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SYNERGY BETWEEN LPS AND SLACK: A CASE STUDY IN BRAZILIAN HORIZONTAL HOUSING DEVELOPMENTS

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ABSTRACT

Construction projects are remarkably unique, given the specific nature in which their production processes are organized and the high levels of variability and uncertainty that permeate their entire life cycle. Several initiatives can be implemented to mitigate the effects associated with unpredictability in construction projects. The Last Planner System has emerged as a valuable tool to provide greater confidence in the planning of construction projects. Another practice that has been increasingly adopted in the sector is the use of buffers. Despite the incipient perception that buffers may be associated with waste, studies conducted in airports and logistics centers have suggested their use as a valuable ally in combating uncertainties and protecting the production system. Research also points to the combined use of buffers with pull planning to reduce the effects of variability. In view of the foregoing, this study aimed to investigate the use of slack practices together with the long-, medium-, and short-term plans of the Last Planner System. The investigation used as a reference the following classifications of time off practices mapped in the literature: Redundancy, work-in-progress and margins of manoeuvre. The research was based on a case study of Brazilian horizontal housing developments. The main finding highlights the synergy between the categories of time off practices found and the objectives established by each of the horizons of the Last Planner System. Furthermore, other dimensions of analysis, such as logistics, supplies, security, may arise due to the nature of the project typology, and the need for practices that mitigate the uncertainties inherent in the execution of these projects.

KEYWORDS

Lean Construction, slack, last planner system.

INTRODUCTION

Construction projects have a unique nature, characterized by distinct products, temporary mobilization of production teams, local production conditions, and the need to meet pre-established criteria of cost, execution time, quality, and risk (Ballard and Howell, 1998; Limmer,

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2008). In addition to these factors, construction projects are commonly associated with high variability and high levels of uncertainty (Formoso et al., 2021). However, as noted by Onho (1988), the basis of a well-balanced production system lies in its stability.

In the field of construction projects, the Last Planner System (LPS) has emerged as a valuable tool to ensure that the work that should be done can be done. With LPS, it is possible to manage an inventory of available work, from which teams commit to what they will do, improving workflow and increasing the reliability of construction planning (Samad et al., 2017; Ballard 2000).

In parallel, studies have proposed the use of buffers as protection measures against variability (Fireman et al., 2022). Traditionally, buffers have been viewed as a form of waste because of the lack of a clear recognition of their potential to add value to production processes. Nevertheless, their consistent application has proved to be an important ally in combating uncertainty and increasing predictability (Horman et al., 2003).

Buffers can be defined as a set of resources implemented to protect the production system against unforeseen events, fluctuations, and delays in resource availability (Alves and Tommlein, 2003). Formoso et al. (2021) and Saurin (2017) introduced the concept of slack. Although related to the buffer approach, slack practices, in addition to addressing uncertainty aspects, contribute to meeting demands or actions at a more strategic level. Buffers are mostly recommended for dealing with random variability that can undermine production goals (Büchmann-Slorup, 2014).

Previous studies described slack as a leading element in combating variability. Fireman (2018) assessed the influence of slack on work standardization in the construction environment. Saurin et al. (2021) discussed practical applications, requirements, and consequences of using slack according to strategic orientation and resource availability.

Recent studies have explored the application of slack resources and practices in construction, focusing on large-scale projects such as airport terminals and logistics centers. The investigations aimed to establish an association between slack and LPS-based planning and control methods, particularly in the context of pull planning, to effectively manage variability (Fireman et al., 2022).

Based on the study of Fireman et al. (2022), who proposed the slack practices and resources (SPR) model, this research aims to investigate the use of slack concepts and their consonance with LPS practices for reducing variability and protecting production systems in the context of horizontal housing developments in Central-Western Brazil.

SLACK

Lean construction focuses on minimizing non-transformative steps (waiting, inspection, handling), especially through reduction of variability (Koskela, 2000). As pointed out by Hopp and Spearman (1996), variability is defined as the lack of uniformity of a class of entities, which can be random (equipment downtime) or systematically observed in a given system (product diversity).

The literature contains some discussions on the subject. Ballard (2001) discussed the impacts of slack on cycle times, underscoring gains in reliability and, consequently, reduced variability. Saurin et al. (2013), in studying guidelines for managing complex systems, noted that slack contributes to absorbing the impacts of variability. Slack can take various forms, such as redundant equipment, underutilized space, excess labor, and time margins; however, it may potentially mask problems and obscure system inefficiencies.

The role of slack practices in supporting organizations to deal with variability has been discussed and associated with different managerial processes (Fireman et al., 2022). Saurin and Werle (2017), in a literature review, analyzed slack in sociotechnical systems and proposed a structured framework to better understand slack practices, their uses, and categories (Table 1).

Based on the framework of Saurin and Werle (2017), Fireman et al. (2022) investigated how slack practices and/or resources can be used in production planning, demonstrating their positive effects in mitigating variability at different hierarchical levels (long-, medium-, and short-term planning).

LPS

LPS improves the reliability of activities in the short term, functioning as a shield against variability in planned work and promoting workforce engagement through increased collaboration of the work teams that integrate the decision process (Ballard, 1994). In LPS, planning is structured on three levels. At the lowest level, what will be done is the result of the planning process that best aligns what should be executed (planned) with what is possible to be executed based on constraints imposed by the scenario (Ballard, 1994). The medium-term plan (six-week look-ahead) determines the path to achieve these objectives, identifying and removing constraints and ensuring that resources (materials, information, and equipment) are available for task execution (Ballard, 1994). The master plan focuses on global objectives and constraints, addressing the project as a whole and describing what should be done.

Table 1: Slack practices (Saurin and Werle, 2017)

Practice	Definition	Subcategory	Definition
Redundancy	Resources in addition to the minimum necessary to perform a function (Nonaka, 1990) or more than one resource performing the required function (Azadeh et al., 2016).	Standby	The redundant resource is not immediately involved in the task at hand, and is typically not present in the operator's immediate environment (Clarke, 2005).
		Active resource	The redundant resource is involved in the task at hand (Clarke, 2005).
		Redundant procedures	Redundant checks are made to detect failures, usually involving different professionals and types of inspection (Ong and Coeira, 2010) and alternative procedures to execute an activity (Saurin and Werle, 2017).
Work-in-progress	Resources waiting to be processed in between process steps and stages.	Simultaneous work zones	Number of simultaneous work zones in a construction site. They offer alternative activities to keep the teams busy in case of temporary stoppages in one or more work zones (Bashford et al., 2003; Sacks et al., 2010).
		Stock of materials	Stocks of semi-processed products, raw materials, and finished products (Saurin and Werle, 2017). The latter two types are interpreted here from an expanded view of work-in-progress (i.e., raw materials are waiting to be processed, whereas finished products are waiting to be delivered to customers).
Margins of maneuver	Practices that create or maintain margins that allow the system to function despite unexpected demands (Saurin and Werle, 2017).	Defensive practices	Practices that create or maintain margins that allow the system to function despite unexpected demands (Saurin and Werle, 2017).
		Autonomous practices	Practices restricting other units' actions or borrowing other units' margin (Stephens et al., 2011).
		Coordinated practices	Practices that recognize or create a common-pool resource from which two or more units can draw (Stephens et al., 2011), such as multifunctional workers or general-purpose machines (Fireman et al., 2018).

RESEARCH METHOD

METHOD DESCRIPTION

Certain factors must be considered when selecting the research strategy. These include the type of research question, the extent of control the researcher has over events, and the emphasis on historical or contemporary events (Yin, 2003). According to Yin (2003), a case study approach is recommended for research with exploratory characteristics or descriptive aspects in a real and contemporary context. It should be noted that this research method has some inherent limitations regarding result generalization, as its focus lies on seeking an analytical understanding and interpreting facts within the studied context (Costa, 2010). This study aims to understand how slack practices and resources are applied in the context of horizontal housing developments. Thus, a case study approach aligns well with the research theme.

The data were collected by an auxiliary researcher, who acted as a consultant in the studied project. The company where the study was carried out had no previous experience with LPS. The consultant provided guidance on the development of long-, medium-, and short-term plans, logistics plans, and control routines and offered training and workshops for indirect workers. The consultant's role in the project was not that of a decision-maker; rather, the role focused on ensuring the implementation of core LPS practices and facilitating the identification of waste during planning phases. The consultant remained in the project for approximately 9 months, being 4 months for the development of long-term and logistics plans and 5 months for the formulation of medium- and short-term work routines.

The content of this study is divided into four parts: (i) a brief contextualization of the theme, (ii) a description of the chosen company and its characteristics in the context of lean implementation, (iii) an overview of the data collection process and the researchers' contributions to the project, and (iv) a presentation of the findings from the case study.

THE SELECTED COMPANY AND CONSTRUCTION PROJECT

The research was conducted in a Brazilian construction company founded in 1986. The company specializes in residential civil construction, specifically in medium- and high-end buildings and horizontal developments (residential lots) (Figure 1). The company has launched 37 projects, resulting in the construction of 22 million m^2 over its 35 years of history. Recently, the company has expanded its operations to include house construction projects.

Figure 1: Illustrative image of the horizontal housing project (source: the authors)

The project selected for the case study is a horizontal housing development with 626 units and 37,000 m^2 built. The project has a total duration of 25 months, starting in October 2022 and predicted for completion in December 2024.

DATA COLLECTION

The data used in the research were acquired by the auxiliary researcher during the consulting process of the study project. The data sources included documents generated in the period and participant and non-participant observations. There were no major difficulties in data collection, as the consultant had direct access to project plans, control documents, and work routines.

The **analyzed documents** included long-, medium-, and short-term plans; minutes of meeting with contractors; logistics plans, including site layout and zoning studies of inventory areas and equipment; constraints identified in weekly meetings for medium-term planning; weekly plan spreadsheets and daily monitoring spreadsheets of production leaders' goals.

Participant observations were conducted by the consultant, who integrated the planning team responsible for drafting all stages of long-term and logistics plans for the project. Although actively engaged in discussions, the consultant lacked decision-making authority. The consultant also took part in about 20 medium-term planning meetings addressing issues related to the construction staff and support sectors, and participated in approximately 60 daily meetings for monitoring weekly goals.

Non-participant observations were carried out weekly during visits to the site. These observations involved monitoring practical aspects in progress, such as instances when a supplier truck was used to transport material kits. Observations also included reviewing documents produced during the consultant's absence. Of note, the consultant did not partake in all short-term planning meetings where weekly goals were defined.

From this, the time off practices consolidated by Fireman et al. were used as a reference. (2022) seeking to identify the action, map the practice of time off and classify the variability and resources involved.

RESULTS

LEAN IMPLEMENTATION

The lean implementation process began in April 2022 with the structuring of the long-term strategy and logistics plan for a single project. Lean planning introduced the concept of work packages, whereby it is possible to create work scenarios that take into account pace variations, activity durations, and labor histograms. A total of five scenarios were created, with participation of about 15 professionals from Operations, Planning, Budget, Projects, and Strategy departments. The company's top management ultimately chose the optimum version in terms of time and cost.

Scenarios were generated using the time path tool in zoomed view and the line balance tool in the most detailed version. Each version incorporated variations in productivity based on the rainy periods of the city. The site is situated in a region prone to intense rainy periods lasting up to 5 months per year. This reduction in productivity was subsequently transformed into time spaces between work packages. At this point, the first slack was identified, categorized as redundancy (standby).

After the long-term plan was developed, the next step was to promote the diffusion of lean concepts within the organization and create work planning and monitoring routines. LPS served as the basis for unfolding the masterplan into medium-term, short-term, and daily routines. Medium-term routines involved collaborative planning with the company's support sectors, with goals and restrictions defined over an 8-week horizon. Short-term routines, referring both to weekly schedules and daily hurdles for goal monitoring, were prepared by the production team together with outsourcing labor supervisors.

An important component of the work planning routines was the inclusion of work logistics as an essential part of the production process. Given that the project is a horizontal development, the logistics of supplying work fronts played a key role in ensuring productivity. The horizontal displacement of production leaders was physically demanding, making it challenging to effectively manage materials and staff across all fronts. Therefore, logistics leaders were involved in the formulation of medium-term plans, weekly work planning routines, and daily monitoring routines.

Currently, lean implementation has become a significant pillar within the company's restructuring process. Placed under the coordination of the planning sector, it encompasses all five ongoing projects of the company and is centered on reducing variability, enhancing the stability of the production system, and meeting deadlines.

CASE STUDY

The study included team members who had participated in the project since the development of the long-term plan. The production manager, production engineer, engineer, and planning assistant and logistics coordinator also participated in this study. Therefore, it can be said that the team was highly qualified to identify and evaluate opportunities for slack practices in all planning horizons (long, medium, and short term) and the logistics of the project.

The key element of medium- and short-term planning was work packages. All work fronts were designed to allow observation of package evolution, as well as supply and kitification routines. This view was essential for decision-making by site managers when identifying priorities and points to be strengthened in day-to-day management.

Thus, in this research, the analysis was segmented into LPS horizons, namely long, medium, and short terms. Furthermore, a separate analysis was carried out for on-site logistics, given the importance of its integration with planning.

LONG-TERM PLANNING

Long-term breaks were mainly associated with periods of intense rainfall during project execution (Table 2). In this scenario, protection against time variability was achieved by the insertion of waiting times between work packages to ensure that work fronts would not be interrupted by incomplete predecessor tasks.

Table 2: Description of slack practices in long-term planning (source: the authors)

ID	Instantiations of slack practices	Slack practices	Variability tackled by slack practice	Slack resources	Unintentional consequences
1	Use of a generator to cover power shortages	Redundancy – active	Possibility of receiving more energy from the supplier	Financial	None
2	Insertion of waiting times between work packages in long-term planning	Redundancy – standby	Delays in predecessor tasks negatively affect successor tasks, delaying the schedule	Time	None
3	Worker accommodation camp larger than necessary to meet a potentially greater labor demand than initially planned in the resource histogram	Margins of maneuver – autonomous	Lack of dining area infrastructure could result in last-minute mobilization of labor	Space	Increase in worker camp infrastructure
4	Schedule final deliveries before the customer's deadline	Work-in-progress – stock of materials	Protection against unforeseen events that could influence the delivery date	Time	None
5	Project coordinator acting as the resident engineer for the training of new members	Redundancy – active	The project coordinator worked together with the resident engineer to develop technical tasks for the new team member	People	None
6	Use of productivity estimates lower than the historical average in the masterplan	Margins of maneuver – defensive	Possible low performance of the production team	People	None
7	The purchase of extra production equipment was considered in the budget to replace contractor equipment	Redundancy – active	Ensure that third-party labor does not remain idle due to equipment shortage	Equipment	Extra space for equipment storage

Aiming to protect against time variability, the planning team decided to use productivity indicators below the company's historical series, foreseeing the potential waste that would occur in these periods. In another scenario, early delivery dates were set as a goal for the production team to generate a greater sense of urgency in decision-making.

Two other slack practices were adopted by the company with the aim of (i) ensuring quick actions against time variability (e.g., by designing a worker accommodation camp with a greater capacity than that estimated by the initial labor histogram to ensure quick mobilizations, if necessary) and (ii) preventing or eliminating idleness at work fronts (e.g., by having own inventory of tools to equip third-party labor teams when they, for some reason, had a shortage of equipment).

MEDIUM-TERM PLANNING

For the medium-term horizon, slack practices were mainly characterized by production protection (Table 3). For instance, third-party labor teams were mobilized from other projects to compensate for newly integrated teams during their learning cycle.

Table 3: Description of slack practices in medium-term planning (source: the authors)

ID	Instantiations of slack practices	Slack practices	Variability tackled by slack practice	Slack resources	Unintentional consequences
1	Preemptive kit assembly	Work-in-progress – stock of materials	Delays could impact tasks requiring these resources (kits)	Materials	Increase in the area for kit storage
2	Resident engineer acting as a backup front-line production leader	Redundancy – standby	Engineer acting as production leader to compensate for the lack of front-line supervisors	People	None
3	Spare third-party teams mobilized from other worksites to support the learning curve of new teams	Redundancy – standby	Spare teams to support the possibly low productivity of new teams	People	Temporary increase in logistics demand
4	Company designer developed a formwork plan because the contract designer delayed plan delivery	Redundancy – active	A delay in plan delivery could delay the beginning of the work	People	None
5	Purchase of raw material from secondary supplier to cover delays in delivery from the main supplier	Redundancy – active	Delay in material delivery could lead to idleness on work fronts	Materials	None
6	Integration training carried out together with labor teams from other construction sites to speed up possible future mobilizations	Redundancy – standby	Delays in work tasks that would require team mobilization	People	None
7	Alteration of wooden formwork plans for columns to facilitate assembly at the work front	Margins of maneuver – autonomous	Low productivity of the carpentry team	Projects	Additional demand placed on the design team
8	Alteration of the prestressed beam layout to facilitate the assembly of electrical installations embedded in the slab	Margins of maneuver – autonomous	Low productivity of the electrical team	Projects	Additional demand placed on the design team
9	Intended accumulation of concrete tasks to achieve the minimum volume of the concrete mixer truck	Margins of maneuver – autonomous	Achieve the minimum volume for concrete delivery	Materials	None

In another situation, because of a delay in material supply by the primary supplier, the procurement team purchased materials in duplicate from another supplier to ensure that successor work packages would not be penalized by a shortage of resources. In both cases, resource redundancy was deliberate to maintain the production pace.

As a margin of maneuver and to protect production, the company's project team had unscheduled demands when a layout plan did not have sufficient efficiency in production. As a result, plans had to be revised to increase labor productivity, as was the case when column layout plans were revised to increase the productivity of carpentry teams and when layout plans for prestressed beams were revised to increase the productivity of the slab installation team.

SHORT-TERM PLANNING

Short-term breaks were taken mainly to ensure the uninterrupted flow of teams and the rhythm of work packages scheduled in weekly meetings with production leaders (Table 4). The practices categorized as margins of maneuver had greater prominence. For instance, a team of masons was allocated to a carpentry front to prevent idleness. Also for this purpose, the excavation backhoe originally used for digging infiltration wells was mobilized to the bobcat front, as the latter had to undergo unscheduled maintenance.

Table 4: Description of slack practices in short-term planning (source: the authors)

ID	Instantiations of slack practices	Slack practices	Variability tackled by slack practice	Slack resourc e-es	Un-intentional consequen-ces
1	Implement Saturday work schedules	Margins of maneuver – autonomous	Low productivity during weekdays	Time	Direct and indirect overtime costs
2	Plan alternative activities to prevent teams from idling in the event of delays in the predecessor task	Work-in-progress – simultaneous work sites	Delay in the predecessor task	People	None
3	Carpentry teams from column production fronts redirected to the slab front to offset any delays	Redundancy – standby	Carpentry teams working on columns are used as reinforcement for the slab team to compensate for delays	People	None
4	Backhoe for digging infiltration wells being used to replace work carried out by bobcat on foundations	Margins of maneuver – coordinated	Backhoe being used to replace equipment under maintenance	Equip-ment	None
5	Mobilization of a concrete truck from a third-party supplier to make up for unavailability of the company's concrete plant	Margins of maneuver – autonomous	Third-party supplier providing concrete during maintenance of the local plant	Materials	None
6	Resident engineer inspected the quality of tasks carried out after the production leader verified the service	Redundancy – redundant procedures	Tasks completed without being inspected for quality	People	None
7	Deployment of mason teams to the column carpentry service to offset delays	Margins of maneuver – coordinated	Idle workers	People	None

Slack practices were also carried out to ensure compliance with short-term goals, as noncompliance could lead to delays in medium- and long-term goals. For example, work was scheduled on Saturdays to recover goals not reached during the week. A third-party concrete mixer truck was deployed to compensate for the absence of the construction company's own truck, thereby ensuring the supply of concrete to the work fronts.

LOGISTICS

The adoption of slack practices was observed in processes depending on supply logistics, particularly margins of maneuver involving equipment used to transport materials. For example, a ¾-ton truck supplying kits was used to supply steel column starters. A backhoe digging infiltration wells was used to move earth from other work fronts.

Slack practices related to work in progress (stock of materials) were also identified. A buffer area was planned for the storage of raw materials, and material kits were delivered before the planned deadline. These slack practices were adopted to ensure that labor teams or work fronts would not run out of materials, protecting production against equipment failures and delivery of third-party raw materials (Table 5).

Table 5: Description of slack practices in construction site logistics (source: the authors)

ID	Instantiations of slack practices	Slack practices	Variability tackled by slack practice	Slack resources	Unintentional consequences
1	¾-Ton truck adapted for installation kits being used to supply steel column starter	Margins of maneuver – coordinated	Mobilization of new equipment for unloading at new work sites	Equipment	None
2	Use of supplier's pick-up truck to transport small volume materials	Margins of maneuver – autonomous	Mobilization of new equipment for unloading at new work sites	Equipment	None
3	Storage areas designed with buffer zones for the delivery of raw materials	Work-in-progress – stock of materials	Delays in the delivery of raw materials by suppliers could impact work sites	Space	Increase in the storage space for raw materials
4	Forklift adapted to assist in unloading raw materials delivered by the supplier	Margins of maneuver – autonomous	Equipment can speed up the unloading of materials from suppliers	Equipment	None
5	Workers aiding the Munck truck mobilized to the assembly of steel column starter kits	Margins of maneuver – autonomous	Support labor used in the absence of supplier labor	People	None
6	Backhoe for excavating infiltration wells allocated to moving excavated soil from other work sites	Margins of maneuver– autonomous	Equipment being used in the absence of supplier labor	Equipment	None
7	Preemptive provision of kits to work fronts to safeguard against unforeseen logistics equipment issues	Work-in-progress – stock of materials	Equipment-related unforeseen events can result in shortage of materials at work fronts	Materials	None
8	Deduct one hour when calculating the productivity of supply logistics equipment	Margins of maneuver – defensive	Possible unscheduled downtime of machines and equipment and possible low performance in meeting demands	Equipment	None
9	Construction leader verifies the number of material kits delivered and checked by the warehouse team	Redundancy – redundant procedures	Delivery of kits with missing components	Materials	None

CONCLUSIONS

This research portrayed how slack practices and resources can be used to reduce the impact of variability in the context of horizontal residential developments. On the basis of the classification proposed by Fireman et al. (2022), a case study was conducted for the identification, classification, and analysis of slack practices and resources.

The following chart shows all slack practices mapped in this study for each LPS horizon and logistics (Figure 2). The LPS production planning tool allowed structuring the analysis into three planning horizons. Horizons comprised slack practices of different natures.

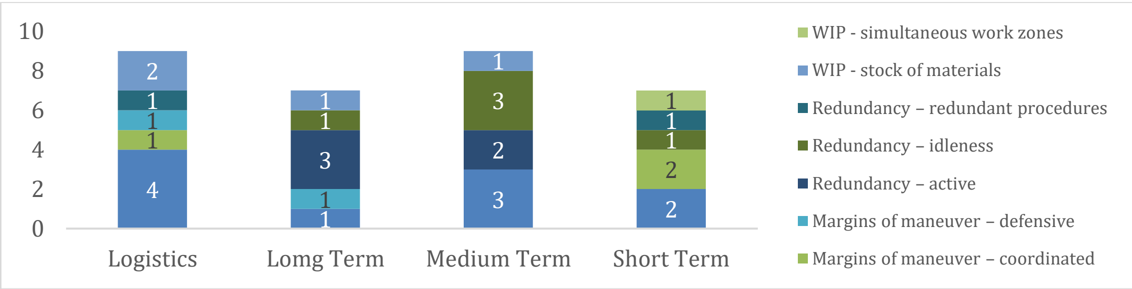

Figure 2: General distribution of slack practices mapped in this study (source: the authors)

In the long term, redundancy slack practices were the most prominent, used to ensure the continuous flow of labor teams. In this horizon, the main slack resources were time and people. The medium-term horizon was characterized by a variety of slack practices. The main practices were redundancy (active and standby) and margins for maneuver. This scenario converges directly with the main objectives of the planning horizon, as its focus is to provide greater reliability to the production system and protect production via resource availability. People and materials were the major slack resources. In the short-term horizon, autonomous and coordinated margins of maneuver were the main slack practices. This finding suggests prior alignment towards safeguarding field teams by taking immediate actions to address daily unforeseen events, avoiding the loss of short-term work packages.

Finally, according to the characteristics of the studied project, logistics was identified as a key element for the effectiveness of long-, medium-, and short-term slack practices adopted to protect production. Therefore, we conducted a more in-depth analysis of this area. There was a greater focus on the acquisition, organization, and distribution of materials and/or equipment, as evidenced by autonomous margins of maneuver and work-in-progress (stock of materials). Another concern of logistics was ensuring availability of equipment in all distribution operations. Such concern was evident by the various actions focused on optimizing equipment use in the supply of materials and inputs.

This study demonstrated how LPS and slack practices and resources interact to protect variability, and how other dimensions of analysis can arise depending on project characteristics, such as logistics, safety, and supply. The uniqueness of this case study is a limitation of the research. The stage of maturity of LPS implementation might have hindered the clarity of horizon objectives by construction teams. Furthermore, because it is an ongoing project, it was not possible to clearly evaluate the results and impacts of slack practices and resources identified in project planning.

Future research should analyze a greater number of developments with similar characteristics to gain a deeper understanding of the use of specific slack practices and resources, leading to more reliable recommendations and improved project outcomes. Furthermore, comparing these results with other similar studies can provide good considerations regarding the use of SPRs for the management of construction projects.

Additionally, there is an opportunity to investigate the infrastructure stage of the project, as our study focused solely on the housing execution phase. A quantitative/qualitative analysis of the impact of slack practices and resources should be carried out to investigate the effectiveness of actions. Finally, given that logistics played a significant role in slack practices and resources, further studies should assess their impacts on LPS horizons.

It was possible to observe that slack practices span across all LPS horizons; depending on the nature and typology of the project, other relevant horizons may arise to protect production against variability. Logistics emerged as a critical element, given the characteristics of the studied construction project and the strong influence of logistics actions on the horizons of the production system as a whole.

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