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CONTRIBUTION OF LEAN TECHNIQUES TO INDUSTRIALIZED CONSTRUCTION ADOPTION: A BARRIERS MITIGATION APPROACH

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ABSTRACT

Despite the benefits associated with industrialized construction (IC), it has low overall levels of adoption. IC is an innovation that is not aligned with institutionalized project supply chains; it has implications in process integration that intensify adoption barriers. Several studies have shown the effectiveness of implementing Lean techniques in different stages of the IC process. This paper exposes the analysis of the contribution of implementing Lean techniques to performance, process flow, knowledge management, and value addition. The implementation results are analyzed in terms of their contribution to mitigating the IC adoption barriers identified in the Chilean context. A systematic literature review is carried out to identify the Lean techniques implemented in some of the phases of the IC process. The analysis of the results reported and the contribution of the implementation of Lean techniques to the mitigation of the impacts of some of the existing barriers to the adoption of IC is conducted using thematic content analysis. Thirty Lean techniques are identified whose implementation results are related to the mitigation of conditions associated with 76.5% of the IC adoption barriers considered to be of high and very high impact for the Chilean context.

KEYWORDS

Lean construction, prefabrication, assembly, off-site construction.

INTRODUCTION

Industrialized construction (IC) has been identified as a promising approach to improving project performance. Despite the associated benefits, IC presents an incipient level of adoption and implementation (Jaffar & Lee, 2020), and it still faces immense resistance from the industry and the market (Razkenari et al., 2019). In Chile, the construction industry faces pressures and substantial threats related to the shortage of skilled labor, increased labor costs, the disruption of new competitors, and the postpandemic economic crisis scenario. Due to this, the Chilean Chamber of Construction has identified the adoption of IC as one of the three levers that

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encourage leaps in productivity, along with Building Information Modeling (BIM) and digitization (Matrix Consulting, 2020). However, the adoption of IC in Chilean construction maintains low levels (Construye 2025, 2022).

The adoption of IC is an example of the diffusion of innovation. In the construction industry, the diffusion of innovation is extremely slow due to the adoption processes being carried out amid a complex series of barriers (Wuni & Shen, 2020), which directly affects the perception of the offer of improved utility compared to existing technologies. Because of this, IC implies technological adoption and a cultural management process aimed at reducing the uncertainties associated with the perceived benefits of innovation.

IC is a phenomenon oriented toward the integration of processes, which implies long-term relationships between the different actors, advanced supply chain management, a design oriented to better support the manufacturing and installation phase, and the capture of experience and knowledge management aimed at continuous improvement (Lessing, 2015). It is an innovation not aligned with institutionalized project supply chains. These chains, therefore, require a change in the process that implies that multiple companies modify their practice in a coordinated way (Lavikka et al., 2021). This condition intensifies the difficulty of implementing innovations in project networks that consist of numerous parts and present fragmentation.

Many of the emerging problems in IC implementation experiences are related to the forms of adoption, that is, a focus on the incorporation of industrialized construction systems under a context of organizational structure, project development model, and conventional work methods (Andersson & Lessing, 2017); such characteristics include highly fragmented scenarios, poor communication, information exchange, cooperation and coordination between actors, and using conventional acquisition methods. These adoption conditions lead to failed experiences and unsatisfactory/inconsistent performance results.

Numerous papers have illustrated the contribution of Lean techniques in the domain of supply chain management and the rationalization of construction processes. In the field of IC, various studies have shown the effectiveness of different degrees of implementing Lean techniques in different stages of the process (Innella et al., 2019). Given the above, one of the emerging research directions involves a combination of IC and Lean techniques. However, the systematic analyses described in the literature in this field are insufficient, and there needs to be more clarity about the progress of current research. Therefore, reviewing previous research on implementing Lean techniques in the various stages of the IC process is opportune. Similarly, based on the implementation results, we analyze the contribution of these techniques to performance, process flow, innovation management, and value addition and mitigate the impacts of conditions identified as barriers to adopting IC.

RESEARCH METHOD

A systematic literature review (SLR) was carried out to identify the Lean techniques implemented in the different phases of the IC process. Additionally, a thematic content analysis (TCA) was conducted to analyze the results of the reported implementations and the contribution of the implementation of these techniques to the mitigation of the impacts of some of the existing barriers to the adoption of IC.

The search for related research papers published between 2017 and 2023 was conducted in the Scopus and Web of Science (WoS) electronic databases. The criteria for database selection were based on the fact that these databases are the largest in the field of inquiry; Web of Science has a longer time frame, while Scopus has more recent articles (Chadegani et al., 2013). The search equations were built according to the following combination criteria: TITLE-ABS-KEY (("lean construction" OR "lean practice" OR "lean principles" OR "lean tools" OR "lean strategies" OR "lean techniques") AND ("off-site construction" OR " industrialized building system" OR "industrialized construction" OR "modern method of construction" OR "prefabrication" OR "modular construction)) AND (LIMIT-TO (PUBYEAR, 2017-2023). Through the search strategy, 36 articles were selected from the electronic databases. Following the criteria for the exclusion of irrelevant articles, based on the nonexplicit declaration of Lean techniques or a specific phase of the IC process, seventeen were discarded. The resulting nineteen studies were included in the analysis.

The studies on implementing Lean techniques in IC processes were analyzed from a quantitative and qualitative approach. The quantitative analysis integrated the prevalence of the techniques and results found in the literature. The qualitative study was carried out based on the thematic content analysis (TCA) method to identify relationships between outcomes associated with Lean techniques and IC adoption barriers. The barriers identified by Ortega (2022), with high and very high impacts on the context of Chile, were taken as a basis for the analysis of the contribution of Lean techniques to the mitigation of the impacts of the existing barriers to the adoption of IC.

FINDINGS

LEAN TECHNIQUES IMPLEMENTED IN THE IC PROCESS

Nineteen studies were identified from the literature review that address implementing Lean techniques in different stages of the IC process. These studies, their country of origin, and the associated industrialized system examined are presented in Table 1.

Table 1: Studies resulting from the literature review.

Id.	Authors	Country	Industrialized system
1	(Ahmad et al., 2019)	Malaysia	Precast components
2	(Barkokebas et al., 2021)	Canada	Unspecified
3	(Bataglin et al., 2017)	Brazil	Precast ETO systems
4	(Bataglin et al., 2022)	Brazil	Precast ETO systems
5	(Bortolini et al., 2019)	Brazil	Precast ETO systems
6	(Brown et al., 2019)	Canada	Wall Assembly Line
7	(Chauhan et al., 2019)	Finland	Unspecified
8	(Darwish et al., 2020)	Canada	Panelized Homebuilding
9	(Gbadamosi et al., 2019)	United Kingdom	Design for Assembly
10	(Goh & Goh, 2019)	Singapore	Prefinished volumetric
11	(Heravi & Firoozi, 2017)	Iran	Precast steel frame
12	(Heravi et al., 2021)	Iran	Precast steel frame
13	(Laika et al., 2022)	Iran	Precast concrete
14	(Marte Gómez et al., 2021)	United Kingdom	Unspecified
15	(Peiris et al., 2021)	Australia	Precast components
16	(Placzek et al., 2021)	Germany	Additive manufacturing
17	(Shabeen & Krishnan, 2022)	India	Precast components
18	(Li et al., 2018)	China	Precast components
19	(Xiong et al., 2018)	China	Unspecified

In the studies, thirty implemented Lean techniques were identified. These techniques were grouped according to the purpose of the implementation: identifying and reducing waste, improving flow, adding value, and continuous improvements. Eleven Lean techniques associated with identifying and reducing waste were found, aimed at identifying waste (3), reducing cycle time (1), reducing batch size and work-in-progress (4), increasing transparency (2), and materials management (1). Regarding improving the flow and reducing variability, fourteen techniques were identified aimed at reducing flow variability (1), increasing manufacturing flexibility (2), increasing stakeholder and systems integration (3), improving product and operation flow (2), pull production (2), reducing process variability (2), and leveling production (1). One identified technique was found to be associated with adding value and oriented toward decision-making (1). Finally, regarding striving for perfection and continuous improvements, four techniques were identified (4). Table 2 shows the thirty techniques identified based on the grouping stated, and the ID number of the study (according to Table 1) in which each technique is listed.

Table 2: Lean techniques implemented in the IC process.

Goal		Techniques	Included by (ID from Table 1)
Identifying and reducing waste	Identifying waste	T1 - Value stream mapping (VSM)	2, 11, 13, 14, 17
		T2 - Genchi Genbutsu (Gemba)	2
		T3-5 Whys technique (RCA)	13
	Red. cycle time	T4 - Total Productive Maintenance (TPM)	12
	Reduction of batch size and work-in-progress	T5 - Takt Time planning	4,14
		T6 - Work-In-Process (CONWIP)	18
		T7 - Location-Based Planning (LBP)	4
		T8 - Line of balance (LOB)	4
	Increasing of transparency	T9 - Visual boards/management	4, 14, 15
		T10-5S	13, 5
	Material mgmt.	T11 - Kanban	1, 10
Improving flow and reducing variability	Flow variability	T12 - Last planner system (LPS)	4, 11, 14
	Flexible manufacturing	T13 - Process modularity (PM)	4
		T14 - Bidirectional workflows (BDW)	16
	Stakeholder and systems integration	T15 - Integrated Project Delivery (IPD)	4
		T16 - Lean Project Delivery (LPD)	14
		T17 - Target Value Design (TVD)	4, 14
	Product and operations flow	T18 - BIM	2, 3, 4, 5, 6, 9
		T19 - Simulation	6, 8
	Pull production	T20 - Just-in-time (JIT)	1, 4, 10, 13, 14
		T21 – On-demand production (ODP)	16
	Process variability	T22 - Mistake proofing (Poka-yoke)	14
		T23 - Cross training (CT)	10
	Leveling the production	T24 - Standardization (Procedure, time,	15
		T25 - Process Specification Language (PSL)	19
Value	Decision-making	T26 - Choosing by advantages (CBA)	7, 14
Continuous improvement	Aiming to perfection	T27 - Kaisen	2
		T28 - First Run study	14
		T29 - Quality Check (QCH)	14, 16
		T30 - Total Quality Management (TQM)	10

Registered implementations are tied to different phases of the production process. A total of 10.5% of the studies report implementations in the design phase, including 6.7% of the identified techniques. The design phase's implementation focuses on adoption decision-making and design for assembly. Off-site production is the phase addressed most frequently; 63.2% of the studies report implementations in this phase, and 63.3% of the identified techniques emerge from them. The implementations reported in the off-site production phase focus on rationalizing the production process. The on-site assembly phase is addressed in 26.4% of the studies, with the implementation of 60.0% of the techniques. The focus of the implementations associated with this phase is to improve the installation process by synchronizing off-site production with on-site production. The most prevalent Lean techniques found in the literature are Building Information Modeling (BIM) (31.6%), Value Stream Mapping (VSM) (26.3%), and Just-in-time (JIT) (21.1%), followed by 5S, the Last Planner System (LPS), and visual boards, which are reported in 15.8% of the studies. Figure 1 presents the prevalence in the literature of the identified Lean techniques.

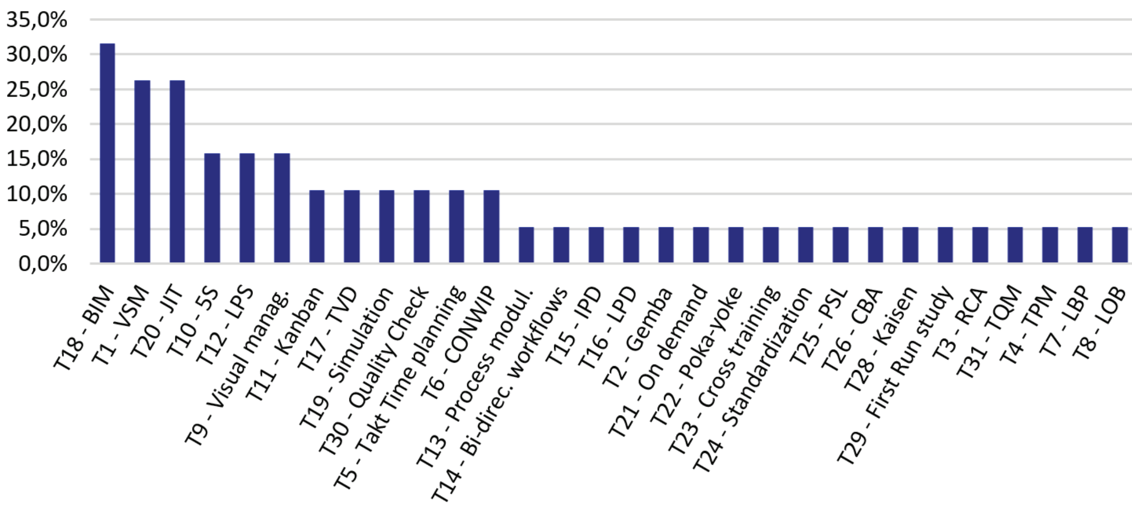

Figure 1: Prevalence of Lean techniques in the literature

Results associated with the Lean techniques implemented

Studies relate specific results to the implementation of Lean techniques. These results can be divided into two categories: diagnostic and interventional. Of the studies, 36.8% report results associated with the possibility of an adequate diagnosis, that is, waste identification from the use of the VSM, Gemba, and RCA techniques.

In terms of the results of the intervention, improvements in the performance process flow, knowledge and labor management, and value addition were identified. A total of 68.4% of the studies report changes in performance indicators. A total of 57.9% of the studies report a reduction in process time. This reduction is associated with lead time reduction (36.8%), cycle time reduction (36.8%), and idle time reduction (47.4%). Likewise, 26.3% of the studies report a decrease in costs; 21.1% mention the reduction of costs related to the off-site production process, 21.1% report total project costs, and 26.3% report labor costs. A total of 21.1% of the studies reported quality improvements linked to the early detection of deviations and eliminating design errors and inappropriate designs. A total of 42.1% of the studies report more significant control over the work in process, 15.8% declare a general improvement in performance, and 31.6% declare an improvement in productivity.

Regarding the improvement of the process flow, studies report results associated with decreased fragmentation among stakeholders and phases of the process. A total of 36.8% of the studies report improvements in terms of early integration and adequate conditions for integration, namely, adequate collaboration among actors from different phases (31.6%) and improvements in communication (31.6%). Linked to these improvements in terms of integration, 26.3% report greater synchronization between design and off-site production, and 15.8% report greater synchronization between off-site production and on-site installation. A total of 5.3% of the studies report a reduction in transport processes.

Some studies report improvements associated with knowledge and labor management. A total of 21.1% of the studies declare a decrease in the complexity of knowledge management linked to the increase in transparency and standardization. Likewise, 15.8% report a reduction in risk at work, and 5.3% report a reduction in training time for the workforce.

Regarding value addition, 15.8% of the studies report that implementing Lean techniques increases the satisfaction level of end users, and 10.5% report that such implementation provides adequate support for decision-making on IC adoption. A total of 22 results were identified, which are presented in Figure 2.

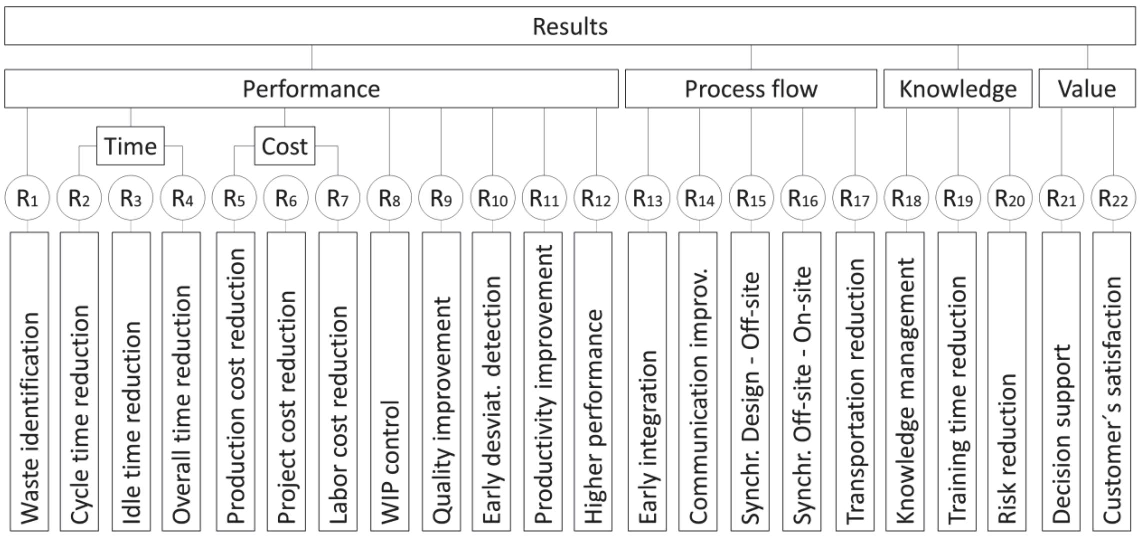

Figure 2: Results of the implementations of Lean techniques reported in the literature.

In 42.1% of the studies, the reported implementation integrates only one Lean technique. In most of these cases (15.8%), the implemented technique is BIM. The CONWIP, VSM, simulation, PSL, and CBA techniques are integrated into the rest of the cases of isolated technique implementations. In 21.1% of the studies, the implementations integrate two Lean techniques; these are simultaneous implementations of JIT and TPM, JIT and Kanban, VSM and LPS, and BIM and simulation. A total of 10.5% of the studies report implementations that integrate three techniques such as bidirectional workflows, on-demand production and quality checks, visual management, 5S, and standardization. A total of 10.5% of the studies simultaneously incorporate four techniques, 5.3% incorporate five techniques, 5.3% incorporate nine techniques, and 5.3% incorporate eleven techniques. It is opportune to point out the form of implementation of the techniques as being either isolated or together since the results reported by the studies result from the specific type of implementation in terms of the confluence of different techniques. Therefore, even though the results attributed to implementing a particular technique can be traced in the studies, there is the incidence of the synergistic effect of implementing multiple techniques to consider. Figure 3 presents the relationship among the identified Lean techniques and the specific results associated with their implementation.

LEAN CONTRIBUTION TO MITIGATION OF IC ADOPTION BARRIERS IMPACTS

Based on the previous relationship between Lean techniques and results, the areas of incidence of these results were analyzed to identify relationships among them and the barriers to IC adoption. That is, we aimed to identify from the results the possible contribution of implementing Lean techniques to modifying the conditions constituted as barriers and, consequently, mitigation of their impact. In previous research (Ortega, 2022), existing IC adoption barriers have been identified, and their level of impact has been evaluated for the Chilean context. The barriers assessed as having high and very high impact have been previously grouped into cultural, quality, market, cost and finance, design and development, innovation and technology, skills, regulations, status, diffusion, and logistics. In the present study, these barriers were analyzed and regrouped based on the possibility of their mitigation from Lean implementations. The authors acknowledge that grouping barriers into typologies is highly subjective and that there may be overlaps between groupings. The proposed grouping seeks to align with the results related to Lean technique implementations.

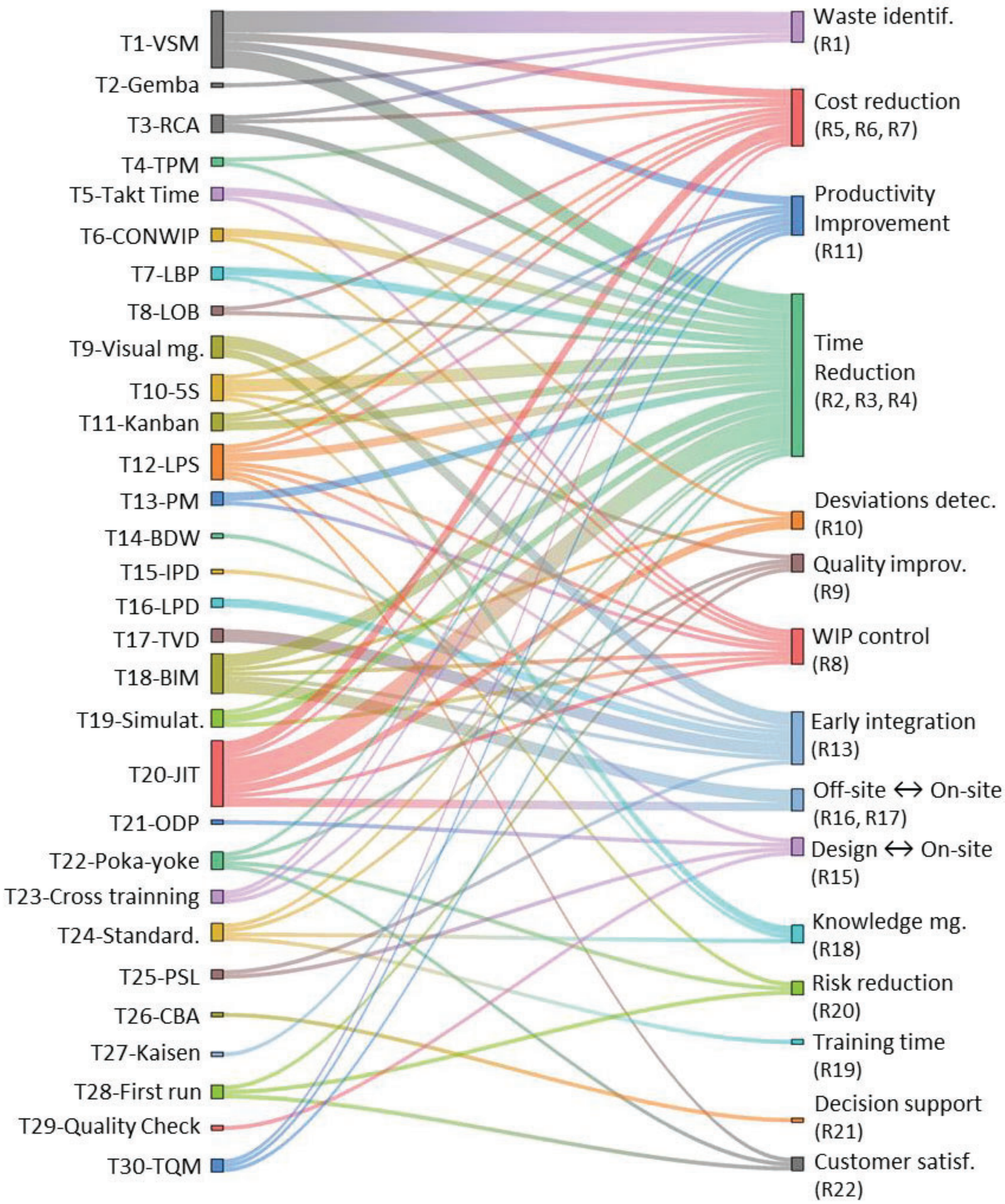

Figure 3: Results associated with Lean techniques.

Initially, the barriers were analyzed based on their dependence on external agents. Sixteen high external dependence barriers were identified, which are related to limitations of offers, demands, regulations, external incentives, financing possibilities, and external actors' IC knowledge. These barriers are as follows: lack of offers from manufacturers, low standardization level of materials/elements, higher and volatile cost of materials, low market demand, low client/consumer/general public acceptance/valuation, unsuitable for small projects, difficulty obtaining financing, lack of regulations, rigid regulations, incompatibility between current and emerging regulations, lack of more demanding quality regulations, lack of quality assessment/accreditation instruments, lack of knowledge on the part of the state, lack of modernization of university curricula, lack of government incentives, and lack of financing for system innovation ventures. These barriers were not included in the relationship analysis with the results related to Lean techniques. However, other barriers with less dependence on external agents were included in the analysis. These barriers were grouped according to their association with performance, process flow, and knowledge management.

Barriers associated with performance.

The barriers associated with performance indicators are as follows: higher overall cost (B1), higher initial costs (B2), higher costs of technology (B3), higher labor costs (B4), difficulty obtaining advances (B5), higher cost of transportation (B6), difficulty in achieving economies of scale (B7), greater economic risk (B8), longer setup times during the planning stage (B9), and longer setup times during the design stage (B10). Eighty percent of these barriers are related to conditions that, according to the results reported, are modified by implementing Lean techniques. Only barriers B3 and B5 are not directly related to any of the results. The result R4, namely, time reduction, is associated with the implementation of VSM, RCA, Takt time planning, COWIP, LBP, LOB, 5S, Kanban, LPS, process modularity, BIM, JIT, standardization, and Kaisen, can help mitigate the impact of barriers B8 and B9. Results R5, R6, and R7, which are linked to cost reduction related to implementing VSM, RCA, TPM, LOB, 5S, Kanban, LPS, JIT, cross training, and TQM, can help mitigate the impact of barriers B1, B2, B4, and B8. The result R7, namely, labor cost reduction, is directly related to barrier B4. The result R15, which is associated with implementing bidirectional workflows, on-demand production, and quality checks, can contribute to mitigating the impact of barrier B7. Result R17, which is related to the implementation of JIT, can contribute to mitigating the impact of barrier B6.

Barriers associated with process flow.

The barriers associated with the process flow are associated with a lack of integration and changes in the process. The barriers linked to the lack of integration are fragmented supply chains (B11), short-term business relationships (B12), inappropriate project delivery models and contracts (B13), poor communication/coordination among stakeholders (B14), and poor collaboration among stakeholders (B15). The results 13 and 14, associated with implementing visual management, LPS, IPD, LPD, TVD, BIM, and PSL, can contribute to mitigating the impact of barriers B11, B13, B14, and B15.

The barriers linked to changes in the process refer to changes in planning and design, off-site production, transportation and storage, and on-site production. The barriers associated with planning and design are as follows: lack of adapted planning and control structure (B16), inadequate approval and quoting processes (B17), incompatibility between traditional and industrialized designs (B18), inability to define/freeze design early (B19), design limitations that affect customization (B20), inflexibility to apply late changes to the design (B21), lack of design standardization (B22), and low investment in the design stage (B23). The result R15, related to implementing bidirectional workflows, on-demand production, and quality checks, can mitigate the impact of barriers B18, B19, B20, B21, and B22. Likewise, the results R21 and R22, associated with the implementation of LPS, Poka-yoke, CBA, and the first-run study, can contribute to mitigating the impact of barrier B20. Despite not being declared as a direct result, the results in performance improvement associated with the implementation of techniques such as LPS, LOB, and LBP, which establish planning and control methods, allow linking these techniques to the mitigation of the B16 barrier.

The barriers associated with off-site production are the inflexibility of production lines to respond to changes (B24), limited productive capacity of suppliers (B25), and poor management and production in the factory (B26). Result R15, which is associated with implementing bidirectional workflows, on-demand production, and quality checks, can contribute to mitigating the impact of barrier B24. Results R11 and R12, which are related to the implementation of VSM, Kanban, LPS, simulation, JIT, Poka-yoke, cross training, and TQM, can contribute to mitigating the impact of barriers B25 and B26.

The barriers associated with transportation and storage are long transport distances (B27), increased transportation restrictions (B28), and the lack of storage and transport quality measures (B29). Result R17, which is associated with implementing JIT, can contribute to mitigating the impact of barriers B27, B28, and B29.

The barriers associated with on-site production are increased site restrictions (B30), low tolerances between precast systems and on-site structures (B31), the predominance of conventional over industrialized processes (B32), and a lack of recognition of indirect construction cost impacts (B33). Result R16, which is associated with implementing BIM, JIT, and PSL, can contribute to mitigating the impacts of barrier B31.

A total of 69.6% of the barriers associated with the process flow are related to conditions that, according to the reported results, are modified by implementing Lean techniques.

Barriers associated with knowledge management.

The barriers associated with knowledge management are related to knowledge, skills and experience, and change and motivation management. The barriers linked to knowledge, skills, and experience are the low documentation of economic benefits (B34), low levels of R&D in the industry (B35), the lack of university-industry joint work (B36), the lack of planning capacities (B37), the lack of technical skills (B38), the lack of skilled labor (B39), the lack of capacities to adopt technology and innovation (B40), the lack of capacity to objectively benefit assessment (B41), inadequate education and training (B42), the lack of capacity to synchronize off-site and on-site activities (B43), the lack of previous design experience (B44), the lack of previous on-site management experience (B45), and the lack of previous construction experience (B46). Results R11 and R12, which are associated with the implementation of VSM, Kanban, LPS, simulation, JIT, Poka-yoke, cross training, and TQM, can contribute to mitigating the impact of the B37 barrier. Results R18 and R19, which are related to implementing visual management, 5S, and standardization (procedures, time, quality), can contribute to mitigating the impact of barriers B38, B39, B40, and B42. Result R10, which is associated with the implementation of TPM, BIM, and JIT, and result R15, which is related to the implementation of bidirectional workflows, on-demand production, and quality checks, can both contribute to mitigating the impact of the B44 barrier. Result R16, which is associated with implementing BIM, JIT, and PSL, can contribute to mitigating the impact of barriers B43, B45, and B46.

The barriers linked to change and motivation management are the lack of support for adoption (B47), negative perception of failed experiences (B48), the lack of IT adoption (B49), the lack of BIM adoption (B50), and resistance to change (B51). Result R21, which is associated with implementing CBA, can contribute to mitigating barrier B47.

A total of 72.2% of the barriers associated with knowledge management are related to conditions that, according to the reported results, are modified by implementing techniques. Some of the barriers not considered in the field of incidence of the reported results, such as low documentation of economic benefits (B34), can find mitigation in the study of the phenomenon of IC adoption and strategies aimed at improving implementations, such as the studies considered in this document.

CONCLUSIONS

This research conducted an SLR of the Lean techniques implemented in the IC process, using the Scopus and Web of Science (WoS) database. The literature review results showed thirty Lean techniques whose implementation modify conditions associated with 76.5% of the IC adoption barriers considered high and very high impact for the Chilean context, and based on this, could contribute to mitigating the impact of the barriers on adoption scenarios.

The contribution of the implementation of Lean techniques in the cases studied is based on several factors: (i) the rationalization of the process associated with the identification and reduction of wastes, which leads to an improvement in performance indicators (cost, time, quality, productivity) and contributes to reducing the negative perception related to failed experiences and unsatisfactory and inconsistent results; (ii) the reduction of fragmentation, which is associated with greater early integration, better communication and collaborative work, and greater synchronization between phases, both between design and off-site production, as well as production or off-site and on-site installation, and (iii) the management of knowledge and change.

Research efforts in the field of IC management, from a Lean approach, are concentrated in the off-site production phase. A total of 63.2% of the studies, from which 63.3% of the implemented Lean techniques emerge, have this phase as a focus of interest. The number of studies focused on IC design management and construction site management, from implementing Lean techniques, is limited.

The approaches based on integration include integration among actors of a phase and among phases of a project, while practices aimed at reducing the level of fragmentation between projects are not identified. The techniques reported as IPD, LPD, and TVD are framed at the project scale. The adoption of IC by construction companies implies establishing a structure to manage continuous processes to develop and manage their production system and the associated subsystems, as well as the execution of construction projects. This approach that integrates continuous processes and discrete projects requires different technical systems, organization, processes, and supply chains than traditional construction companies. The approach to overcoming the B12 barrier, namely, short-term business relationships, implies not only integration at the project level but also the search for solutions to the loss of tacit knowledge, with a focus on how to work together effectively after the dissolution of the teams at the end of the projects. This aspect emerges as a field of potential contribution of Lean techniques not addressed in integrated studies.

The current document contributes to the body of knowledge on IC management by discussing the implementation of Lean techniques and their contribution to mitigating adoption barriers. Likewise, in terms of practical contribution, it identifies specific Lean techniques that can be integrated into different phases of the IC process and links them to results that modify conditions associated with adoption barriers. These findings constitute input based on the proposition of implementations that utilize a Lean approach that, based on performance improvement, process flow, knowledge management, and value addition, contributes to reducing the number of uncertainties associated with the perception of the improved utility of IC versus conventional construction and, consequently, to mitigating barriers to IC adoption.

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