perspective, LO can be defined as a tool for standardizing office processes, thereby enhancing staff performance (Bodin Danielsson, 2013). These changes are not only about processes but also about organizing the workspace to improve the flow of activities within the room. However, LO efforts not only improve the office but also allow leaders to focus overall rather than micro-manage (Bodin Danielsson, 2013).

Additionally, it enables the establishment of a system to avoid authoritarian leadership and, if not, to be more transparent, thereby increasing the importance of the work team through constant feedback. Furthermore, according to Martins & Frederico (2025), the most used concepts in LO are Value Stream Mapping (VSM), Standardized Work, Kaizen Events, Visual Management, the 8-step Problem-Solving Process, and 5S. These tools share a strong relationship with project management and LC. Additionally, to address problems with deliverables and information exchange, an organizational system model (SIPOC) appears to integrate concepts of integrated suppliers and customers (Zhang et al., 2022).

Considering these synergies between LC & LO, an important element emerges that decision-making in large-scale projects should be in "real time", since delays could have significant economic impacts and put the project's delivery at risk. For this reason, and given the ongoing digital transformation, the use of Business Intelligence (BI) is necessary to make timely, efficient decisions (Mäkinen, 2017). BI has been an umbrella term for the concepts, tools, and methods for improving decision-making through support systems (Lim et al., 2013). Within the field of business BI, a very important concept for management decision-making appears, which is Business Performance Management (BPM), which allows the use of scorecards and dashboards for the graphical representation of information to analyze and visualize relevant variables of the project and to be able to make future projections (Lim et al., 2013). Finally, there are synergies between LO & BI, as both concepts enable the reconfiguration of information flows and the strategic management of organizations through administrative changes (Freitas & Freitas, 2020). Figure 1 summarises the proposed integrative framework. In this framework, LC provides production-oriented routines for planning reliability, commitment management, and waste reduction; LO improves administrative and engineering support flows that condition field performance; and BI enables visibility, feedback, and faster managerial response through dashboards and structured indicators. The framework, therefore, assumes complementarity rather than overlap: LC structures field execution, LO stabilizes office and support interfaces, and BI connects both domains through timely information and performance monitoring. From this perspective, Lean – Digital integration is not treated as a technological add-on but as a socio-technical system that combines routines, information flows, and decision support. An LC, LO & BI approach systematically integrates continuous improvement into construction projects, considering both field and office work, as well as feedback between digital spaces and field information, to support better managerial decision-making. The following section outlines the research phases for implementing the framework LC, LO & BI in a sanitation megaproject in Panama.

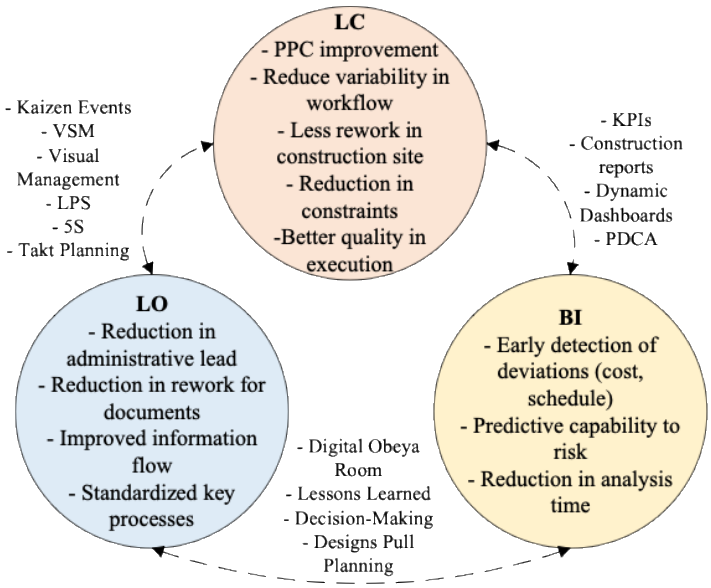

Figure 1. Integration of results and tools between LC, LO & BI.

RESEARCH METHOD

This research adopted a single-case study strategy to investigate the joint implementation of Lean Construction (LC), Lean Office (LO), and Business Intelligence (BI) in a sanitation infrastructure project. A case study was selected for its suitability for analyzing complex socio-technical interventions in real organizational settings and for explaining how and why improvement mechanisms work under specific premises and constraints. Analytically, the study relied on a baseline-versus-post-intervention logic combined with pattern matching between intervention mechanisms and observed performance signals. The underlying assumption was that LC routines would improve planning reliability and commitment discipline, LO interventions would stabilize information and support flows, and BI artifacts would shorten feedback cycles and strengthen managerial responses. Thus, the analysis did not seek deterministic causal proof, but analytical plausibility based on temporal alignment, triangulation across sources, and consistency between expected mechanisms and observed changes.

The implementation was structured in three phases: (1) organizational and project diagnosis, (2) implementation of LC–LO routines and BI artifacts, and (3) monitoring and control to compare initial conditions with post-intervention performance (Figure 2). The implementation was carried out in three main phases: the first consisted of diagnosing the project and the organization to understand their main difficulties and challenges, during which the organizational structure, roles, responsibilities, costs, planning, and contracts of the project were evaluated. The second phase involved implementing Lean tools and methodologies. A master plan was developed to understand the project's full scope, and a medium-term plan was established with corresponding indicators. In the case of the Look-Ahead, one of the most crucial indicators was the Percent of Constraint Removal (PCR) (1), to evaluate the efficiency in releasing constraints (Lagos & Alarcón, 2021). Additionally, in the short-term planning, the Percent Plan Complete (PPC) was used to evaluate the effectiveness of on-site execution (Issa, 2013). Furthermore, as well as developing two dynamic BI dashboards, the first a dashboard to keep daily control of the execution activities, and the second dashboard to make a weekly control with the indicators defined for the areas of construction, equipment, topography, designs, quality, supplies, planning and costs, contracts, social, environmental, and safety.

$$Percent\ of\ Constraint\ Removal\ (PCR) = \frac{Constraints\ removed\ on\ time}{Total\ constraints\ scheduled\ for\ removal} \quad (1)$$

The third phase consisted of follow-up and monitoring of the project after implementing the Last Planner System (LPS), Lean tools, dashboards, and other tools to compare its initial state with its subsequent state and obtain key insights into the project and the organization. Additionally, each indicator was measured daily or weekly to reduce information cycles, with the diagnosis baseline as the reference. The following section will describe the case study's context and the design implementation.

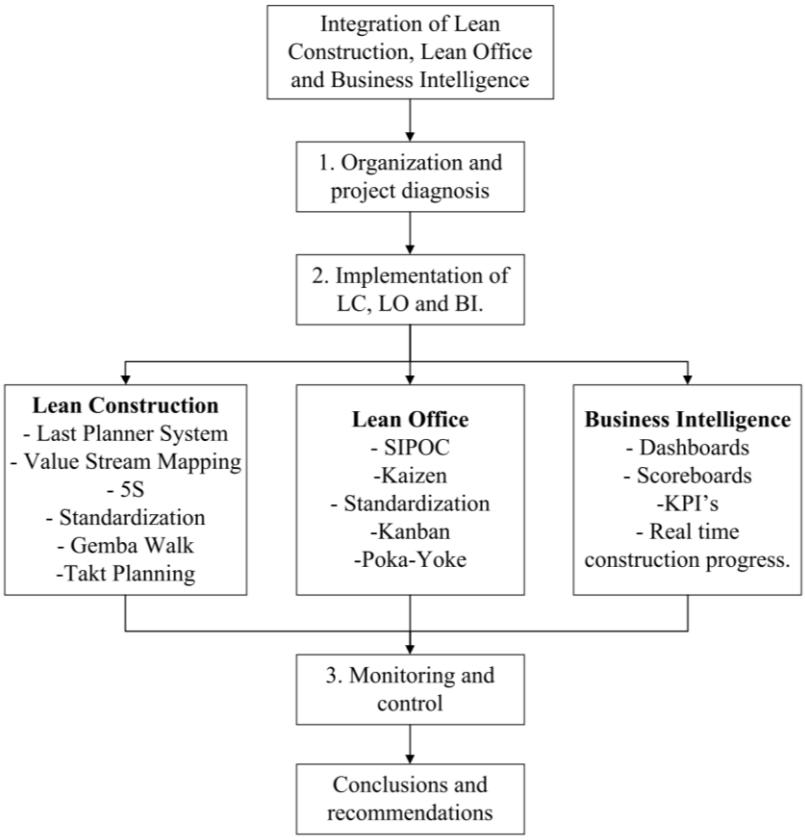

Figure 2. Research method of LC, LO, and BI integration.

CASE STUDY CONTEXT AND DESIGN IMPLEMENTATION

This research adopted a single-case study strategy to investigate the joint implementation of Lean Construction (LC), Lean Office (LO), and Business Intelligence (BI) in a sanitation project in Panama. The case was selected due to its high managerial complexity, fragmented interfaces between engineering and field production, and the need for fast, reliable decision-making under high cost and schedule pressure. The Panamanian project comprises a US$60 m-plus contract with more than 45 km of sanitation networks in western Panama, requiring integrated control of design deliverables, site execution, and quality assurance across multiple operational fronts. The vision presented in this case study is that of the builder, who was contractually commissioned by the client, the Ministry of Health of Panama, to design and construct the project, which was co-financed by a multilateral bank.

The study was designed as an intervention-based case study structured in three sequential phases: (i) project and organizational diagnosis, (ii) implementation of LC and LO routines supported by BI dashboards, and (iii) monitoring and control to compare baseline conditions

with post-intervention performance. This design enabled the research team to establish an evidence-based baseline, deploy socio-technical routines and digital artifacts, and assess early performance signals through structured learning cycles. Across the three phases, the intervention aimed to stabilize production, increase commitments, and improve the information exchange between the office and the field through an integrated management framework and real-time visibility.

To strengthen methodological rigor, the study followed a case study protocol that specified the intervention phases, data sources, and collection procedures. All evidence was documented and organized to maintain a clear chain of evidence linking diagnosis findings, prioritized actions, deployed routines/artifacts, and observed performance signals.

Phase 1 – Organizational and project diagnosis. The diagnosis phase was executed as an intensive first cycle with five objectives: (1) understanding ongoing activities and operational dynamics, (2) clarifying the contract and managerial context, (3) identifying improvement opportunities, (4) mapping people/process interactions, and (5) defining the next implementation steps. Data collection combined multiple sources and perspectives to build a baseline of operational and managerial conditions. Activities included multi-moment analysis samples; visits to operational fronts (e.g., ramales, tunnels, and collectors) with direct observation of production conditions; review of a large volume of documents and KPIs; and seven semi-structured interviews with strategic, tactical, and operational stakeholders to understand the project and organization status clearly. Also, process mapping was performed across production (execution) and supporting departments, including key production milestones, handoffs, and planning cycles. Indirect processes were also analyzed to identify hidden constraints and waste affecting field execution. The diagnosis cycle was complemented by gemba-based field observations, including a chronology analysis of critical operational activities to identify sources of variability and productivity losses. Meanwhile, a multidisciplinary Swimlane workshop was held to further support the diagnosis by mapping production processes and interfaces, identifying bottlenecks, and consolidating a structured list of operational and organizational problems.

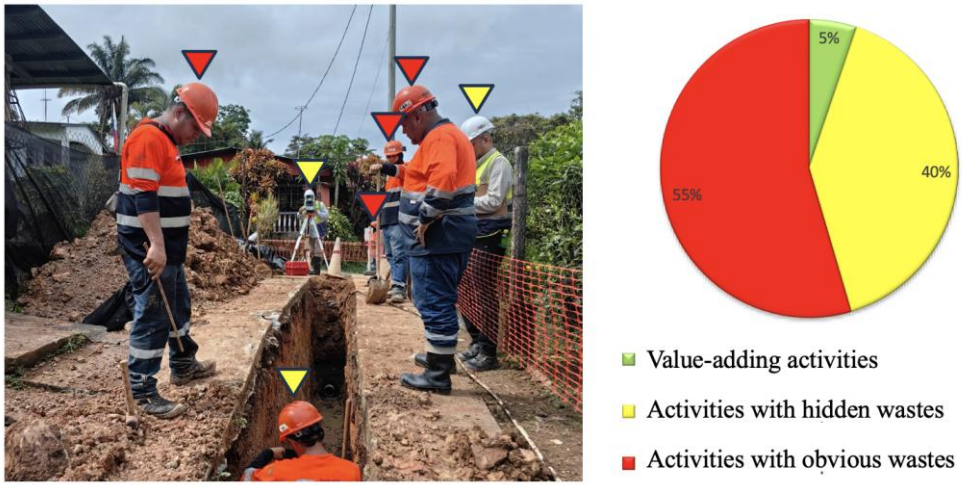

Figure 3—Chrono analysis of Sanitary pipe installation.

The diagnostic outputs were translated into a prioritized improvement agenda using an effort–impact logic, enabling the definition of actionable themes and an implementation roadmap. Six main action topics were consolidated: (1) production strategy and attack plan stabilization; (2) internal processes for the technical/design office; (3) structuring planning routines through the Last Planner System (LPS); (4) productivity improvements; (5) quality-related internal processes; and (6) training/standardization. This prioritization step ensured

traceability between observed constraints and the intervention mechanisms deployed in subsequent phases.

Reliability was reinforced through data triangulation and cross-validation across sources and organizational levels. Interview insights were systematically confronted with document/KPI reviews, gemba observations, chrono-analysis records (Figure 3), and workshop outputs to mitigate single-informant bias and ensure consistency of the baseline problem landscape. The diagnosis outputs were consolidated in structured visual maps and prioritization matrices, enabling shared verification with stakeholders before implementation.

Phase 2 – Implementation of Lean Construction, Lean Office, and BI. Based on the diagnosis and prioritization, the intervention plan focused on stabilizing execution through routines across planning horizons and improving the trustworthiness of information flow between engineering and field production. The implementation roadmap was organized around defining the production strategy and operational sequencing, reorganizing engineering and support processes to improve deliverable flow, and deploying the Last Planner System for integrated planning and control, supported by periodic checkpoints.

LC routines were introduced to structure long-term, medium-term, and short-term planning and to strengthen commitment management. Medium-term routines emphasized constraint removal (PCR) discipline through a weekly periodicity, promoting coordinated actions across departments to reduce uncertainty. Additionally, short-term planning routines reinforced weekly meetings and commitment adherence through structured follow-up and systematic learning from plan failures. Meanwhile, constraint management performance improved, as the team increased its ability to resolve overdue tasks by 85% between May and July 2025, reinforcing the link between managerial strategy and production stability. In addition, training was conducted with construction workforce leaders to teach them tools such as the Ishikawa Diagram, the A3 format, and 5S, thereby transmitting the tools and principles of Lean Construction to the project workforce and breaking the implementation barrier that is normally focused on the strategic and operational levels.

On the other hand, with field-oriented routines, LO interventions were applied to the technical/design office and project support flows to reduce rework, improve transparency, and stabilize information delivery to construction. Actions included demand management, workflow standardization, and kanban-based controls to improve the precision and visibility of design status and deliverables. Furthermore, SIPOC implementation was carried out in the technical office area responsible for designs, where the different types of designs were analyzed and standardized from inputs to deliverables to facilitate information exchange. Moreover, these built-in enhancements resulted in a structured improvement backlog, consolidating 38 prioritized improvement actions aimed at improving information flow reliability and strengthening the engineering-to-construction integration. Before this initiative, there was no formal improvement backlog in this department.

Furthermore, a Power BI ecosystem was developed to provide real-time field visibility and decision support across the organization. This ecosystem included structured dashboards and visual controls designed to track engineering flow and production performance while enabling managerial alignment through recurring review routines. For example, a dynamic dashboard was developed to track the location of each sanitary pipe meter throughout the project process flow, following a logical order: Design, approved design, built, tested, and paid by the client. This logical sequence enabled accurate monitoring of the project's execution, quality, and payments (Figure 4). As a result of this BI & LO implementation, the update frequency, which was previously weekly, became daily, with shorter information cycles, allowing management to make faster decisions. Furthermore, another key artifact developed in this phase was a dashboard named “control tower” aimed at increasing transparency between field and office

processes and supporting coordinated response actions. The control tower integrated four management areas across 15 departments using a portfolio of 50 indicators, establishing a shared performance reference to sustain feedback loops and enhance decision-making speed.

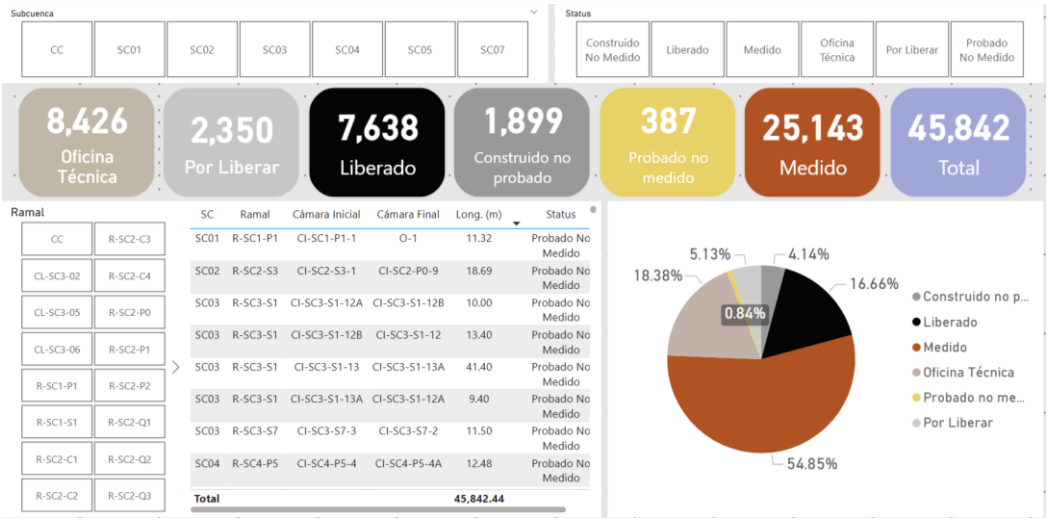

Figure 4. Dashboard in Power BI to control the construction process.

Phase 3 – Monitoring and control. The diagnosis phase enabled the construction of a baseline problem landscape and prioritization rationale. In contrast, the monitoring phase supported a before/after comparison to identify changes in routine adherence, constraint resolution responsiveness, and information flow stability. Triangulation across sources (interviews, documents, KPI review, gemba observations, workshop outputs, and dashboards) enhanced internal validity by reducing single-source bias and reinforcing the causal plausibility of the link between deployed routines/artifacts and observed operational changes. For example, during a kaizen standardization event for the collector installation process, which included topography, logging, excavation, pipe installation, and filling with compacted material, execution time was reduced by 35% through optimized construction processes, better material logistics, and the elimination of bottlenecks.

After deploying routines and BI dashboards, monitoring and control focused on comparing baseline versus post-intervention performance using operational indicators and managerial. Additionally, these dynamic dashboards had to be synchronized with routines in the technical office department (designs), where schedules were developed using Pull Planning. This synchronization reduced scheduling misalignments between design and construction by 40%. Meanwhile, look-Ahead performance was monitored through constraint removal indicators (PCR), while short-term reliability was tracked through PPC and adherence-to-plan measures. During the implementation, periodic checkpoints were conducted to consolidate progress, identify persistent bottlenecks, and adjust routines, responsibilities, and governance mechanisms. Moreover, a shared incentive mechanism was developed to reduce staff overtime costs, which initially accounted for up to 26% of the project's workforce costs. Following implementation, overtime costs decreased by 48% (to 12.5% of workforce costs), and the corresponding incentives were distributed to eligible employees, thereby achieving the project goals set for each week in short-term routines.

Improvements were observed in the Look-Ahead, specifically in the PCR, increasing from 30% to 45% in 2 months. The intervention theory assumed that strengthening commitment routines (short-term PPC discipline) and removing constraints through governance (medium-term responsiveness) would increase planning reliability and reduce execution variability (Lagos & Alarcón, 2021). These improvements were observed during a period of relative stability in team composition and without major scope changes; however, as in any real-world

project setting, concurrent contextual factors may also have influenced performance. Therefore, the findings should be interpreted as analytically consistent with the LC – LO – BI intervention rather than as evidence of exclusive causation

DISCUSSION OF RESULTS

Firstly, the diagnosis indicated that several aspects needed to be addressed, including operational, strategic, organizational, and control. The first phase involved a near-complete restructuring of most areas to accommodate LC implementation. One of the first actions was to transform a design area into one with practically no communication, creating a more collaborative environment with SIPOC, Kanban boards to follow up on activities, and daily check-in and check-out meetings, which generated greater dynamism in fulfilling activities. Additionally, the dashboards generated with BI enabled greater control and, above all, greater commitment from project management to improve each area's KPIs. In Figure 5, the information was collected weekly; in some activities, the percentage of activities executed relative to the planned was considerably higher.

In Collectors' productivity, productivity improved by an estimated 14%, and in sanitary pipes by up to 20% per week, indicating that a better flow of information, with improvement cycles implemented on site, had a significant impact on KPIs. These results are consistent with other Lean Construction implementations, which show improved productivity and reduced waste (Osorio-Gómez et al., 2020). Similarly, in China, a study examined the specific incidence of LC in megaprojects, leading to improvements informed by project managers' experiences (Ibrahim et al., 2025). Moreover, implementing LO & BI during May and July 2025, the designs of 7.6km of sanitary pipes were made; in a previous period, the designs had been 2.4km, which indicates an improvement of 216.67% in the efficiency of the designs, results that could have been possible from a correct integration of leadership, standardization and Lean-digital tools for its monitoring. Results that coincide with improvements in other implementations, for example, in a LO implementation in the public sector in Portugal, a 44% reduction in lead time was achieved in accounting, financial, and human resources processes (Monteiro et al., 2015).

Also, in a Digital Twins study in Latin America, 84% of the companies consulted said that they implemented LC (Martinez et al., 2025); however, they were found to only work at the managerial level, indicating a gap between managerial and operational vision in construction projects (Martinez et al., 2025). Likewise, in other projects, an LC & BI implementation has enabled better decision-making and shorter feedback loops within short-term routines (McHugh et al., 2025). Early performance signals indicated operational traction after deploying the short-term routines: Percent Plan Complete (PPC) improved from 13% to 40%, suggesting higher compliance with the planning system, although still below desired maturity levels. In the case of the chronology of sanitary pipe installation, with 95% of waste between evident and hidden, reductions of up to 50% were achieved with a structured design of the production system; these are considerable improvements without reaching optimal states.

These results pose a challenge for the further integration of LC practices with digital transformation methodologies to enhance LC&LO outcomes (Ramirez & Iordanova, 2025). In the literature review of Lean & BIM implementations, it is also evident that there are organizational barriers that prevent a more fluid and faster adoption of new processes, resistance to change, very bureaucratic processes, low willingness to invest in new technologies, and low employee training (Hosseini et al., 2015; Osorio-Gómez et al., 2024; Siebelink et al., 2021). In this way, this human-managerial-technological approach can serve as a basis for implementation in other infrastructure or building projects, ensuring improvements in costs, time, and scope. Hence, it is essential to align the organization's strategic objectives with the project's objectives and the indicators for each area. The LC, LO & BI framework serves as an

integrative methodology, from strategic vision through process changes to more operational data collection enabled by technology.

CONCLUSIONS

The implementation of LC in large-scale projects has been shown to improve productivity; however, there are few documented cases of its application in sanitation projects in a Latin American context. Considerable improvements implementing LC, LO, and BI were evidenced without reaching the optimal ones, since it was a project in a fairly complex context where exogenous variables had an impact on performance, such as cuts in the supply chain, worker strikes, problems in permits to build sanitary pipes, and other government measures that prevented a more fluid development of the construction processes. The findings suggest that productivity gains were associated not with any single tool, but with the complementarity between production planning routines, office-flow stabilization, and digital visibility mechanisms.

The synergies between LC, LO, and BI were evident. Because LC presented philosophy as the general framework of the production system. However, in more administrative matters, there were still some shortcomings that had to be complemented with LO to make administrative processes more effective, including bottlenecks and the most common restrictions identified in the Look Ahead. Additionally, to improve communication between the administrative part – and the work, it was necessary to have a better flow of information from the data collected in the field, and that this data could be evaluated by the management almost in "real time", in this situation the implementation of dynamic BI dashboards, were a fundamental complement to have a more efficient decision-making and that shares visual management principles with LC. Moreover, a three-way implementation framework is presented with LC, LO & BI, which contributes not only to the improvement of productivity that was evidenced in the different areas of work, but is also an organizational improvement framework that is aligned with the principles of LC and has synergies with the objectives of digital transformation in the construction sector. This interaction between Lean-Digital must be enhanced in infrastructure construction projects, since the improvements achieved will benefit not only the project's builders and contractors, but also the communities that receive faster infrastructure development, fewer cost overruns, and improved quality. Finally, this integration of LC, LO & BI can serve as a new framework of reference for the execution of new infrastructure projects financed by multilateral banks, and more transparent design/execution phases are among the mechanisms for risk reduction and greater public-sector involvement.

Some limitations of the study were that data collection at the beginning of the project was delayed longer than usual, as the project's peculiarities became apparent. Additionally, resistance to change was evident at the beginning among some employees of the company, who considered that some processes were fine as they were, which made it difficult to implement changes more quickly. Other constraints stemmed from external factors, such as rainfall, which increased dramatically from March onwards, preventing most outdoor activities. The workers' union also had strict rules on working during the rain. As future research, it is proposed to carry out similar studies in other construction projects to identify other barriers, both organizational and contextual, that prevent higher levels of productivity from being achieved; additionally, to carry out research in other Latin American countries to understand if there are rules and/or regulations that allow infrastructure projects to be carried out without excessive requirements. Likewise, more in-depth quantitative research using advanced statistical methods or multi-criteria decision models would be appropriate to better understand the synergies between LC, LO, and BI and their possible impact on the sustainability of projects from this approach. Finally, these established routines are one of the pillars of broader concepts such as Digital

Twins. Still, they can also serve as an important basis for implementation in a sanitation project in a Latin American context.

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