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ROLE OF COLLABORATION IN PRODUCTION PLANNING AND CONTROL IN THE CONTEXT OF MODULAR CONSTRUCTION

Louise C. Amaro [1], Carlos T. Formoso[2], Iamara R. Bulhões [3] and Alexandre Soares[4]

ABSTRACT

Modular construction projects have complexity attributes that differ from conventional projects. To address this complexity, collaboration within production units and between different units is essential, as it contributes to resilient performance. The aim of the investigation is to understand the role of collaboration in the implementation of production planning and control (PP&C) in modular construction projects, considering complexity attributes. A case study was conducted at a Brazilian modular construction company. The unit of analysis was the PP&C system developed in this company for managing construction site installations, strongly based on the Last Planner System. As a result, a list of collaborative processes for planning and controlling modular construction projects was presented. Each process was thoroughly evaluated across six categories of collaboration factors: behavior, communication, team, management, technology, and contractual aspects. Collaborative processes related to meetings addressed the highest number of collaboration categories, suggesting that these are the most collaborative processes. In a high-complexity project, as it is typical of this modular construction company, addressing the highest number of collaboration factors contributes to alignment between sectors and achieving project objectives.

KEYWORDS

Lean construction, Production Planning and Control, Modular Construction, Collaboration.

INTRODUCTION

Modularity can be defined as the decomposition of a product into subsets and components, which facilitates standardization and increases the variety of products (Gershenson; Prasad; Zhang, 2003). Furthermore, it is considered that a modular product is composed of modules consisting of independent units with their own functionalities and standardized interfaces (Miller; Elgard, 1998; Gershenson; Prasad; Zhang, 2003). These units, according to Gibb (1999), can have a high degree of finishings installed in external environments (off-site), reducing the amount of activities carried out on-site, or they can also be limited to structural components, with the remaining activities completed on-site.

1 Ph.D. Student, Building Innovation Research Unit (NORIE), Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, Brazil, louisechiarello@hotmail.com, orcid.org/0000-0002-3412-4584.

2 Professor, Building Innovation Research Unit (NORIE), Universidade Federal do Rio Grande do Sul (UFRGS). Porto Alegre, RS, Brazil, formoso@ufrgs.br, orcid.org/0000-0002-4772-3746

3 Assistant Professor, Building Innovation Research Unit (NORIE), Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, Brazil, iamara.bulhoes@ufrgs.br, orcid.org/0000-0002-1519-0455.

4 CEO, Visia Construção Industrializada, Brazil, alexandre@visia.eng.br.

A new approach for industrialized construction has emerges from the application of the concept of modularity, named Modular integrated Construction (MiC). According to Pan and Hon (2018), MiC is a disruptive and innovative approach that transforms traditional fragmented construction with site-based installations into a value-oriented process with integrated manufacturing and assembly processes, providing greater quality, productivity, safety, and sustainability, when compared to traditional construction.

Due to the benefits provided by this new approach, such as increased speed, cost reduction, improved quality of construction, and reduced environmental impacts, it has grown substantially in many parts of the world, by replacing traditional construction methods (Molavi; Barral, 2016). Unlike traditional on-site construction, MiC usually involves a broad supply chain, with a complex network of stakeholders involved, in all construction stages, such as planning, design, legal approval, site preparation, modular manufacturing, transportation, storage, and on-site installation (Wuni; Shen, 2020). In this context, in order to get the full advantages of industrialization, proper planning for modular construction is necessary, especially in ensuring that manufacturing, transportation, storage, and installation occur in a timely and integrated form (Molavi; Barral, 2016).

The application of the modularity concept, from one hand, reduce the complexity of on- site construction operations, but, on the other hand, adds complexity by the need to coordinate several production units, e.g. design teams, manufacturing plants, construction sites. According to Saurin and Gonzalez (2013), complexity in socio-technical systems involves four attributes: (i) a large number of dynamic interactions among elements; (ii) a wide diversity of elements; (iii) unforeseen variability; and (iv) resilience to deal with an uncertain and dynamic environment. Considering these attributes, it can be stated that modular construction fits into a complex socio-technical system mainly due to the large number of manufacturing, transportation, and intensive assembly procedures, as well as the high degree of uncertainty and variability among processes. Additionally, other characteristics such as project and production fragmentation, coordination of activities in the factory and on-site, delivery process constraints due to large and heavy assembly and installation equipment, coordination to ensure that manufacturing, transportation, and assembly occur in the desired sequence and time, the need for highly skilled workers and specific construction techniques, also increase the system's complexity (Jensen; Bekdik; Thuesen, 2014; Molavi; Barral, 2016).

The complexity in modular construction systems is the combination of the intrinsic complexity of the modules and the composition of the system as a whole, which affects decision-making (Alkan; Bullock; Galvin, 2021). In this context, the management of these systems must be resilient, meaning that the managerial team should respond when undesirable events occur, monitor and anticipate developments, threats, and future opportunities, as well as learn from past experiences (HOLLNAGEL, 2018). Since it is not possible to completely eliminate variability, the production planning and control play a key role in coping with complexity in a modular construction system, and can make major contributions to resilient performance.

The Last Planner System (LPS) (Ballard, 2000) has a set of practices that have a positive impact on resilient performance, such as hierarchical planning and control, identification and removal of constraints, collaborative meetings, and a combination of delay and anticipation indicators (HAMERSKI Et Al., 2023). In fact, Pourrahimian et al. (2023) emphasize that a vital component for the success of LPS implementation is collaboration among all parties involved. Additionally, LPS promotes collaboration by bringing problems to the surface timely and enabling conversations that contribute to problem solving (Skinnarland, 2012). Those practices can also contribute to develop resilience potentials.

This research work is based on the premise that collaboration within production units and among different units is essential in Production Planning and Control (PP&C) of modular construction projects as it contributes to resilient performance.

Previous studies have explored several aspects related to production management and the implementation of the Lean philosophy in modular construction. Innella et al. (2019) discuss the implementation of lean techniques in the modular construction industry, covering all production stages, based on a systematic review. Olawumi et al. (2021) analysed digital tools and technologies in modular construction and how these impact production planning and control processes. Additionally, Khodabocus and Seyis (2024) investigated risk management in modular construction projects, providing insights into effective risk management approaches, which are strongly related to production planning and control.

Lerche et al. (2020) investigated the application of LPS in modular construction in the context of offshore wind farms. That study pointed out some benefits of applying the LPS in the specific context of modular construction, emphasizing collaboration as an essential element for effective production management. However, those authors have not deeply analysed the role of collaboration within this scenario.

The research question that guided this investigation was: How to improve the role of collaboration in planning and controlling modular construction projects? Therefore, the aim of this research work is to understand the role of collaboration in the implementation of production planning and control in modular construction projects, considering complexity attributes that differ those projects from the conventional ones. The collaboration considered in this study is related to the coordination among stakeholders involved in PP&C, both within each production unit, or between them. The expected practical contribution of this investigation is to devise a framework for assessing the degree of collaboration in the implementation of production planning and control systems, while the theoretical contribution is to understand the nature of collaborative processes, considering the context of modular construction.

COLLABORATION FACTORS

Collaboration is a process that requires the involvement and integration of different stakeholders, promoting a sense of involvement and ownership. In construction projects to collaboration plays a key role in improving reliability of project planning, leading to improvements in project performance (Elsayegh and El-adaway 2021a).

Elsayegh and El-Adaway (2021a) identified and defined collaboration factors impacting construction planning, based on an analysis of literature on collaborative planning in the construction industry over the past 30 years. In a subsequent study, Elsayegh and El-Adaway (2021b) divided the 50 proposed factors into six categories: behaviors, communication, team, management, technology, and contractual aspects. Table 1 presents the proposed collaboration categories by those authors and their definitions adapted according to the respective factors.

In this investigation, collaborative practices have been analyzed from the perspective of those six categories proposed in Elsayegh and El-Adaway's (2021a) initial study. The choice of this research as a reference for the concept of collaboration is justified as it is very recent study, based on an extensive literature review on construction planning and control.

Table 1 - Categories affecting collaboration in planning (adapted from Elsayegh and El-Adaway, 2021).

Categories	Description
Behaviors	Adaptive or resistant reactions to changes, dedicated commitment to the collaborative process, influence and dependency among parties, presence of leadership, building mutual trust and respect, and continuous effort to improve the collaborative process.
Communication	Formality and effectiveness of communication, frequency and type of meetings, sharing of lessons learned, early involvement of key project participants, timely reporting and updates, constructability feedback, and stakeholder contribution to schedule development.
Team	Relationship among project parties, skills, experience, and knowledge of those involved, vision and goal alignment, team members' ability to get along, engagement and active participation, motivation and incentives, guidance and workshops, training, and promotion of creativity.
Management	Stakeholder and management involvement, centralized workplace, management and sharing of risks/uncertainties, resource sharing, continuous focus on the customer, standardization of planning practices, joint problem-solving and decision-making, use of indicators, and identification and removal of constraints.
Technology	Efficient sharing of information and technology, BIM modeling for project understanding and implementation, and the use of tools and techniques, including visual signals, elimination of visual obstacles, and procedures to maintain a clean and organized workplace.
Contractual aspects	Definition and flexibility of scope/work packages, impact of project characteristics (type, size, and complexity), and effective conflict resolution.

RESEARCH METHOD

RESEARCH DESIGN

Case study was the research strategy adopted in this investigation, as it enables exploration of social-technical phenomena in real-world settings (Flyvbjerg, 2011). This study was carried out in a company involved in the delivery of modular construction projects, named Company A. The unit of analysis was the PP&C system developed in this company for managing site installation, which was strongly based on the Last Planner system. The research was divided into three phases: (i) understanding the problem and case study selection; (ii) collecting data on PP&C implementation; and (iii) cross analysis between PP&C practices and collaboration.

In the first stage, visits to the company and participant observation in planning meetings were conducted with the aim of understanding the context and complexity attributes of modular construction projects. At this stage, two projects (A and B) were chosen as case studies. The second stage consisted of collecting data on the development and implementation of a PP&C system for the selected projects. Initially, a production system design was carried out, followed by the development and implementation of the three planning and control levels, similar to the Last Planner System (LPS). Location-based planning was used at the long term planning level.

In stages 1 and 2, the sources of evidence used were: (i) participant observations of 58 medium-term meetings and 45 short-term meetings; (ii) direct observations at the construction sites, totalling 4 visits to the site of each project; (iii) semi-structured interviews with the project A and B engineer, planning coordinator, design manager, and manufacturing manager; (iv) workshops, comprising 2 Lean concepts training sessions and 5 Plan discussion workshops; and (v) document analysis such as Line of balance; Medium-term plans; and Short-term plans.

In phase 3, a list of PP&C practices was produced, including traditional LPS practices and also some additional ones that emerged along the implementation process, some of them necessary to deal with the complexity that exists in modular construction projects. Some of these practices were associated to different hierarchical levels, although some of them were related the PP&C as a whole. Each practice was then grouped into collaborative processes, such as meetings, technological tools for visualization and information exchange, as well as problem cause analysis processes. This organization of practices occurred because some of them do not directly involve collaboration but are integral parts of processes that promote collaboration. Thus, collaborative processes were analyzed in terms of categories of collaboration factors (Table 1), proposed by Elsayegh and El-Adaway (2021b). These categories were used to understand the role of collaboration in each process, enabling the evaluation of each based on the nature of collaboration. Data analysis was based on the subjective assessment of the degree to which the processes meet the collaboration factors of each category. Each collaborative process was assigned a weight corresponding to the degree to which it meets the factors, according to the following criteria:

- Weight 1.0: a process widely used in the company and strongly meets the category.
- Weight 0.5: a process is partially used in the company and partially meets the category.

For example, the process of analyzing the causes of non-compliance with work packages is a practice that the company implements; however, they analyze the causes superficially, without providing feedback or discussing action plan in meetings. Therefore, the process is carried out partially, involving only collaboration in identifying the cause, and not in the entire cycle of continuous improvement.

- Weight 0: a process that has no relation to any factor of the category. In this case, there is no evidence in the process that it is related to the analyzed category.

The result of the analysis stage consists of a table where the rows represent the PP&C practices and their respective collaborative processes, and the columns represent the categories of collaboration factors. By summing the weights assigned to each process, it was possible to analyze the practices with the highest degree of collaboration, as they address more categories, and also the categories most addressed by the implemented processes. With this tool, it was possible to analyze the relationship between the collaborative processes of PP&C and collaboration in modular construction projects, identifying opportunities for improvement. The authors assigned those weights based on their perceptions, using the data observed during the study to substantiate their decisions. The method proposed in this study can potentially be scaled to suit various projects, companies, and development stages within the modular construction industry. In phase 3, it is possible to select more practices according to the specific context of each project or company and group them in the same way in collaborative processes such as meetings, technological tools, information exchange and problem cause analysis. Those processes can then be evaluated according to categories of collaboration factors, previously established in the literature. The selection and evaluation of collaborative processes within different scenarios allows the method to be applicable to other contexts.

DESCRIPTION OF THE COMPANY AND PROJECTS

Company A has delivered modular construction projects since 2001. It has two main types of products: (i) heavy reinforce concrete modules used for penitentiaries; and (ii) steel chassis modules for other types of buildings, including schools and hospitals. The main reason for choosing this company is the fact that a Lean Production implementation program started in 2022, including all stages of project delivery: design, manufacturing, logistics and site installation. The two projects chosen for this investigation consisted of the construction of penitentiaries. The heavy modules used in this type of project is a patented solution, consisting of volumetric units arranged laterally to a central corridor, and above this, circulation through upper walkways for exclusive use by staff. The system involves two central elements: (i) cell-type module, and (ii) walkway-type module.

Project A involved the construction of a new prison complex (1650 vacancies), including prison areas (1884 vacancies), collective living spaces for inmates, administrative and technical areas, and infrastructure, summing up an area of 15,000 m². Different types of prefabricated components were used: 3 light modules, 240 heavy concrete modules, 120 walkway-type modules, and 566 W panels. The project duration was 12 months, starting in July 2022.

Project B consisted of a demolition of an existing penitentiary in two stages, and the construction of new cells, collective living spaces, administrative and technical areas, summing up 23,250 m². The construction stage started in July 2022. The main prefabricated elements were: 366 light modules, 220 heavy concrete modules, 110 walkway-type modules, and 798 W panels. During the first stage of the project B, part of the prison was in operation. Both projects had to be built in parallel, as the remaining prisoners from project B had to be transferred to Project A after it was concluded, This added some additional elements of complexity, the interdependence between the two projects, and the constraints for access of the construction site of Project B, due to the penitentiary in operation.

RESULTS

CHARACTERISTICS OF MODULAR CONSTRUCTION PROJECTS

Several complexity attributes of production systems in the company involved in the investigation:

(i) Large number of dynamic interactions between elements: This is mostly related to the interdependence between production units. The company has two manufacturing plants serving several construction projects. Individuals involved in factories, logistics operations, construction sites, design, and supplies are constantly interacting with each other. Additionally, these elements are strongly interconnected, meaning that the action of one sector directly impacts another due to the high degree of interdependence. Another important factor is that the company carries out design, fabrication, and assembly of various projects simultaneously, which become interdependent due to resources shared between them.

(ii) Wide diversity of elements: There were different hierarchical levels and disciplines involved, such as factory coordinators, project coordinators, architects, structural engineers, construction coordinators, engineers, workers, planning analysts, suppliers, logistics coordinators, etc.

(ii) Unforeseen variability: There was much uncertainty related to site conditions, fluctuations in demand, clients' requirements, and local regulations. The combination of variability and interdependences between production units tens to propagate variability.

(iv) Resilience: It refers to the system's ability to adjust its performance in the face of expected and unexpected conditions (Saurin; Gonzalez, 2013). This is a necessary attribute to be developed in the management system in order to cope with the existing complexity.

PP&C PRACTICES IMPLEMENTED

These are the main elements of the PP&C system: (i) Production System Design (PSD): it starts with the identification of requirements for the execution of this specific type of project (penitentiaries), which is based on the experience obtained by the company in previous projects, and also on the specific requirements of the projects A and B. Its scope involves the definition of a location system, layout, overall installation sequence, workflows, logistics flows, necessary capacity of the workforce and equipment, and 4D BIM simulation. Representatives from different sectors were involved in PSD: design, factory, construction site, material supply, logistics, planning, and contract management.

(ii) Long-term Planning: Based on the PSP, a location-based plan (line of balance) for the whole project, in which the main project milestones were defined. The final definition of the long-term plan was also developed in collaboration with different company sectors and made available online to all of them. Based on that plan a set of metrics based on the status of each location was defined, for controlling cycle time, work-in-progress, project progress, and batch completeness. The Production Status Matrix, which allows check-in and check-out in each location to be informed by each crew, plays a key role in the production of those metrics. This tool was only partially implemented, due to the lack of automated and user-friendly data collection tool.

(iii) Look-ahead Planning: Hybrid weekly meetings were carried out, considering a 6-week window, to allow the participation of representatives from different areas of the company. Both individuals in charge of identifying and removing constraints were involved. Those constraints were not limited to materials and labor, but also involved logistical and safety aspects. Responsibilities for eliminating these constraints were allocated among team members, each with a deadline for resolution. Due to the lack of effectiveness in removing constraints, an analysis of the causes for the non-removal of constraints was implemented. In this process, it was necessary to justify why constraints were not removed, and the group exchanged ideas on how to solve specific problems.

(iv) Short Term Planning*:* Weekly meetings were carried out on-site, in which work packages were assigned to each crew, specifying task content and location. Those meetings typically lasted for an hour, involving the site manager, engineering assistant, and crew leaders. An online spreadsheet was used to store and make available information to everyone. Site assembly activities were planned for a two-week horizon due to the need of the manufacturing plants planning process. Traditional LPS metrics were used, such as the Percent Plan Complete (PPC), and the causes for non-compliance.

(v) General PP&C practices*:* A set of additional practices related to the planning and control process as a whole was also implemented: digital dashboards with long, medium, and short-term metrics, weekly meetings for the joint analysis of medium and short-term indicators (involving top managers), and planning different types of slack at different planning levels. Additionally, there was a weekly planning alignment meeting, in which each sector (design, manufacturing and site installation) presented the existing plans, in order to align demands and identify the possibility of adding new projects or specific activities. Regarding Visual Management, besides the dashboards, and location-based plans, several visual devices were producing, including boards for displaying plans, constraints and metrics.

After multiple planning cycles, the need for load plans emerged, mainly to formalize the exchange of information between the sectors. Due to the existing uncertainty in the projects, issues on site installation were communicated to the manufacturing plant in order to confirm the capacity to meet project demands. This plan formalizes project needs, factory production, and logistics capacity, thus reducing the information conflict generated by informal communication, often conducted via WhatsApp. This tool was shared with the sectors involved, with the aim of increasing transparency and aligning everyone's demands.

ANALYSIS OF COLLABORATIVE PROCESS

In Table 2, the results of the analysis regarding the relationship of collaborative processes with the factors of collaboration categories are presented. Results in green correspond to processes that strongly adhere to the category, those in yellow represent processes that partially adhere, and those in white indicate processes in which none of the factors were observed.

Table 2 - Relationship between Collaborative Process and Collaboration Factor Categories

	PP&C practices	Collaborative Process	Collaboration categories						TOTAL
			Behav	Commun	Team	Manag	Tech	Cont.	
Production System Design	Identification of project requirements Definition of sequencing and batches Involvement of all sectors pre-project	Meetings at the beginning of the project	1	1	1	1	0	1	5
	4D BIM simulation	Technological tools	0	0	0	0	1	0	1
Long-term plan	Location-based plan Development of a visual long-term plan Indicators for assessing time deviation	Meeting at the beginning of the project, with different company sectors	1	1	1	1	0	1	5
	Production Status Matrix	Technological tools	0,5	0	0	0,5	0,5	0	1,5
Look-ahead Planning	Standardization (routine) Identification of constraints. Participatory decision-making	Meetings to identifying and removing constraints	1	1	1	1	0	0,5	4,5
	Non-removal of constraint	Analysis of the causes	1	0,5	0	0,5	0	0,5	2,5
	Online spreadsheet of constraints	Technological tools	0	0	0	0	1	0	1
Short Term planning	Standardization (routine) Definition of work packages Backlog of work packages Participation in decision-making. PPC Indicators	Meetings, involving the site manager, engineering assistant, and crew leaders.	1	1	1	1	0	0,5	5,5
	Implementation of corrective actions	Analysis of the causes of non-compliance	0,5	0,5	0	0,5	0	0,5	2
	Online spreadsheet shared data widely	Technological tools	0	0	0	0	1	0	1

Table 2 (continued) - Relationship between Collaborative Process and Collaboration Factor Categories

	PP&C practices	Collaborative Process	Collaboration categories						TOTAL
			Behav	Commun	Team	Manag	Tech	Cont	
General PP&C practices	Weekly alignment meetings of PP&Cs	Meetings in which each sector presented the existing plans	1	1	1	1	0	1	5
	Analysis of indicators with top management	Meetings for joint analysis of metrics.	1	1	1	1	0	1	5
	Set of interconnected dashboards for control	Technological tools	0	0	0	1	1	0	2
	Introduction of different types of slack	Information sharing between sectors and levels	0	0	0	0	0	1	1
	Load planning	Tool that allows information exchange	0	1	0	1	1	0	3
		TOTAL	8	9	6	9,5	5,5	7	

Collaborative processes related to meetings addressed the highest number of collaboration categories. This is because these practices are characterized by being formalized processes (management category) and involve several participants in the PP&C process. Members are expected to commit to plans (behaviour category), exchange information (communication category), align their objectives and goals, sharing risks and uncertainties (team category), and define procedures for conflict resolution (contractual aspects category). In a highly complex project, as it is typical of this modular construction system, addressing the highest number of collaboration factors contributes to improve to an effective coordination between sectors in order to achieve project objectives.

Processes linked to technological tools for visualization, information exchange, and shared understanding mostly addressed the technology category. The company invested in visual devices in planning to support project understanding and visualization of plans and metrics. These tools included planning spreadsheets, performance dashboards, and project activity warnings. All tools were made available online, and different stakeholders had access through the company server. Additionally, interactive screens and video calls were used to support planning routines. Therefore, the transfer and sharing of updated information among project stakeholders through involved different means, such as reports, spreadsheets, dashboards, and messages, with the aim of making everybody aware of the project process.

Another important factor concerns the complexity of the project. There was a formal process of using different types of slack in order to make project delivery more reliable, such as: (i) definition of alternative assembly flows (Project B), due to potential layout restrictions; (ii) possibility of producing some precast elements on-site, (iii) inventory of some standard small-size components at the manufacturing plants (e.g. furniture); (iv) spare formwork elements, among others. Slack planning was the result of information sharing between sectors and levels, either in formal meetings or informally, including brainstorm events to solve emerging situations, especially in the construction site. The most frequently used collaboration factor category in the collaborative processes was Management, justified by the operational nature of the practices included in this category, including participation in meetings, use of metrics that contributes to everyone's understanding. The least addressed category was related to Team, as these factors have a strong social character, such as team and stakeholders' skills, experiences, motivation, creativity, involvement and empathy. These competencies are related to each individual and the relationship among team members. These criteria are essential for collaboration, although not directly identified in processes. They must be present in the company and are not easy to develop in the short term. Therefore, a key topic for future research is to develop approaches for improving these competencies among stakeholders.

Two collaboration practices have been identified as only partially ineffective, and demand further attention: (i) the analysis of non-compliance problems with work packages, and (ii) the control of production status. In the former, although teams formally identified the causes of non-completion of work-packages, this process was done very superficially, and there was not enough effort to plan how to deal with the most frequent or severe problems. Regarding the latter, the company faced problems in implementing the production status matrix, such as poor definition of the location system, late updating of the matrix, and unreliable information. These two practices, besides promoting continuous improvement, also help understanding problems and monitoring the work-in-progress in other sectors of the company. These are necessary practices for collaboration and especially for integration among different sectors of the company.

CONCLUSIONS

This research presented a list of collaborative processes for planning and controlling modular construction projects. Each process was thoroughly evaluated across six categories of collaboration factors: behavior, communication, team, management, technology, and contractual aspects. It must be pointed out that some processes stand out for strongly promoting collaboration across multiple categories simultaneously, such as the use of PSP meetings, project kickoff meetings, look-ahead and short-term meetings, weekly PP&Cs alignment meetings among different sectors, and meetings for a joint analysis of metrics. Therefore, these processes need to be maintained and improved to promote collaboration.

However, evidence showed that although most practices address some collaboration factors, there are still areas that need to be improved to ensure more effective collaboration among stakeholders, especially the Team category. In this category, processes emphasizing motivation, engagement, and increasing team's sense of belonging need to be implemented.

This study is part of an ongoing doctoral thesis that will continue to delve into the analysis of collaboration factors in PP&C practices. One of the next steps in this investigation is to do and in-depth analysis of the 50 collaboration factors proposed by Elsayegh and El-Adaway (2021a), and understand the interactions between the categories. Regarding limitations of this investigation, it must be pointed out that this article has focused on formal collaboration practices implemented in a specific company. Further work is necessary to understand the role of informal practices that also contribute to foster collaboration. Additionally, the results reported are related to a single modular construction company. This study presents an analysis of collaborative processes in the early stages of implementation of a production planning and control model, based on LPS, and the results are limited to the specific context of that company. Therefore, the proposed recommendations are specific to this context, and cannot be generalized to the entire industry. Future studies must explore the context of other companies, considering other planning practices and collaborative processes.

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