León, W., Guevara J., & Garcia-Lopez, N. (2024). Exploring the limitations and opportunities of industrialized construction in Colombia from a Lean perspective. In D. B. Costa, F. Drevland, & L. Florez-Perez (Eds.), *Proceedings of the 32nd Annual Conference of the International Group for Lean Construction* (IGLC32) (pp. 401–415). doi.org/10.24928/2024/0174

EXPLORING THE LIMITATIONS AND OPPORTUNITIES OF INDUSTRIALIZED CONSTRUCTION IN COLOMBIA FROM A LEAN PERSPECTIVE

William León[1], Jose Guevara [2] and Nelly García-López[3]

ABSTRACT

Despite the significant impact that industrialized construction (IC) has on the project production chain and its clear influence on productivity levels across the industry, multiple limitations hinder its suitable implementation worldwide. Existing research has identified synergies between the implementation of Lean Principles (LP) and the adequate implementation of IC processes. However, most of these studies have been carried out in markets with a high maturity and implementation levels of both IC and LP. This paper aims to explore the synergies between the implementation of LP and opportunities for improvement for the effective implementation of IC in Colombia. This article presents a qualitative analysis of twenty semi-structured interviews with construction professionals from some of the largest construction companies in Colombia. The analysis revealed that despite growing interest in applying IC by leading companies in Colombia, the current implementation of IC principles is still low. Additionally, the application of LP such as continuous improvement, variability reduction, value generation, and waste reduction are identified as key enablers for IC.

KEYWORDS

Industrialized Construction, Lean Principles, Productivity, Developing Countries, Semi-structured Interviews, and Literature Review.

INTRODUCTION

The implementation of industrialized construction (IC) has been recognized as a viable approach to enhance project performance (Andersson & Lessing, 2017). IC implementation implies a significant shift in the construction paradigm, indicating a fundamental restructuring of organizational frameworks and methods (Smith et al., 2018). Despite its benefits, the implementation and adoption of IC are still in their early stages, as the market and industry continue to pose substantial challenges (Lessing et al., 2005). In developing countries, these challenges include skilled labor shortages, rising labor costs, low productivity, and a lack of standardization. Interestingly, these issues can be mitigated through the implementation of industrialization processes (Vásquez-Hernández et al., 2022).

[1] Ph.D. research assistant, Civil and Environmental Engineering Department, Universidad de los Andes, Bogotá, Colombia, wm.leon10@uniandes.edu.co, https://orcid.org/0000-0002-2533-853X

[2] Associate Professor, Civil and Environmental Engineering Department, INGECO research group director, Universidad de los Andes, Bogotá, Colombia, ja.guevara915@uniandes.edu.co, https://orcid.org/0000-0002-3485-9169

[3] Assistant Professor, Civil and Environmental Engineering Department, INGECO research group, Universidad de los Andes, Bogotá, Colombia, ne-garci@uniandes.edu.co, https://orcid.org/0000-0001-9053-0897

On the other hand, construction management literature shows that Lean Principles (LPs) allow for improved integration by fostering long-term relationships among stakeholders. This is beneficial for implementing IC, as LPs facilitate sophisticated supply chain management, simplify design for manufacturing and installation, and enable experience capture and knowledge management for continuous improvement. Consequently, an increasing body of literature recognizes that LPs offer tools that strengthen and support the implementation of IC practices (Zhou et al., 2023).

This paper aims to gain insight into the dynamics between the concepts of IC and LP in Colombia, serving as an initial reference for the maturity level in developing countries (Smith et al., 2018). The goal is to provide a preliminary diagnosis of the status of IC implementation and identify strategies that can facilitate and enhance its implementation(Vásquez-Hernández et al., 2023).

POINTS OF DEPARTURE

INDUSTRIALIZED CONSTRUCTION

Standardization of processes, mass manufacturing, and reduced unpredictability are the main goals of industrialized construction (Dave et al., 2016). This approach differs from conventional construction methods, which frequently exhibit considerable variability and depend heavily on the subjective judgment and experience of the contractor (Hairstans & Smith, 2018). Industrialized construction seeks to create a consistent production model that guarantees punctual delivery, resource stability, and quality assurance. Its objective is to integrate repeatable production cycles and transparent processes, thereby enhancing predictability and reliability in construction project planning (Ji et al., 2017).

In the construction sector, there is no universally agreed-upon definition for the term "industrialization" (Liu et al., 2019). Depending on the specific guidelines and features of construction processes, it encompasses various developmental phases and maturity levels, ranging from in-situ production systems to fully prefabricated systems (Andersson & Lessing, 2017). In the context of this research, we based our interviews on the industrialized construction framework developed by Lessing (Lessing, 2015), that views industrialized construction as a system composed of eight IC practices: planning process and control, supply chain management, technical systems development, customer focus, factory-based component manufacturing, information and communication technology utilization, performance measurement and integration of prior experiences.

LEAN PRINCIPLES

According to Koskela (Koskela et al., 2002), Lean Construction is a concept based on production theory that is crucial for the advancement of economical, sustainable, and effective practices in the Architectural Engineering and Construction (AEC) industry. This approach focuses on maximizing the final value of the building product for the client, reducing waste, and continuously improving processes to enhance management of construction projects (Koskela et al., 2002). When this concept is applied, processes become more productive, leading to increased project profitability and a reduction in wasteful practices that result in value loss for the project (Aslam et al., 2021). Consequently, LC is viewed as an essential tool for maximizing value and eliminating waste (Igwe et al., 2020).

This general definition of Lean Construction incorporates some implementation principles, such as identifying the value of the product from the customer's point of view, establishing a value chain for each product, characterizing a value stream, eliminating waste, implementing a

pull workflow (Pull System), ensuring continuous process improvement, maintaining transparency, and providing training (Bajjou et al., 2019).

RESEARCH METHODOLOGY

Using a mixed methods approach, this study combines a literature survey with a qualitative analysis based on the perspectives of professionals in Colombia's construction industry. The goal is to cross-validate the interview findings with theoretical foundations of the global state of the art in IC and LP. This specific methodology was chosen because it provides a strong synergy between qualitative data gathered from ongoing project experience in Colombia and the assessment of literature that supports or explains IC behavior. It offers a thorough review of the state of continuous improvement in specific work contexts, examining constraints and obstacles from a Lean perspective. These opposing and reliable points of view make it possible to critically assess the situation and identify areas for further improvement.

Using this data, a cross-analysis of the benefits of industrialization and lean principles is conducted, with a particular emphasis on the relatively new industrialized construction sector and its unique risks and problems. In conclusion, a list of constraints and opportunities for development in the industrialized construction sector in countries with low levels of industrialized construction maturity is established.

FIRST STEP – PAPER SELECTION STRATEGY

This step involved searching the Web of Science database for relevant articles. Key ideas were extracted from the selected articles to establish a reference framework for understanding the concept of global IC and its implications for the construction process (Doerfel & Barnett, 1999). In addition to this general search, a focused investigation was carried out to identify Lean principles in the construction sector, exploring their implications, advantages, restrictions, and consequences on the production chain in construction projects. Concepts such as Lean Construction, Industrialized Construction, Last Planner System, and Productivity served as the foundation for this specific search.

SECOND STEP –INITIAL QUALITATIVE ANALYSIS

The authors adopted a qualitative approach, conducting over 20 hours of expert interviews to analyze the qualitative data. These interviews were recorded, transcribed verbatim using NVivo software, and subsequently synthesized into a coherent narrative that encapsulated the significance of LP within the realm of IC (Biygautane et al., 2019). Before conducting the interviews, interviewers explained key concepts to ensure respondents were aware of proper definitions of IC practices and LP with the aim of reducing the risk of bias or interviewer-induced partiality.

THIRD STEP – MULTICATEGORY UNIT ANALYSIS

This phase involved summarizing the data gathered from the 20 hours of interviews and initiating the process of distilling the key ideas covered (Yin, 2018). To achieve this, it was essential to identify the analytical categories with the greatest influence and generality. These categories were subject to further examination during the results discussion (Yin, 2003). According to Taylor (Taylor et al., 2011), utilizing these categories or units of analysis helps highlight key ideas, facilitating a better understanding of how IC and LP synergize in nations with low IC maturity. Key topics of discussion include efficiency, rework, information flow, productivity, and collaborative work settings. Throughout this discussion, these ideas will be referred to as units of analysis or categories.

FOURTH STEP – COMPARISON, LIMITATIONS AND OPPORTUNITIES ANALYSIS

To validate and assess the findings comparatively, data from qualitative interviews related to LP and IC are juxtaposed with an examination of relevant literature. This process involves aligning qualitative classifications and interview data with conclusions drawn from a global body of research on lean construction. Through a comparative analysis, a precise point of reference can be established to identify constraints, opportunities, and potential areas for continuous improvement in nations with low IC maturity (Yin, 2003). Figure 1 presents the methodological approach.

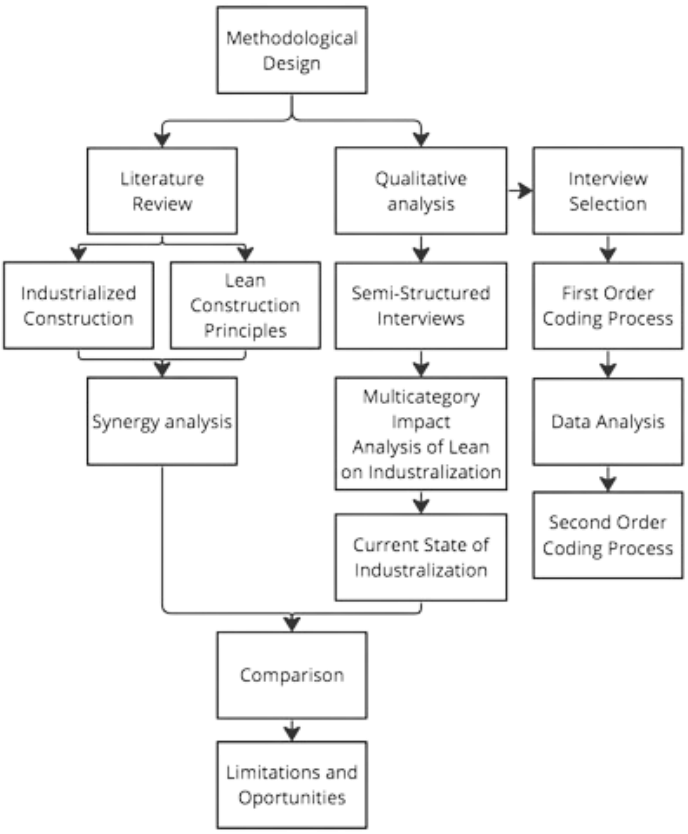

Figure 1: Methodology

RESULTS

A comprehensive profile of the respondents, including their years of experience and area of work in the construction industry, is presented in Table 1. These profiles serve as the basis for conducting semi-structured interviews, information processing, and extracting categories for analysis.

Table *1*: Interviewees

Interview	Sector	Years of experience	Field of experience
1	Design and construction execution	3	Design
2	Design and construction execution	3	Coordination
3	Design and construction execution	7	Construction
4	Design and construction execution	4	Design
5	BIM Manager	7	Model
6	BIM Manager	7	Model
7	BIM Manager	3	Coordination
8	BIM Manager	4	Coordination
9	Construction Manager	3	Construction / Industrialization
10	Construction Manager	3	Construction / Industrialization
11	Construction Manager	3	Construction / Industrialization
12	Construction Manager	4	Construction / Industrialization
13	Lean Manager	5	Productivity
14	Lean Manager	4	Processes
15	Lean Manager	3	Scheduling
16	Lean Manager	7	Scheduling
17	Project Manager	5	Productivity
18	Project Manager	5	Scheduling
19	Project Manager	5	Budget
20	Project Manager	6	Scheduling

Table 2 provides a summary of IC practices derived from the literature review, interviews, international references, and selected quotes illustrating Colombia's current adoption status.

Table *2*: IC practices

IC Practices	Literature-based description	Colombia-based description
Planning and Control	Effective management and organization throughout the design, fabrication, assembly, and other related operations are essential to achieving goals and providing customers with the best value define the concept of planning and control. (Lessing et al., 2005).	"Initiatives focused on process optimization at various stages of the project life cycle are increasingly being observed, including the early implementation stages of systems such as the Last Planner System."
Supply chain management	This concept refers to the optimization of construction activities, from the construction site to the factories where pre-assembly takes place. The aim is to improve logistics and supply management at all stages. (Erik Eriksson, 2010).	"Prefabricated building solutions can only be employed on-site with a specific number of components on specific projects."
Technical systems development	This idea involves integrating technical production systems throughout every stage of the project to enhance the quality of the final product and standardize processes. (Lessing et al., 2005).	"It is considered acceptable at present the development of technological systems focused on continuous improvement of quality and process standardization."
Customer focus	This concept refers to a managerial vision where there is a production focus based on the customer, understanding that it is necessary to ensure that products are delivered to the end consumer with the appropriate cost and quality. (Lessing et al., 2005).	"Strong connections exist between the builder and the client. Items are crafted with the customer and the market in mind."
Factory-based component manufacturing	Building components are manufactured with state-of-the-art equipment in comfortable working environments that promote efficient manufacturing (Abdel-Jaber et al., 2022).	"The construction techniques are by no means entirely prefabricated and preassembled. Most procedures are carried out on-site."
Information and communication technology utilization	This concept refers to a working structure where accurate and reliable data exist to make operations more industrialized. Current Information and Communication Technology should provide tools for effectively managing updates and revisions of digital content, along with solutions for data interchange and storage (Sacks, Koskela, et al., 2010; Sacks, Radosavljevic, et al., 2010; Sami Ur Rehman et al., 2022).	"The implementation of the Common Data Environment is progressing through many of the key stages of the construction process, alongside efficient collaborative processes."
Participant relationships	This concept refers to the development of adequate relationships among participants focused on enhanced performance and the production of effective outcomes that optimize value. Fostering sustained engagement with the processes. (Koskela et al., 2002).	"Discipline coordination is continuously improving and favoring standardization, resulting in fruitful outcomes for process optimization."
Performance measurement	This concept refers to the use and improvement of methods aimed at optimizing construction processes through industrialization strategies. (Ballard, 1993).	"It is observed that strategies for mass construction involve standardized procedures, ensuring consistency across processes, schedules, and resources."

A summary of LP based on interviews, literature review, and selected quotes illustrating Colombia's present potential for improvement is shown in Table 3.

Table *3*: Lean Principles (LP)

LP	Literature-based description	Colombia-based description
Continuous improvement	Organizational guidelines emphasizing continuous process enhancement (Koskela et al., 2019).	“The Last Planner System is being implemented alongside methodical meetings as the fundamental tools to foster an environment of continuous process improvement.”
Improving flow and reducing variability	Strategies focus on controlling time deviations in the execution of activities and ensuring a continuous flow of processes (Salhab et al., 2022) (Garcia-Lopez & Fischer, 2024).	“A significant variability is observed in the execution of activities at all stages of the project life cycle.”
Value generation	Long-term projects that add value for the client (Koskela et al., 2019; Sacks, Koskela, et al., 2010.	“The creation of value for the client is the foundation of project design, ensuring the production of goods suited to the market.”
Waste reduction	A methodical and ongoing approach to waste reduction (Igwe et al., 2020; Womack, 1996).	“Preliminary, experience-based attempts are observed to reduce waste, but with many opportunities for improvement. There is no standardization in waste reduction practices.”

In Table 4, the primary LP are listed, along with their direct impact on IC practices. These serve as instruments for continuous improvement and as means of facilitating implementation, particularly in emerging nations.

Table 4: LP and IC practices interaction

2nd-Order Codes (LP)	1st-Order Codes (IC practices)	References	Illustrative Quotes
Continuous improvement	Supply chain management	(Aslam et al., 2020, 2021; Ballard, 1993; Koskela et al., 2002, 2019)	"There is no culture of continuous process improvement or learning from past experiences. The production system and project stages are consistently developed in the same manner. A shift in the learning paradigm would facilitate the implementation of more efficient processes."
	Information and communication technology utilization	(Eastman, 2008; Sacks, Koskela, et al., 2010; Sacks, Radosavljevic, et al., 2010; Sami Ur Rehman et al., 2022; Sharma & Trivedi, 2021; L. Zhang et al., 2017)	“In terms of technology, we remain quite traditional. We don't learn from past mistakes and avoid adopting new tools due to a fear of change.”

Table 4 (Continued): LP and IC practices interaction

2nd-Order Codes (LP)	1st-Order Codes (IC practices)	References	Illustrative Quotes
Improving flow and reducing variability	Planning and Control	(Chauhan et al., 2018; Gonzalez et al., 2008; Hamzeh et al., 2016a, 2016b; Kenley, 2004; Laufer et al., 1994) (Garcia-Lopez & Fischer, 2024)	"Project planning and process variability often result from inadequate information management. The absence of effective channels hinders the standardization of processes."
	Technical systems development	(Cândido et al., 2014; Pasquire & Ebbs, 2017; Tatum, 2005; Vásquez-Hernández et al., 2023; F. Zhang et al., 2019)	"There is a lack of standardization in our processes, leading to variations in execution and an inability to control uncertainty. The absence of standardized technical systems hampers productivity. It is crucial to implement standardization and eliminate variability."
	Participant relationships	(Ballesteros-Pérez et al., 2020; Fischer et al., 2021; Gonzalez et al., 2008; Lindhard et al., 2019; Poshdar et al., 2014; Salhab et al., 2022; Thomas et al., 2002; Tommelein, 1997)	"It is common to encounter information silos. Poor integration of disciplines hinders effective communication and decision-making efficiency. The flow of information is consistently disrupted, making process optimization unattainable."
Value added	Customer focus	(Freeman et al., 1991; Gomez & Rameson, 2019; Igwe et al., 2020; Kim & Ballard, 2010a, 2010b)	"I believe the current construction industry recognizes the significance of the end customer. Value creation is intricately tied to establishing a direct relationship with the client and understanding their needs and expectations."
	Factory-based component manufacturing	(Abdel-Jaber et al., 2022; Bajjou et al., 2019)	"In the context of prefabrication, significant information gaps exist. We lack effective implementation of these technologies and an understanding of their added value. There is considerable resistance to change. If viewed from the perspective of value creation, people would likely embrace these new trends more readily."
Waste reduction	Performance measurement	(Igwe et al., 2020; Maraqa et al., 2020; Womack, 1996)	"Undoubtedly, waste poses a challenge for project managers. While we are aware of its presence, finding effective ways to mitigate this problem remains elusive. Implementing active and radical measures against this issue could significantly enhance project performance."
	Planning and Control	(Chauhan et al., 2018; Gonzalez et al., 2008; Hamzeh et al., 2016a, 2016b; Kenley, 2004; Laufer et al., 1994)	"Once again, planning and time control in construction are influenced by nearly all variables. Surprisingly, the matter of waste has not been forcefully addressed as a mitigation measure. It is crucial to acknowledge the necessity of responsibly managing waste as a means to enhance the reliability of planning."

DISCUSSION

EXPLORATION OF IC MATURITY IN COLOMBIA

Based on Table 2, the maturity of IC in Colombia is still incipient in certain enumerated categories. Interview responses show that construction projects in Colombia implement many industrialization practices, but their level of development is still in early stages. The implementation of prefabrication, technology in construction systems, coordination, process standardization, and planning relationships between the developer and contractors present clear improvement opportunities for a comprehensive and efficient implementation of industrialization initiatives according to the parameters obtained from Lessing (Lessing, 2015).

As shown in Table 2 and 3, the areas with the relative highest degree of implementation are not directly related to prefabrication or the development of technical systems, as areas focused on information management, collaborative work environments, and coordination between the developer and the client demonstrate a more advanced level of development. The categories of customer focus, utilization of information and communication technology, and performance measurement reflect a more positive perception of development according to the interviewees.

Results show that the primary focus of industrialization in Colombia is on strategies that facilitate the integration of key industry players and optimize project life cycle processes and management techniques. For instance, value generation from customer integration and waste reduction within the implementation efforts associated with LPs outperforms technological implementation or prefabrication shown in Table 2. Accordingly, it is noteworthy to emphasize that, based on the semi-structured interviews, only two of the eight IC practices have reached an advanced level of maturity. Furthermore, both the literature study and the respondents' perspectives indicate that none of the four LPs discussed in this research currently effectively support the application of real-world IC in Colombia.

LIMITATIONS IN THE INDUSTRIALIZATION PROCESS

The challenges associated with performance metrics primarily involve increased overall project costs, higher early-stage expenses, and elevated technological expenditures. This includes greater economic risk, higher labor expenses, increased transportation costs, and longer timeframes during the planning and design stages. Most of these obstacles are linked to circumstances that would change if LP were implemented—essentially, focusing on value generation and continuous process improvement (Andersson & Lessing, 2017).

Furthermore, the lack of integration and process modifications are typically associated with hurdles in process flow (Qi et al., 2021). The primary causes of integration barriers include disjointed supply chains, inadequate short-term business partnerships, unsuitable project delivery models, and contracts, as well as insufficient cooperation and communication among involved parties (Ekanayake et al., 2021a). Once again, applying LP, centered on creating cooperative work environments that optimize information flow and discipline integration, could help overcome these obstacles (Ekanayake et al., 2021b). The result is that many of the IC practices may potentially benefit from the improvement of flow and reduction of variability.

Additionally, there are noted obstacles related to planning and design. A clear absence of a planning and control framework tailored to the specific market requirements is observed within these barriers (Vásquez-Hernández et al., 2023). Incompatibilities between conventional and industrialized designs are apparent, as are constraints on customization, the failure to specify or decide on the design in a timely manner, the inflexibility of applying changes to the design later, the absence of design standardization, and minimal investment in the design stage (Qi et al., 2020).

Finally, inadequate change management, low motivation, and a lack of experience, training, and knowledge in construction firms are impediments related to knowledge management. This includes a lack of process documentation, low levels of research in the industry, insufficient collaboration between academia and industry, inadequate planning capabilities, a lack of skill techniques, a shortage of skilled labor, an inability to objectively assess the benefits of industrialization, inadequate education and training, an inability to synchronize off-site and on-site activities, and a lack of prior design, on-site management, and on-site experience as some of the barriers related to knowledge, skills, and experience (Kedir & Hall, 2021).

IMPLICATIONS AND OPPORTUNITIES

This study integrates literature review with the collection of empirical information from semi-structured interviews with experts in the Colombian industry. This combined methodology helps identify fundamental LP associated with opportunities for improvement in the construction sector, fostering synergy and facilitating their proper implementation.

Results suggest that the construction industry in Colombia has embarked on a significant transition toward industrialization, but still has ample room for continuous improvement and significant opportunities for development in many IC practices. This presents significant challenges in terms of productivity, efficiency, and value generation. Therefore, the simultaneous application of LP in each of the previously analyzed categories holds great potential to expedite the implementation of industrialization and its seamless integration with construction paradigms in Colombia.

The four main LP identified in the results phase demonstrate substantial potential for improvement across the eight IC practices addressed in this study. This approach can bring about significant changes in the industry, promoting process standardization, enhancing information flow, increasing productivity, integrating multidisciplinary groups, and creating streamlined processes to accelerate the production chain. The combined impact of LP and IC practices facilitates the effective implementation of an acceptable level of maturity of industrialization in the short term in Colombia and offers a valuable pathway to accelerate efficient IC practices in other countries with a low IC maturity.

Finally, this study, structured from construction projects in Colombia, provides valuable information about the current state of industrialization in developing countries, which constitute a significant sector in global construction. This study also enables understanding of improvement opportunities in the development of industrialization in countries with initial stages of maturity. The analysis is useful to other Latin American countries with similar industrialization conditions and Lean implementation efforts.

CONCLUSION

Through semi-structured interviews and a comparison with the literature in the Scopus and Web of Science (WoS) databases, this study conducted an analysis of the influence of LP in IC practices in Colombia. Based on the results of the literature review, four LP were identified. These principles have the potential to mitigate the impact of adoption barriers by modifying critical conditions that are considered to have a high and very high impact on the adoption of IC practices in the Colombian context.

Various criteria were used to assess how much the application of LP contributed to the examples under study. First, it is observed that the identification and reduction of waste contribute to the improvement of performance metrics (cost, time, quality, and productivity), thereby mitigating the negative perception associated with unsuccessful attempts and inconsistent outcomes. Second, the reduction of information silos is associated with enhanced

communication and teamwork, increased early integration, and improved phase synchronization—both between design and external production and among production, external installation, and internal processes. Third, knowledge, value creation, continuous improvement, and change management are crucial aspects. Research efforts in LP within the context of project management are particularly focused on the external production phase. A substantial body of research and the consulted experts agree that incorporating LP at an early stage enhances the adoption and implementation of IC practices in the construction industry.

There are limited studies focusing on the application of LP in both construction management and integrated design management in countries with low IC maturity. Practices aimed at reducing project fragmentation are not well-documented. However, integration-based approaches involve collaboration among project stakeholders within a phase and across different project phases. To manage their production system and associated subsystems, oversee current operations, and execute construction projects, construction companies require an integrated vision of work across disciplines. This strategy, which integrates discrete projects with continuous activities, requires different technical systems, organizational structures, procedures, and supply chains compared to traditional construction enterprises.

By examining the utilization of LP and their role in reducing adoption barriers, the current paper offers a practical contribution by identifying specific Lean strategies that can be integrated into various stages of the continuous improvement process and linking them to outcomes that modify circumstances related to adoption obstacles in IC practices implementation. These findings serve as input for transformations based on the LP, which, through process flow, knowledge management, performance enhancement, and value generation, helps reduce the uncertainty surrounding the enhanced utility perception of coordinating fitted work units compared to conventional construction practices, thereby lowering adoption barriers.

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