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TAKT AND PULL ZONES IN THE CONSTRUCTION OF LOGISTICS WAREHOUSES

Gustavo Bridi Bellaver[1], Bernardo Martim Beck da Silva Etges[2], Lauro Henrique Alves Rego[3] and Luis Staudt[4].

ABSTRACT

This article will describe how the application of lean philosophy tools in the construction of logistics warehouses can offer new perspectives on project planning, promoting clearer and more visual communication, collaboration, and decision-making processes. this article investigated the use of takt and pull planning methods for the development of an integrated management system for logistics warehouses located in different Brazilian cities. Takt planning of scheduled activities decreased waiting times, leading to a reduction of approximately 8% in the execution time of construction works. Other benefits included greater team engagement and participation in activity planning and sequencing. Two takt zones (repetitive elements) and one pull zone (non-repetitive elements) were demarcated at each construction site, which were planned using line balancing as a unifying element. This strategy facilitated visual management by the field team, ensuring that the entire planning process flowed through the actors actively involved in carrying out the work. In a questionnaire-based survey, construction teams reported great improvements in planning, work comprehension, and coordination between work fronts, as well as improvements in visual management and collaboration. The responses indicated a notable shift in how the field team approached planning and conceptualized their work and demonstrated that the incorporation of takt and pull planning concepts was essential for achieving these results.

KEYWORDS

Last Planner System, Lean construction, Logistics warehouses, Pull planning, Survey, Takt planning

INTRODUCTION

The desire to increase construction productivity is driven by the sector's known inefficiency in transforming raw resources into commodities and the importance of building or infrastructure development for economic growth (Hussain & Al-Turjman, 2021), so more than More than ever, strategies to redesign the production chain, analyze internal and operational processes and seek alternatives and opportunities to produce increasingly more efficiently are objectives of organizations seeking to sustain themselves and grow in the market (Sage et al., 2012).

[1] M.Sc. Civil Engineer, Project Manager, Climb Consulting Group, Porto Alegre, Brazil, gustavo@climbgroup.com.br, https://orcid.org/0000-0002-4937-5861

[2] PhD Candidate, M.Sc. Eng., Founding-Partner at Climb Consulting Group, Federal University of Rio Grande do Sul, Porto Alegre, Brazil, bernardo@climbgroup.com.br, orcid.org/0000-0002-3037-5597

[3] Civil Engineer, Quality Control Coordinator, LOG Comertial Properties, Belo Horizonte, Brazil, lauro.henrique@logcp.com.br, https://orcid.org/0000-0002-9519-2644

[4] PhD Civil Engineer, Consultant, Climb Consulting Group, São Leopoldo, Brazil, luis@climbgroup.com.br, orcid.org/0000-0002-2398-2102

In this context, more recent studies present a wide range of Lean Construction tools to reduce waste and improve production efficiency, which can be used depending on the type of construction or integrated. Zhang and Chen (2016) bring lean techniques and practices that were brought from lean manufacturing, such as daily meetings, Kanban and value stream mapping, in addition to the Pull Planning methodology of the Last Planning System (LPS) concept presented by Silva, Etges and Pereira (2022), which the application in construction brought considerable benefits in meeting deadlines in the construction of buildings.

Takt Planning, Haghsheno et al. (2016) defines it as a methodology that can also result in increasing the stability of the production system in activities with repetitions. It is widely used in various production processes, such as bridge construction, underground construction, tunnel construction and excavations, due to its repetitive work package characteristics, which is why the use of a Takt becomes highly relevant (Haghsheno et al., 2016). Also according to the authors, there are restrictions on the use of this tool in buildings, since often not all floors and the layout of environments are designed identically, and these conditions make greater preparation and planning necessary to integrate the different areas into one. Common takt. In this sense, Formoso et al. (2011) states that the focus should be on the causes of losses, rather than trying to monitor or control the consequences of losses in production, using techniques and tools that have greater adherence to the construction typology and the objectives sought.

Bringing this scenario to the construction of warehouses, Mora (2016) highlights that it is an area that maintains the same concern in the real estate segment, seeking to offer design and construction solutions with appropriate attributes in terms of quality, deadlines and agreement. with the needs of potential customers. Kamaruddeen et al. (2020) presents in their study research results on several modular warehouse construction projects around the world, only 30% of projects can be completed on time, while the rest have experienced delays. In addition to having an impact on excess costs, delays also cause other impacts, such as customer dissatisfaction.

Therefore, this article aims to study the applicability of the Pull and Takt Planning tools in the construction of logistics warehouses as they have previously been identified as the most suitable methods for this type of construction and as the most appropriate alternative to resolve the problem of difficulty in complying with the construction schedule identified, in addition to the perception of a gap that currently exists due to the lack of studies on lean thinking practices in this construction model.

To achieve the research objectives, the work was divided into three main stages, the first being a literature review on the warehouse market in Brazil in order to understand its relevance, and the Takt and Pull planning methodologies. The second stage consisted of structuring the methodology, with the elaboration of strategies for applicability to the phases of building a warehouse, and the third stage, the application of practices in the field in a unified way in works in progress, in order to obtain and evaluate the performance of the work, in addition to the perception of engagement of those involved. The results could be compared to other constructions that do not use the methodology, and, finally, it was possible to conclude that adoption of the practices provided an 8.3% reduction in the total construction time, in addition to contributing to better management, visibility the direction and stability of production.

THE LOGISTICS WAREHOUSE MARKET IN BRAZIL

Poletto (2011) defines that logistics warehouses are enterprises developed in a large area already subdivided, in which these industrial or logistics lots are organized and sold for this purpose, containing infrastructure of paved roads suitable for supporting heavy loads and vehicle traffic, guides , gutters and sidewalks, rainwater galleries, sewage collection and treatment system, drinking water network, electricity and public lighting, signage, and even preserved green areas, where each company or investor is responsible for the construction of their own shed. According to the author, within this type of enterprise, warehouses are commonly built by investors who seek to rent them to an end user.

Mora (2016) observes that currently the development of the Brazilian market for logistics condominiums has adjusted to the new demands and needs of the logistics market, due to the demand for competitiveness and efficiency present in the operation of companies and business segments that rely on large logistics infrastructures, including large storage centers.

Recent data from a survey by specialized consultancy Colliers (2024), concluded that the 51 projects delivered throughout the year added 2.3 million m² to the country's existing inventory, surpassing the mark of 25 million m² of high-end logistics condominiums throughout the national territory, an increase of 10% in the São Paulo region. With the expectation of a fall in interest rates in Brazil throughout 2024, the market is expected to register new acquisitions of logistics assets, making clear the importance of implementing production strategies in this area of construction to monitor the viability of these projects.

TAKT PLANNING

The influence of assembly line principles on building construction was first observed during the construction of the Empire State Building in New York City in 1930. The project emphasized the need to achieve continuous production, accomplishing construction cycles of one pavement per day. This systematic approach not only marked a significant transformation in the construction practices of the time but also established a paradigm for efficiency and productivity in the construction industry. The cost, execution time, and safety indicators of the project were markedly better than those of any comparable enterprise. Thus, the project stood out for its technical innovation and brought significant benefits to civil construction (Kenley and Seppänen, 2010).

As argued by Haghsheno et al. (2016), takt implementation provides increased stability for production systems, contributing to reducing inventories and waiting times between activities, while optimizing transportation through continuous flows. Takt planning is of utmost importance for effective synchronization between different areas, ensuring that individuals operate at an agreed-upon pace. According to Hopp and Spearman (2008), takt time planning provides a standardized time for the execution of each activity in the production line, leading to synchronization of individual deliveries. Adequate definition of the daily production quota provides greater predictability and stability for supporting sectors, while mitigating the influence of variability in customer demands. Frandson, Berghede, and Tommelein (2013) defined takt time as the unit of time within which a product must be produced in order to match the demand rate. Haghsheno et al. (2016) emphasized the importance of understanding the production process and its delivery milestones for defining work packages, including the scope of each action area and the sequencing of activities.

It is possible to determine the takt time of a logistics warehouse project using the equation proposed by Reck and Fireman (2023) (Equation 1). The takt time is mainly influenced by the following three variables: the time available for project execution, the number of slots, and the number of service packages. Additionally, the equation includes a practicability coefficient referring to project-specific uncertainties and characteristics, such as climatic uncertainties. As pointed out by Binninger, Dlouhy, and Haghsheno (2017), the takt time should not be understood as a fixed number applicable to all projects; rather, the takt time should be specific to each project, accounting for its particular characteristics and boundary conditions.

$$\text{Takt time} = \frac{\text{Available time} \times 80\%\ \text{Practicability}}{(\text{Repetitions} + \text{Number of activities} - 1)} \qquad \text{Equation 1}$$

A work package, as described by Haghsheno et al. (2016), represents the subdivision of a construction project into smaller areas, which helps to structure and quantify the activities that need to be carried out at each location. The duration of each work package and batch should be similar, thereby providing a stable rhythm to the construction process, with fewer restrictions. Binninger, Dlouhym, and Haghsheno (2017) stated that one of the goals of lean is to reduce batch sizes and individual production times. However, the definition of takt time also depends on the variability and stability of the construction system. Thus, because of the high level of instability of construction processes, a weekly takt is typically adopted. The more refined the takt time, the higher the level of uniformity and control required in the enterprise.

The purpose of lean construction, takt planning, and takt control is to achieve continuous and uniform processes, creating value-generating activities with equal durations throughout the entire process chain (Binninger, Dlouhy, and Haghsheno, 2017). As observed by Haghsheno et al. (2016), takt implementation is particularly relevant for processes that occur frequently and exhibit significant similarity throughout the project. Haghsheno et al. (2016) also underscored that, for the implementation of the takt system to produce positive results, it is essential to ensure that all activities have been completed as planned at the end of each cycle. This enables the uninterrupted execution of subsequent activities, promoting gains in productivity through workflow simplification and transparency.

PULL PLANNING

Pull planning is an LPS tool initially designed to improve productivity. Its conceptual framework was later redirected to creating predictable workflows and fostering rapid learning in various fields associated with civil construction, such as programming, design, construction, documentation, and project delivery (Kalsaas, Grindheim, and Læknes, 2014). Tvedt (2020) described pulled planning as one of the latest additions of the lean thinking toolkit whose function is to create a reliable flow of work across a team of experts.

As noted by Kalsaas, Grindheim, and Læknes (2014), pull planning originates from the master plan, which contains the project's delivery milestones. Similar to takt planning, the project is subdivided into slots, serving as control areas and providing rhythm to work fronts. This approach enables a more efficient and synchronized management of activities throughout the entire project.

As outlined by Tiwari and Sarathy (2012), reverse planning is the subsequent step following the identification of the main project milestones. The method starts from the final delivery and retraces all steps back to the present moment, mapping out the work required for project completion. This approach supports a more detailed understanding of critical steps and activities involved in project development. Kalsaas, Grindheim, and Læknes (2014) complemented the description of the pull planning approach, highlighting the importance of using visual elements in routine management, such as planned start and end dates. These elements generate a clear and accessible representation of the project schedule, making it easier to understand and track planned milestones.

Tsao, Draper, and Howell (2014) described pull planning as a tool that promotes collaborative planning, in which solutions for project execution are reached jointly. Tvedt (2020) underscored that the critical point for success is the collaborative participation of experts, enabling interaction with different perspectives, reducing waste, and anticipating difficulties. Tiwari and Sarathy (2012) argued that pull planning allows building a transparent environment that is empathetic to the difficulties of other team members. This facilitates communication and generates a sense of trust and belonging.

As noted by Silva, Etges, and Pereira (2022), with the development of a transparent environment in which people participate in decision-making and are aware of the team's problems, activities are carried out with greater agility. In this environment, an action plan encompassing the restrictions and potential risks that may impact production is developed. This plan defines deadlines and responsibilities for the solution of the identified points, contributing to efficient management of issues that may arise throughout the project.

Kalsaas, Grindheim, and Læknes (2014) underscored that traditional planning is often long and complex, requiring a large volume of pages and graphics, making it difficult to identify the status of the enterprise with regard to its schedule. Tiwari and Sarathy (2012) reported that pull planning helps the team to build a comprehensive, transparent, flexible, and collaborative planning process in a simplified way. This agile and transparent approach to planning allows for a clearer and more accessible understanding of project progress.

METHODS

Action research was the methodological approach adopted in this paper. Action research focuses on solving real problems (O'Brien 1998) and contributing to the organization's development, being based on simultaneous and collaborative action and research (Coghlan and Brannick 2001). The model was defined on a construction site and replicated in four other warehouse construction sites in Brazil. In each project, the model was adapted to the specific needs of the work site. All figures shown in this work are from the same warehouse, where the pilot was done. Considering the action research, the current paper aims to bring insights from a real case study connecting pull and takt zones for planning of non-repetitive and repetitive activities and the benefits perceived by its participants. After the planning intervention was applied in five work sites, a survey was sent to the involved team members such as managers, engineers, analysts and assistants (n = 43), and 39 individuals completed the questionnaire, representing a 90.7% response rate.

The studied company, herein referred to as Company A, has existed for more than 15 years as one of the largest developers of logistics assets and warehouse rental companies in Brazil. Currently, it has more than 1 million m² of built logistics warehouses in 16 states and 34 cities in the country. The company has eight ongoing developments, corresponding to 365 thousand m2, and delivered 600 thousand m2 of gross leasable area in the last two years. Company A constantly invests in improving product quality, using the best market practices to offer an integrated operation to its customers. Several solutions based on technology and innovation are provided. Nevertheless, up to the beginning of this study, the company had not had contact with lean philosophy or LPS tools. Project planning was carried out in the central office using Gantt charts and sent to worksites.

RESULTS AND DISCUSSION

A typical logistics warehouse facility includes the warehouse itself, which can be modularized to meet specific customer needs, auxiliary facilities for warehouse operation, such as cafeteria, changing room, and guardhouse, and infrastructure networks (INs) for the warehouse and auxiliary facilities. Thus, aiming to promote integrated management based on lean and LPS principles, we defined a model for the planning and management of tasks carried out in the warehouse, outdoor environments, and auxiliary facilities.

The first stage in the development and implementation of the lean management model was defining the macroflow of activities in the three lines (warehouse, INs, and auxiliary facilities). For this, a construction team comprising engineers, analysts, master builder, and construction coordinator was formed for the sequencing of activities and definition of work packages. This step was carried out collaboratively, using sticky notes to promote team engagement and facilitate visual management of the activity. After work package sequences were defined, the tasks included in each work package were described in detail to enhance the understanding of the process and sequencing. Each work package became a line in a line of balance (LOB) and the sequence of those packages served as the sequence of lines in the LOB in the activity planning stage.

Having analyzed in depth the projects of the different ventures of the company, it was understood that takt time was applicable to logistics warehouse and IN activities, which have repetitive elements in their design. Previous works using takt planning in non-repetititve labour have shown a high risk of losing effectiveness in field due to a lack of knowledge of information about productivities, means and methods, defining identical labor content for the trades (Linnik, Berghede and Ballard, 2013; Tommelein, 2017). Therefore, for auxiliary facilities, the focus would be to apply pull planning strategies, given that activities were slightly repetitive and slots differed greatly in workload, for that reason, we could treat them as non-repetitive elements in a pull planning section.

The company had a very large focus on the warehouse and had good control over its activities; however, the other areas received less attention and planning. With the advancement of planning, an integrated vision of all areas was developed, aiming toward work assertiveness. Table 1 depicts the factors evaluated in this study.

Table 1: Evaluation of work zones

Criterion	Takt zone: warehouse	Takt zone: IN	Pull zone: auxiliary facilities
Repetitive unit	Yes	Yes	No
Clear constructive sequence	Yes	Yes	Yes
Possible to determine the rhythm of each slot	Yes	Yes	No
Integrated view of the project (before/after)	Yes / Yes	No / Yes	No / Yes

TAKT ZONE

Takt was applied to enhance production stability, maintain the rhythm of activities, reduce waste, and reduce the total time of project execution. This section explains the repetitive elements aspects in constructing a logistics warehouse.

Takt Zone: Warehouse

The first line to be planned was the warehouse, as it is the core of the project and must be delivered as soon as possible for customers to adapt the facility to their needs to being operation. Logistics warehouses are designed for modularization, so that they can be rented to more than one customer. According to the project designs, warehouses are created as repetitive modules (for rental purposes) that can be compartmentalized in the future if needed. Each module consists of a leasable storage area, reception, and loading docks. It was clear to the project team that the leasable lots would be takted. However, the lots were too small for some activities (e.g., subbase and base execution); therefore, two leasable lots were used for the planning of one slot. When estimating the takt time for the activities (Equation 1), it was observed that dividing by two lots was relevant for several ventures in the company. With this method, the takt time was close to one working week, representing an easy time measure for everyone on the project. The standard slot was defined as 4 lots and 2 sublots for leasing, two receptions, and part of a mezzanine.

The first stage of the process was to prepare the list of quantities for each slot. The list of quantities was not detailed in this step, corresponding to large volumes of work. This was made so as to identify the workload of each work package within slots in the established takt time. This method allowed obtaining the metrics to be controlled on a day-to-day basis. Subsequently, a scheme was drawn on the warehouse layout containing all lots and the quantities of all work packages to be managed (Figure 1).

Takt Zone: INs

The environment surrounding the warehouse, comprising underground and aboveground networks, pavement, and landscaping, posed challenges, primarily contributing to the failure to meet the delivery deadline. IN always differs across worksites because of differences in land type, land size, neighborhood, number of auxiliary facilities, state legislation, and many other factors that influence the project. To identify the rhythm required to meet the client's deadline, it was first necessary to determine the division of areas for takt.

The team decided that areas should be divided so as to meet an attack plan focused on a single work front (designing a train of activities passing through the lots). Lots were designed with area divisions as similar as possible. The aim was to create the most homogenous possible quantity of work for activities passing through lots within a week. Activities would pass to the following lot only after being completed to guarantee adequate starting conditions for the following team. This division ensured a very effective allotment of activities from construction of the subbase onward, given that work quantities were divided by area. Another positive outcome was the good division of lots in underground networks, as many networks run parallel to the warehouse, generating a similar workload to be managed under a takt approach. Therefore, the repetitiveness aspect of the project was satisfied again and takt time would be the methodology to go for. The lot division is shown in Figure 2. The lot layout was drawn and the list of quantities was prepared to obtain monitoring metrics and allow the sizing of teams and equipment.

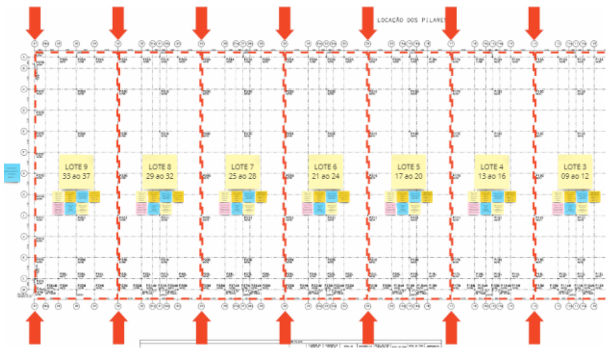

Figure 1: Warehouse layout and lists of quantities for takt time implementation

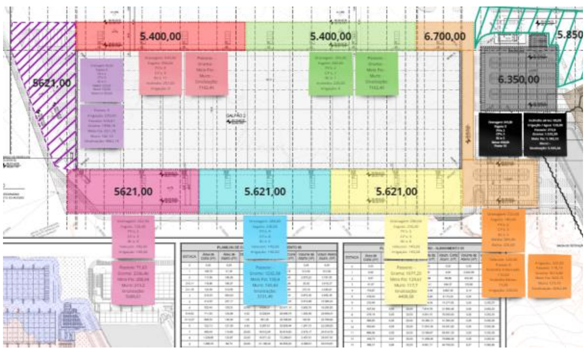

Figure 2: IN Layout and list of quantities of external areas for takt time implementation

PULL ZONE: AUXILIARY FACILITIES

The design of auxiliary facilities (comprising cafeteria/leisure area, changing rooms, reception, truck driver support, water tower, pumping station, measuring booth, and reuse water station) was approached differently. The first step was to prepare all lists of quantities for tasks defined in the macroflow of auxiliary facilities, per building. Not all work tasks were carried out in all buildings (e.g., installing ceramic flooring in the water tower); therefore, takt implementation would be difficult because of the non-repetitive aspect of this activities. As a result, it was decided to apply pull planning for auxiliary facilities, in a collaborative way with the team.

The sequences of work packages were defined by the team. Milestones for the delivery of materials with long lead time and the final work deadline were defined. With this information, the pull planning session began. On the basis of estimated team productivity rates, the necessary deadlines for each work package were determined, defining the work plans of the facilities.

INTEGRATED MANAGEMENT MODEL

Given that two different methodologies were used for planning, it was essential to unify them into a single model for integrated management of the entire project. Visual management is crucial to increase team engagement, communication, understanding of goals, and general alignment of teams to meet deadlines and customer demands. Thus, a LOB was used for unification of plans and visual management of lines.

The union of these methodologies and the definition of visual tools, increasing the transparency of the process, considering the takt phase and the pull phase, proved to be a great gain for the project and a new methodology that can provide a new way of visualizing planning. Not following just one methodology, but using the best of both and generating concise information that adds value to the construction team.

For this, a grid panel was mounted on the wall, and sticky notes were used to construct the lines of balance, being visible to everyone in the room. The columns represented weekly time horizons. The vertical axis was divided into three lines: warehouse (green notes), IN (red notes), and auxiliary facilities (yellow notes). Slots were distinguished by an additional axis used for writing dates. Thus, takt planning was unified with pull planning (Figure 3). The lower part of the panel shows activities differing in the degree of sequencing.

Figure 3: Lines of balance contemplating takt and pull planning zones

SATISFACTION SURVEY WITH THE CONSTRUCTION TEAM

At three months after the beginning of the last project, the construction team was asked to answer a questionnaire to evaluate their perception of value of planning based on lean, takt, and pull methods. The survey contained seven questions rated on a 5-point Likert (1 = lowest level; 5 = highest level). Table 2 presents the questions, their score frequency, and their mean score. An additional item (multiple choice) was used to evaluate whether participants believed the proposed planning tool, together with its philosophy and methodology, to have contributed to other areas of their day-to-day work. The answers are shown in Figure 4.

Table 2: Questions and answers about the process of implementing collaborative planning with takt and pull zones in logistics warehouse construction

Question	Score frequency (%)					Mean
	1	2	3	4	5	
Rate your participation and use of the proposed tools	0%	0%	10.3%	33.3%	56.4%	4.46
Rate your level of understanding of lean construction	0%	2.6%	7.7%	43.6%	46.2%	4.33
Rate the improvement in your understanding of project planning	0%	0%	2.6%	33.3%	64.1%	4.62
Rate the improvement in your understanding of possible interferences between different work packages	0%	2.6%	5.1%	35.9%	56.4%	4.46
Rate the importance of takt planning for collaborative planning	0%	0%	20.5%	28.2%	51.3%	4.31
Rate the importance of pull planning for collaborative planning	0%	0%	17.9%	38.5%	43.6%	4.26
Rate the benefit of viewing warehouse, infrastructure network, and support facility plans in the same tool	0%	0%	2.6%	25.6%	71.8%	4.69

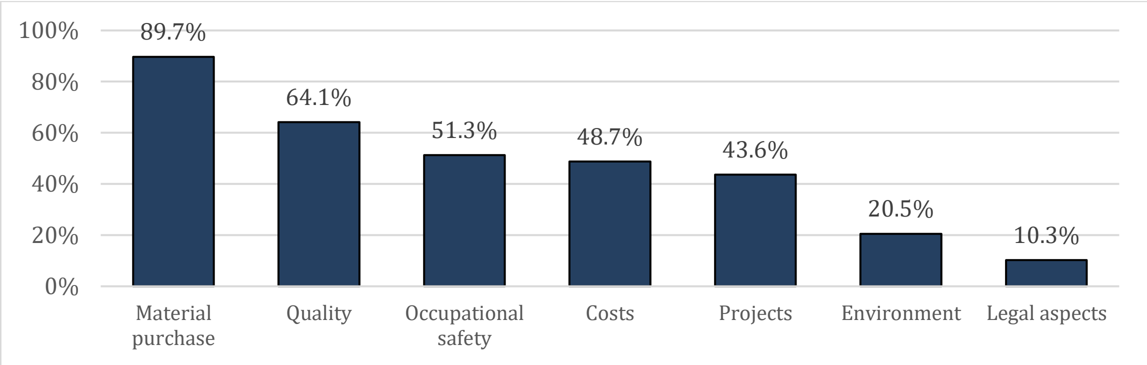

Figure 4: Areas that benefited from integrated planning, as identified by participants

The results showed that the construction team valued the planning strategy. The highest score (5) was attributed to all questions by many participants. The team reported a significant improvement in the planning and understanding of the construction project, as evidenced by question 3: 97% of participants rated the item with a score of 4 or 5. In question 4, concerning the improvement in participants' understanding of interference between work packages, 91% of respondents attributed a score of 4 or 5. The concepts of takt and pull planning were essential for the development of lean, collaborative, easy-to-understand plans. Takt and pull planning concepts were deemed very important (score of 4 or 5) by 80% and 82% of respondents, respectively. Finally, 97% of the team gave high importance (score of 4 or 5) to being able to visualize the different plans in the same visual management tool.

The majority of respondents (35 out of 39) reported improvements in material purchase with the use of integrated management plans. This assertive, visual, collaborative planning method allowed anticipating purchases and visually identifying needs when working together with other routines implemented in the project. The planning technique was also reported to improve quality and occupational safety. The importance of knowing how to identify what is needed to perform a given activity in its fullness, coupled with routines of activity monitoring, was valued by the team. Benefits to cost control were also perceived by participants. Knowing what was happening, what would happen, when, and why improved the understanding of the current situation and the possibility of obtaining better results. Regarding projects, identification of deadline dates well beforehand and their discussion with the multidisciplinary team were valued by participants. The other possible benefits were given minor importance. Therefore, it can be said that lean, takt, and pull concepts not only contributed to project management but also added value to several other areas of the construction project.

The mean scores for planning improvement criteria, represented by items 3, 4, and 7, were 4.62, 4.46, and 4.69, respectively. The overall score of the three items was 4.59, demonstrating that the team had a completely different perception about the way of thinking and executing the work. Questions regarding takt and pull planning concepts had mean scores of 4.31 and 4.26, respectively, demonstrating the importance of these concepts to the team, greatly changing the way of planning and thinking about the project. The findings confirm the importance of these planning tools for construction management.

CONCLUSIONS

Before the implementation of the integrated planning and management system based on takt and pull planning, the team used the Gantt chart as the sole planning tool. All efforts were concentrated on the warehouse, in detriment of external areas and auxiliary facilities. As a result, the company faced average delays of 3.8 months in the delivery of these additional areas after warehouse delivery. With the application of the proposed techniques, the team had a greater engagement with planning goals and metrics and there was a greater involvement of front-line actors. Participants gained understanding of the steps to be executed and greater commitment to the plan because they felt included in its development, not perceiving it as something imposed by another sector or board. The use of the LOB as a centralizing tool of information and guidance for the field team was of great value and increased the clarity of goals, constructive sequences, and future steps. Furthermore, the LOB served as a basis for the planning of medium- and short-term routines in LPS, which were developed on site for better production management and stability.

As a result of the proposed planning, the first executed project had a 4-week shorter delivery date than the previous project (12 months). This is equivalent to a reduction of 8.3% in the total project schedule. For this type of enterprise, there are three major projects occurring in parallel that need to be executed to meet the client's short deadlines. Their visualization helped improve the team's understanding of what is and should be happening on site. The concepts have been applied in other projects. Takt planning proved to be very effective for lots with similar workloads, facilitating the understanding of what was expected by teams on a daily and weekly basis. In activities that varied greatly in quantities between lots, the method did not provide good results, because their planning was not feasible. In these cases, pull planning was a good strategy to ensure compliance with the deadline, engage teams, and plan collaboratively and assertively.

The questionnaire aimed to provide insight into the perceived value and comprehension of the proposed concepts by the construction team. The results indicated an enhancement in the team's understanding of project planning. The method made it easy to understand the influence of a work front on other fronts. It improved visual management, collaboration, and understanding of subsequent steps, goals, and the required rhythm of each work front to meet the client's deadline. In addition to planning, the proposed method brought benefits to material purchase, work quality, occupational safety, cost control, and adherence to time schedules.

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