Ortega, J., Vásquez-Hernández, A., Giménez, Z., & Alarcón, F. A. (2022). Ideation Framework in Industrialized Construction. *Proceedings of the 30th Annual Conference of the International Group for Lean Construction (IGLC30)*, 456–467. doi.org/10.24928/2022/0150

IDEATION FRAMEWORK IN INDUSTRIALIZED CONSTRUCTION

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ABSTRACT

Currently, industrialized construction (IC) is no longer an option, as it has become a necessity for companies that wish to maintain competitiveness and mitigate the pressures in terms of quality, cost, time, and sustainable performance in the construction sector. However, the way to industrialize effectively is still full of uncertainty; companies do not conceive of the incorporation of IC from the early stages, but they start late in the advanced design or even close to the execution phase, which results in the failure of the adoption of these industrialized systems, because such systems require, as a basic condition, thinking early about its incorporation and developing new design integrated and collaborative practices/knowledge. This paper proposes an Ideation Framework in Industrialized Construction (IFIC) that mainly improves the ideation process of ideas/actions within the IC design phase. The IFIC was developed under the design science research methodology. For the evaluation of this framework, the research was based on four case studies. The main contribution is the creation of two fundamental axes for ideation processes: *(i)* Ideation by self-assessment and *(ii)* Referral Ideation, which allows devising and incorporating industrialized solutions in a reliable way in IC projects.

KEYWORDS

Industrialized construction, DFMA, design science, integration, collaboration.

INTRODUCTION

Industrialization of construction has been seen as a solution to mitigate the low performance in terms of time, cost, and product quality of the architecture, engineering, and construction (AEC) industry (Durdyev & Ismail, 2019; Pikas et al., 2021). In this context, this research has been developed at the request of the Industrialized Construction Council of Chile (CCI) and its member companies. The term industrialized construction (IC) is defined as a system in which components are manufactured in mass production under a controlled environment (on or off-site), transported, positioned, and assembled into a structure with minimal additional site works (Osman et al., 2015), under the logic

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of three key concepts: standardization, modularity, and pre-assembly (CIRIA, 2001). The IC benefits include enhanced productivity and building quality, reduced project execution plan, simplified construction process, mitigation of the lack of skilled labor, less environmental impact by reduction and better control of off-site activities, reduced waste, increased occupational safety and health, and reduced overall cost of construction (Durdyev & Ismail, 2019). However, the evidence in the literature shows that there are still impediments at the level of design which prevent its effective adoption (Jaillon & Poon, 2010; Wuni et al., 2021)

IC design process is a strategic phase for improving performance and achieving all the benefits promised by IC because it is where the project objectives are idealized and constitutes the earliest stage where performance requirements can be controlled in the project life cycle (Bogue, 2012; Boothroyd, 2005). It is widely recognized that the design stage determines around 70% of a product's manufacturing costs (Bogue, 2012) and up to 80% of building operational costs (Bogenstätter, 2000). As a result, early-stage decision-making has an important impact on the design phase of IC projects.

IC design implies developing an interactive process that requires adequate integration and early collaboration between architects, contractors, and manufacturers (Jaillon & Poon, 2010; Pikas et al., 2021). Nevertheless, the fragmented nature of the construction industry and the lack of experience and knowledge regarding its use hinder the effective adoption of IC, resulting in errors in IC design owing to conflicts and omissions of considerations that should have been taken at the beginning of the project (Hyun et al., 2022; Zhai et al., 2014). Furthermore, the current state of industrialized design methods is generally based on the traditional design system, which does not consider practices and processes that meet the requirements of the manufacturing and assembly on-site; and organizations operate separately at different stages of the project, not meeting the integration requirements of IC (Andersson & Lessing, 2017; Yuan et al., 2018). For the mitigation of these challenges, Integrated Project Delivery and Design-Build are delivery methods recommended to be implemented in the context of IC projects (Osman et al., 2015; Wu et al., 2019) due to they promote more collaboration and early involvement of the stakeholders. However, they do not provide an explicit framework to support stakeholders in guiding the design process in IC design.

The design for Manufacturing and Assembly (DfMA) principle is widely considered to support the design process in IC by providing considerations to simplify design, production, and assembly. (Yuan et al., 2018). Despite this, the fragmented results of the previous studies difficult built a comprehensive design process that addresses the challenges of IC (Hyun et al., 2022). Another approach is Design for Excellence (DfX); it constitutes an emerging design concept which is based mainly on the principles of DfMA and is considered an integrated design methodology that provides a broader perspective to IC project design (Wuni et al., 2021). However, the same author points out several limitations to apply DfX, from which it is interpreted that being DfX a holistic approach requires a high degree of knowledge of those who implement it, generating difficulties in identifying the appropriate tools to be used; and an important economic investment for the organization.

In summary, to achieve project requirements in IC, collaboration must be intensified from the early stages (design stage) among the stakeholders (Zhai et al., 2014), the project design must be co-created (Wuni et al., 2021), and the interested parties must be organized through necessary administrative and economic instruments (Wang & Li, 2013).

Most of the research recommends more collaboration, early stakeholder integration, and general consideration to guide the design process in IC projects. Nevertheless, there is a lack of research that has developed and tested approaches that show how to organize stakeholders during the process of ideas generation in IC design, which includes activities/tools tailored to address the core elements of IC and structure them step-by-step. In this way, this paper addresses the research gap by proposing an ideation framework in industrialized construction (IFIC) that works within the design phase as a drive and accelerator in the creation of industrialized solutions, based on early integration and intense collaborative work among architects, contractors, and manufacturers as a prerequisite for the success of its application.

LITERATURE REVIEW

The design process must ultimately pass through three spaces: *(i)* inspiration, *(ii)* ideation, and *(iii)* implementation (Brown, 2008). In this research, the focus is the ideation space which is defined as a process of generating knowledge and ideas to support the development of new solutions applicable to the project (Brown, 2008; Peffers et al., 2007). To understand the start-point and define the scope of the IFIC, a variety of ideation methodologies were explored and analyzed. The following methodologies only are used as a reference to guide the structuration process of the IFIC.

IDEATION METHODOLOGIES

Design thinking (DT). Leads the designer to new ways of thinking and ideas so that they can find optimal designs through breakthroughs in design conceptions, based on understanding the real needs of people and by promoting a collaborative work environment among stakeholders to drive continuous improvement (Lo et al., 2019). In DT, the ideation process must respond to human demands and deliver technically and commercially viable solutions (Brown, 2008).

Deep Dive (DD). Deep dive is a technique that allows to quickly getting into the ecosystem of the problem to be solved, with the intention of having a broad understanding of all the variables involved in it and capturing valuable information that serves to generate solutions focused on the improvement of the service or product under study, considering the real limitations of the environment (Horton-Jones et al., 2019).

Open Innovation (OI). The traditional closed innovation paradigm can-not maintain the companies' competitive advantage in the current conditions of markets, in which technological progress is accelerating, and the conditions of satisfaction are changing rapidly. (Xin & Qian, 2011). The same author states that this condition has led to the creation of a new innovation paradigm called open-innovation, in which the premise is that the company must have the ability to leave its comfort zone to explore and acquire new knowledge and originalities offered by new markets; and combine them with internal assets in terms of capabilities and knowledge to develop new solutions that allow delivery an offer that satisfies the market needs and keeps the company competitive.

Agile Design Management (ADM). It is an adaptation of the scrum approach into the design phase of construction projects with the objective of increasing coordination, interface management, collaboration, integration, and transparency throughout all design phases between multidisciplinary teams (Demir & Theis, 2016). In such manner, from Demir & Theis (2016) study, it can be interpreted that as an agile approach, ADM involves many rapid iterative planning and development cycles, allowing constant evaluation focused on continuous product improvement and embracing changes to meet customers' requirements.

Around the generation of ideas and acceleration of the ideation process, other approaches/tools that fall under the umbrella of the Lean Construction were also studied:

Target value design (TVD). It is a management practice that seeks to make customer constraints drivers of design through intimate collaboration between members of the project team (designers, suppliers, builders), focusing on exploring problems and developing solutions for the sake of continuous improvement, waste reduction, and assurance that customers get what they need (Ballard, 2011). In addition, Ballard (2011) states that implementation of TVD has also consistently resulted in the faster and under budget delivery of projects over market expectations.

A3 report. The A3 report has been widely used in the implementation of lean production to serve as a tool to support the improvement processes, which is based on the PDCA system management method, promoting the interaction and integration of all people and areas involved in the problem or situation to be enhanced (Bordin et al., 2018). Furthermore, the author points out that the A3 report implies a significant questioning of the importance of addressing the problem for the organization and clearly establishing the current context as a basis for defining objectives, conducting a root cause analysis, generating countermeasures, developing an action plan and monitoring and controlling the results.

Figure 1. shows the points of overlap of the methodologies presented above, allowing to understand the fundamental phases prior to the ideation process and the different ways of approaching the process itself.

References Methodology	Identify and formulate the problem		Producing solutions
	Phase 1 Understanding the needs	**Phase 2** Problem definition	**Phase 3** Generation of actions/solutions
	Understand	**Define**	**Ideation**
Design Thinking	Empathize with the user needs to define the problem.		Focus on human demand and Market/Technical feasibility
Deep Dive	Identification of direct and indirect causes through quick immersion in the ecosystem where the undesired situation is generated.		Generate a reliable solution covering the risks and current constraints.
Open Innovation	Adopting "open originality" which means getting out of your comfort zone and accepting different perspectives external or internal		Based on internal and external knowledge to meet market demands and company requirements
ADM	Through user stories		Aimed at satisfying customers by adding value
TVD	Understand and define customer value		
A3 report	Understand the context of the problem by going to the site and establishing a shared vision among all stakeholders.		Actions and Shared solutions based on a deep root cause analysis of the problem

Figure 1: Common ground between ideation methodologies

In general, all these approaches are designed to generate a collaborative environment and accelerated ideation process of solutions linked to a need or problem of people/organizations, considering keep or adding value of the service/product. Consequently, the IFIC as a starting point must be made up of strategies/activities that allow a deep understanding and definition of the problem or current situation in a shared manner among those involved to avoid individual biases and to ensure an effective ideation process that navigates within the real context. In addition, the value proposition is a constant that should be the compass that guides the ideation process.

INDUSTRIALIZATION VARIABLES

The findings from a literature review revealed that prefabrication, combined with modular design conception and standardized design, are the core of industrialization in construction, and they help to save time and construction/design costs as building systems are used across projects (Jaillon & Poon, 2010). In this way, it must be the main variables to keep in mind when a design phase starts out in the IC design.

Prefabrication. The main characteristic of the prefabrication construction method is that this method can achieve the integration of the whole process of design, production, transportation, and assembly stages (Zhou et al., 2019), which is a high demand in IC. Therefore, it is a key element to include in the IC design process.

Modular design. In the context of IC, modular design means designing to generate standard volumes to make more efficient production and optimize on-site work, reducing constraints and providing repeatability (Jaillon and Poon, 2010). This process promotes standardization, mechanization, and computerization of construction, improves quality and consequently helps to reduce time and costs due to the simplification of design and assembly (Pons & Wadel, 2011; Yuan et al., 2018). Consequently, thinking about developing a modular design force to consider the implications of the ideas and design solutions downstream (e.g., production and assembly).

Standardized design. This means that IC buildings with different functions and shapes are designed according to a uniform architectural design criterion seeking a symmetrical and repetitive arrangement of the elements that compose the building. (Jaillon & Poon, 2010; Yuan et al., 2018). In other words, standardized design in its simplest form involves establishing the use of standardized components and procedures at the project level (Gibb, 1999).

RESEARCH METHODOLOGY

Design science research (DSR), or constructive research, is an approach commonly used for performing studies in the field of Lean Construction and, in general, in construction management (Da Rocha et al., 2012). The same author argues that several studies in the field of Lean Construction have used this methodology because it serves the dual purpose of solving practical problems and contributing to the body of knowledge at the same time. Some examples of research conducted under DSR and aimed at improving the design process in the AEC industry include the development of a value analysis model to support the building design process carried out by (Giménez et al., 2020) and the work done to improve the process of learning of design management operations by (Lehtovaara et al., 2019).

The artifact developed and evaluated for its intended benefits is an Ideation Framework in Industrialized Construction (IFIC), which is to serve as a framework for the generation of ideas/actions in a faster and more effective way within the design phase in IC projects. The IFIC was tailored under the DSR proposed by Peffers et al. (2007), which includes five iterative steps (See Figure 2): *(1)* problem identification and motivation; *(2)* definition of the objectives; *(3)* design and development; *(4)* demonstration; and *(5)* evaluation. The development and refinement of the artifact was done through four "case studies" (which might rather be understood as means for testing and refining prototypes of the IFIC process) and involved three stages comprising the five steps mentioned.

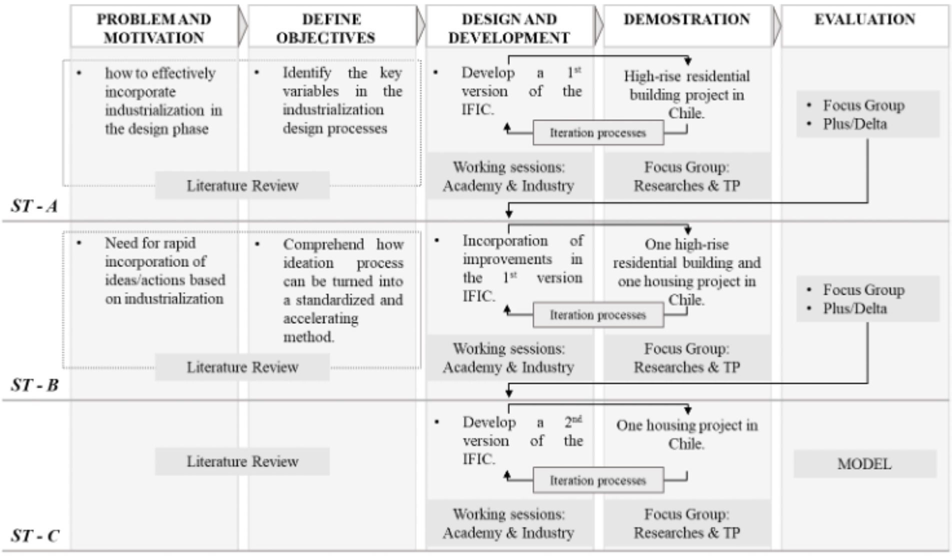

Figure 2: Research processes based on DSR

STEP 1 AND STEP 2: LITERATURE REVIEW AND OBJECTIVES DEFINITION

The systematic literature review (SLR) was performed through specialized journals on engineering and construction project management, conference papers, dissertations, and relevant reports in the construction industry. The search topics were industrialized construction, industrialized design process, barriers in IC, ideation processes, and collaborative methodologies. Based on SLR a clear understanding of the ideation process was achieved, its location within the design phase, and to identify and classify the different methodologies available to carry out the ideation process effectively, into those methodologies that cut across different fields of science and those that have greater proximity to the field of construction. Likewise, it's helped to comprehend the way that these methods promote collaborative work and adequate early integration of actors and identify the relevant variables that conform to the core of industrialization. In addition, the literature review also made it possible to visualize the study gap and to guide the development and approach of the objectives. In this way, two specific objectives associated with stages A and B were proposed: *(i)* identify the basis for incorporating industrialization at the design stage and *(ii)* comprehend how the ideation process can be turned into a standardized and accelerating method.

STEP 3: DESIGN AND DEVELOPMENT

The first version of the IFIC was developed in collaboration with academics and professionals with at least 10 years of experience in management and in the AEC industry and who are part of the CCI and Chilean construction companies. Based on the SLR and the proposed objectives, it was possible to frame the boundaries within which the IFIC would operate. Three fundamental spaces were identified: understanding, definition, and ideation. The spaces of understanding and definition were established because of the coincidences raised in the literature on ideation models, which indicate that they are essential to establish a clear shared understanding of the situation within the project team (TP) and lead the ideation process directly to the solution of the problem. The activities that would comprise the IFIC framework were selected and prepared based on three key aspects *(i)* to enable a clear understanding and definition of the problem, *(ii)* to be adaptable to address the core elements of the IC, and *(iii)* to establish a chronological sequence of implementation among them. After all, version 2 of IFIC was a product of the improvements included in the previous instantiations in stages A and B.

STEP 4 AND STEP 5: DEMONSTRATION AND EVALUATION

Design science research is conducted under many scenarios: experimentation, simulation, case study, proof, or other appropriate activity (Peffers et al., 2007). In the context of this research, multiple cases of study will be applied. This method was selected because of the richness, depth, and quality of the information it allows to collect. In total were four case studies of Chilean projects, two of which are high-rise buildings, and the rest are housing. The selection criteria for the case studies obeyed practical interests such as their similar characteristics of scope, user profiles, and level of design progress, in addition to the researcher's access to the stakeholders involved. All case studies were in their design phase and involved 3 different companies. The demonstration process was divided into three stages: *stage A* was applied to one case study (high-rise buildings), *stage B* to two case studies (high-rise buildings and housing) simultaneously, and *stage C* to one case of study (housing). The application of the IFIC was carried out progressively and sequentially between each stage, generating instances of partial application that served to obtain feedback and to incorporate and test improvements that were then transferred to subsequent stages, allowing for small adjustments to be made. Therefore, several subcycles of instantiations, testing, and refining of the solution were carried out between stages until a proper version of the IFIC was created and then reviewed with the TP and directors.

The evaluation step consists of monitoring and measuring the solution's effectiveness in addressing the needs or problems detected. It implies comparing the objectives of a solution to actual observed results from the use of the artifact in the demonstration and can be done in various ways depending on the nature of the problem and the artifact; such ways include quantitative performance measures, satisfaction surveys, or activities that collect feedback from project stakeholders (Peffers et al., 2007). The usefulness of the IFIC was evaluated in each case study through a focus group meeting comprised of directors and TP of each project, which includes architects, civil engineers, electrical engineers, mechanical engineers, and industrial engineers. Additionally, to measure the results achieved through the implementation of the model, a plus/delta analysis was carried out.

RESULTS · GENERAL OVERVIEW

The main outcome of this research is the framework to support the ideation process in IC design. The IFIC was developed within the umbrella of the research project "Methodology for early incorporation of industrialization in construction projects in Chile". Therefore, some activities must be done before and after the ideation process. Prior, it is recommended to apply methods that allow identify the items/processes/activities (IPAs) with the greatest potential for industrialization and have a relevant impact at the project level. This issue is being addressed within the aforementioned project with studies that are currently in progress; however, in the meantime, available tools and methods must be used. Likewise, after the ideation process, it is recommended to carry out a deep technical and economic evaluation of the ideas/actions generated.

To implement the IFIC, the organization must comply with the following guidelines: *(i)* to have a conceptual or reference project on which to start the ideation process and incorporation of the ideas, *(ii)* to be clear about the incentives that drive the ideation process, *(iii)* to understand the innovation capabilities of the organization, and *(iv)* forming the integrated project team (IPT), which consists of incorporating suppliers and builders in the early stages of the design to know their solutions, production capacity, manufacturing processes, logistics, and production requirements. The ideation process is oriented to create a set of ideas/actions based on core elements of industrialization that allow the IPT to effectively co-create the industrialized system through two fundamental axes: *(i)* ideation by self-assessment and *(ii)* referral ideation.

The IFIC ideation process is approached as an iterative process. The ideation by self-evaluation is the first axis of action within the IFIC, which focuses on clarifying the current state of the design to the IPT. In addition, at this point, the industrialization criteria are established on which the IPAs with the greatest potential to be industrialized will be evaluated. From the self-evaluation, the problems or aspects of the different IPAs that could be improved will emerge, as well as the initial proposals or ideas for improvement. Referral ideation is presented as the second axis of action, given that, at this point, it is assumed that the problems are defined from the previous stage, allowing a precise and rapid ideation process. However, this does not mean that new problems or situations that can be improved may arise. The problems identified during the process will be evaluated based on two criteria: *(i)* impact on the project; and *(ii)* the effort involved in addressing them. Likewise, ideas/actions will be evaluated by measuring their *(i)* impact on solving the problem(s); and *(ii)* the effort involved in carrying them out. Figure 3 shows how the IFIC is structured.

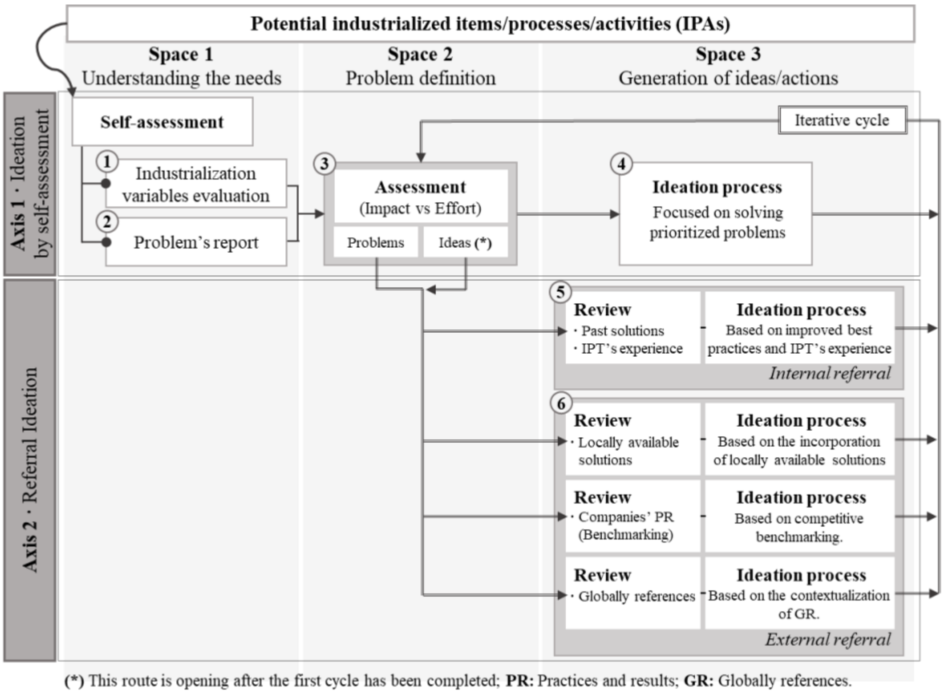

Figure 3. Proposed Ideation Framework in Industrialized Construction (IFIC).

IDEATION BY SELF-ASSESSMENT (ISA)

The focus of ISA is to generate a set of ideas/actions based on the review of the organization's internal capabilities and affectations. The ISA is composed of 2 activities:

Industrialization variables evaluation. This activity is the baseline for the subsequent steps that make up the IFIC. At this point, based on the core elements of industrialization (prefabrication, standardization, modularization), the IPT defines the criteria to be considered in the design, ensuring a framework in accordance with the requirements of the IC. Then, the prioritized IPAs are evaluated by the IPT to verify which criteria have been considered and which have not, to determine if there is room for improvement in the criteria incorporated, and define the problem in those that were not included. An immediate solution/action is proposed for problems that are easy to address. Nevertheless, subsequent activities are designed to deepen the understanding of the problems detected and to continue in the ideation process of ideas/actions.

Problem's report. The objective is to review with the IPT formal organization's problem reports of similar projects to the current one (e.g., post-sales reports), then prioritize these problems based on the incidents that *(i)* have the highest recurrence with end-users and *(ii)* have the greatest direct or indirect impact on the construction phase due to failures in the process or product developed in the design phase. Then, based on the industrialized criteria evaluation, solutions to the problems detected should be devised. Value stream mapping (VSM) is the suggested tool to assist the activity, as it allows to clearly identify the current status, identify the problem(s) and propose opportunities for improvement.

REFERRAL IDEATION (RI)

It consists of the development of ideas/actions based on what has already been devised and implemented in the IC field globally (external referral - ER) and locally (internal referral - IR). This is based on 4 key activities:

(IR)·Past Solutions and IPT's Experiences. In collaborative workspaces, the IPT highlights its capabilities and shares best practices that currently exist or that can be reused from other industrialized projects in which they participated in the past and that are relevant to solve the problems detected or improve the ideas generated.

(ER)·Available solutions. Refers to the periodic search and updating that the IPT must make of those constructive systems, materiality, and industrialized processes that are relevant at the local level and have been successfully put into practice. It also includes an exhaustive review of experiences with suppliers that work directly with the company and have a successful performance in the market. The above is intended to generate a technical sheet that facilitates the use of the opportunity detected.

(ER)·Benchmarking. It consists of comparing the company's practices/methods and results with other companies that apply industrialized principles and systems in their projects to identify differences in performance and detect successful initiatives.

(ER)·Global references. It is associated with conducting periodic technology watches at the product level and industrialized processes in the AEC industry that have been successfully implemented globally. Depending on the size of the IPA, the organization must decide whether to do it for the current project or as a cross-cutting activity at the project program level.

DISCUSSION

Due to the COVID-19 pandemic, all work sessions had to be conducted online, conducted in an interactive way through platforms such as Miro, Mentimeter, Zoom, etc. This made it difficult to fully execute the activities since many members did not feel familiar with the use of the platforms, sometimes generating frustration and demotivation. Moreover, additional work had to be done for the facilitators in terms of training before the start of certain work sessions. In addition, not having mid-level personnel within the IPT, who are the ones who generally materialize the ideas and guidelines that are established, resulted in many ideas with clear viability being left on standby. Among the important contributions, it is the ease and speed with which precise ideas and actions were generated, since within the logic of the application of the activities, once the problem was identified and defined, it was requested to co-create a solution to avoid latencies between both spaces. The virtuous circle that is generated is enriching and possibly more productive than the traditional way, where the changes between the spaces of "understanding and defining the problem" and "generating solutions" is slower.

CONCLUSIONS

The IFIC provides a framework for the generation of ideas/actions at the early stages of IC design and constitutes a multiple analysis tool since it considers temporal aspects (past, present, and future experiences) and three dimensions: people, processes, and technologies (experiences of the IPT and suppliers, problem reports, world references). This framework calls for early integration and intensifies the collaborative work among different disciplines of the project. Moreover, IFIC places the core elements of industrialization as the baseline of the design process and collects successful Lean tools/activities (e.g., A3 Report, VSM, etc.) to be tailored to the IC context and be implemented in chronological way. The context of the development of the IFIC was in projects of early incorporation into the implementation of Lean tools and methodologies. The ideas developed were very diverse in the topics related to IC: from the point of view of *(i)* management: planning, analysis, control, and improvement of processes, and *(ii)* technologies: prefabrication, robotization, automation, standardization, modularization, pre-assemblies, mechanization, and skilled labor. These management and technology approaches were implemented considering aspects to make the process systematic, repetitive, rhythmic, simpler, and more precise within a controlled environment. Nevertheless, most of the ideas generated were related to prefabrication, the area of execution, and the standardization of repetitive elements such as windows, doors, and general furniture.

A limitation of the study is the evaluation of the framework, which was done through activities (e.g., plus/delta analysis) that gather the opinions of the stakeholders and which is planned to be reinforced by measuring it quantitatively in future studies. Furthermore, the focus of the research is not on presenting the results of the practical implementation but rather on showing how the framework was structured. Therefore, future research should focus on showing practical results of IFIC implementation.

ACKNOWLEDGMENTS

The authors would like to acknowledge the funding and support provided by FONDECYT (1181648), CIPYCS, GEPUC, and Industrialized Construction Council (CCI). Also, to VRI-UC and ANID National Doctorate 2022-21220895, for funding the postgraduate studies of two authors and to companies and experts related to the research.

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