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INTEGRATING STANDARDIZED WORK AND PRODUCTION STATUS CONTROL TO SUPPORT LOCATION-BASED PLANNING AND CONTROL

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ABSTRACT

Standardized Work (SW) is an approach to standardize and improve the efficiency of operations cycles. SW can support the implementation of Location-Based Planning and Control (LBPC) by balancing workload between workers, synchronizing different processes and allowing early identification of deviations. Digital technologies can support the implementation of SW by providing real-time feedback to support project monitoring, communication, and information management. The aim of this research work is to propose a model that integrates SW and production status control by using existing digital technologies to support LBPC. Design Science Research (DSR) is the methodological approach adopted in this investigation. The study initially focused on the collaborative identification of critical interrelated activities to implement SW. Then the integrated control model of SW and production status was proposed with the support of visual management devices and digital technologies. As a result, it was possible to effectively synchronize and balance the resources of a set of interrelated activities, increasing the stability of those activities. Therefore, the model can be used as a mechanism to manage variability in LBPC and increase the degree of process standardization while having short cycles of feedback to promote continuous improvement.

KEYWORDS

Location-Based Management (LBM), Takt planning (TP), standardization, production status control, digital technologies.

INTRODUCTION

Standardization is a key managerial mechanism to reduce process variability. In construction, standardization is often focused on achieving compliance with standard procedures, based on the traditional idea of finding the best way of performing an activity, with little emphasis on continuous improvement (Saffaro et al., 2008). By contrast, in the Lean Production Philosophy, standardization is focused on the operations performed by workers (Martin & Bell, 2017) and is known as Standardized Work (SW) (LIB, 2003). SW is an action-oriented procedure in which detailed instructions are established for each operator's work in operations cycles (Ohno, 1997). These procedures lead to the standardization of operations (Mariz, 2012) and are the basis for

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continuous improvement (Liker, 2004). Ohno (1997) suggests that there are three necessary elements for SW: (a) takt time – time available for production, based on customer demand (Alvarez & Antunes Jr., 2005); (b) standard sequence of operations – sequence of steps performed by each worker within a cycle time[5] (Monden, 2011); and (c) standard inventory – minimum amount of items needed in the process that allows the operator to work efficiently (Ohno, 1997). In addition, Fireman et al. (2018) pointed out that slack must be defined when designing SW for any activity and that the existing variability of construction operations must be considered.

Takt time has been strongly related to Location-Based Planning and Control (LBPC), which can be defined as a planning and control approach that makes explicit the workflow and the relationship between construction activities, time and work zones (Olivieri et al., 2019). LBPC involves a set of techniques, including the line of balance (LOB), which represents the master plan (Ballard & Tommelein, 2021). The major benefits of the LOB are that several concepts related to the Lean Production Philosophy are explicitly used, such as batch size, work-in-progress, cycle time and rhythm of processes (Schramm et al., 2006).

SW is a collaborative effort aiming to standardize operations cycles to reduce variability, which plays a critical role in the synchronization of processes. Therefore, different crews can achieve similar cycle times by balancing the workload between different workers or teams and aligning them with an established takt time (Mariz, 2012). Although SW is one of the most important aspects of the Lean Production Philosophy, it is still underutilized in the Construction industry (De Bortoli Saggin et al., 2017). In fact, previous works on LBPC have not emphasized the opportunity of using SW to support the synchronization of processes by using collaborative planning meetings (Binninger et al., 2017).

Moreover, the growing complexity of construction projects has demanded the adoption of digital technologies to support project monitoring, communication, and information management (Bryde et al., 2013). Current data collection and monitoring systems depend on on-field personnel, which is time-consuming and error-prone (Golparvar-Fard et al., 2011; Son & Kim, 2010), while people should spend time analysing progress and metrics, detecting deviations and problems early (Fullerton & Wempe, 2009). Therefore, there are opportunities for using digital technologies to improve progress monitoring, by providing real-time feedback on the status of the production system (Kropp et al., 2018) to improve the capacity to respond and adapt to expected and unexpected changes (Hollnagel et al., 2006).

Therefore, alternative and complementary controls to support existing planning and control approaches are needed to deal with the dynamic nature of construction (Hajdasz, 2014). Controlling production status can potentially increase transparency and promote better communication between trades, which, according to Lehtovaara et al. (2021), must be considered in LBPC approaches. Additionally, technology can be used to monitor construction progress and production status, e.g., 360º cameras attached to hard hats connected to data management cloud platforms (Kropp et al., 2018).

Accordingly to Koskela and Howell (2008), job dispatching consists of assigning a task ready for execution to a crew and communicating this assignment as authorization to start work. However, this procedure is generally done by oral communication (Koskela & Howell, 2008). So, there is an opportunity to develop planning and control models that adopt digital technologies to formally assign workers to tasks and workstations, enhance understanding of planned work and increase commitment.

Studies that address SW in construction (De Bortoli Saggin et al., 2017; Mariz, 2012; Tommelein & Emdanat, 2022) have not explored a broader perspective of the SW basic elements (e.g., sequence of steps, location flows, slack), and neither explored its integration

[5] Cycle time depends on the production capacity and corresponds to the time elapsed between the beginning and end of a cycle to complete all operations (Alvarez & Antunes Jr., 2005).

with production status control with the support of digital technologies. This integration can potentially increase the degree of standardization of production cycles, increase the efficiency of operations, and contribute to the synchronization of processes. So, this research aims to propose a model that integrates SW and production status control by using digital technologies to support LBPC.

RESEARCH METHOD

Design Science Research (DSR) is the methodological approach adopted in this investigation. DSR seeks to produce scientific knowledge (Holmström et al., 2009) while solving problems faced in the real world (March & Smith, 1995) and contributing to theoretical developments (Kasanen et al., 1993). The artifact proposed in this investigation is the production management model, which results from the combination of LBPC, SW and production status control with the support of digital technologies. This research work was based on an empirical study carried out in a Brazilian company involved in the development and construction of residential and commercial building projects, named Company A. This company is well-known in the market for the successful implementation of Lean Production practices and had implemented the Last Planner System for more than 15 years. The main company's motivation to take part in this study was to increase the degree of standardization of critical processes. This study occurred between January and September 2022.

The empirical study was divided into four phases: (1) assessment of the existing planning and control system; (2) analysis of data and proposition of the model; (3) implementation and refinement of the model; (4) evaluation and final discussion. The first phase consisted of understanding the existing situation in one of the company's construction sites. The planning and control system was assessed, and several Quality Management System (QMS) documents were analyzed. Moreover, some workers and site logistics operations were monitored, and critical processes and improvement opportunities were identified. The research team proposed the model in close collaboration with the company's managers. The development and test phase occurred through iterative learning cycles of data collection, analysis and reflection, in which the solution was implemented and collaboratively improved. During the implementation phase, the artifact was evaluated, and at the end of the study, the proposed model's practical and theoretical contributions were identified.

PROJECT DESCRIPTION

The project comprised a residential tower and a commercial area of 15.341,13m², which started in September 2020 and was expected to finish by March 2023. This study focused on the 15-floor residential tower built on structural masonry and internal drywall partitions. Thirteen floors had the same layout, containing 12 apartments. The apartments had between 56m² and 67m² of private area and were divided into three typologies. The apartments had similar work densities, which provided an ideal base to devise and implement the planning and control model proposed in this investigation. The study was performed during the finishing phase when the interior drywall partitions were almost finished.

EMPIRICAL STUDY STEPS AND SOURCES OF EVIDENCE

The assessment of the existing planning and control system included site visits, participation in planning meetings and interviews. Consequently, important aspects were analyzed: building systems adopted, the Location Breakdown Structure (LBS), production batch sizes, the volume of WIP, visual devices to support planning and control, direct observation of vertical and horizontal material transportation operations, layout and stocks. Moreover, the master plan was translated from a Gantt Chart into a LOB using a LBPC software. As an outcome of this stage, some improvement opportunities were identified: the need to plan, standardize and synchronize critical activities based on the SW concept, and introduce the production status control with the support of digital technologies. The **analysis of data and proposition of the model** were focused on a set of critical processes, which were selected according to the following criteria: (a) a high degree of variability; (b) a large number of interdependent activities; (c) about to start activities. A protocol for direct observation of the 3rd, 4th and 5th floors' ongoing activities was applied, and semi-structured interviews with workers were carried out to map the work content of those critical activities (cycle time, sequence of operations and requirements to perform an operations cycle). Data collected included the floor location flow followed by workers, the number of workers and their distribution within the floor, the actual cycle time for each worker to execute each apartment, the trade's floor cycle time and existing procedures. Based on that data, a qualitative and quantitative analysis was conducted to compare work-as-imagined and work-as-done. The improvement propositions included a standard sequence of operations, a detailed division of work zones, a new cycle time for operations, and a production pace for the processes. The digital solutions adopted were: (a) 360° camera mounted on a hardhat and connected to a mobile app to perform offline captures and upload to a cloud-based platform to monitor actual construction progress on the web browser or app; (b) tablets to update production status, collect activity progress data, which trigger quality inspections; and (c) andons to monitor workers' check-in and check-out at different locations and to control the amount of WIP. The andon device was not used as a tool to stop the line when problems occurred and manage production alerts.

The **implementation and refinement** stage started by training managerial and production teams on key lean topics (e.g., LBPC, takt time, batch size, SW and production status control). This training also enabled managers and workers to operate digital technologies and visual devices. The implementation process focused on committing the workers to standard production cycles. Managers, researchers, and team members involved in the critical activities discussed the SW proposal in a collaborative meeting. The conversation focused on discussing the proposed standard production cycles and showing possible earnings they would have if they committed to the plan. Site visits were then made to observe the work performed, monitor production status, and discuss and refine the proposed standard. Finally, in the **evaluation and final discussion** phase, performance metrics were analyzed: the amount of WIP, apartment and floor cycle time variation, production pace deviation and batch adherence. Workers' and management team feedback was collected, and the artifact was then evaluated based on utility and easiness of use criteria, as suggested by March & Smith (1995).

Table 1: Summary of sources of evidence

Phases	Time Spent	Sources of Evidence
1- Planning System assessment 2- Improvement propositions	17 hours 30 min	Direct and participant observations; Semi-structured and open interviews; Document analysis; Photos.
3- Implementation and refinement	46 hours	
4- Evaluation and final discussion	6 hours	Participant observations; Semi-structured interviews

RESULTS

ASSESSMENT OF THE EXISTING SITUATION

The transcription of the existing master plan into a LOB (Figure 1) pointed out some problems: (i) not enough time gaps (buffers) between processes; (ii) limited process synchronization as cycle times varied from three to ten days; (iii) the continuous product flow was emphasized, focusing on executing tasks as soon as possible, and causing workflow interruptions.

A set of five critical interrelated activities was chosen for the implementation of SW: ceiling plaster lining, waterproofing, mechanical protection, and wall and floor ceramic tile (Figure 1). The site manager pointed out that keeping this set of activities on time was challenging. A major cause of this problem was the high amount of WIP: work was spread over several floors, and there were site congestions of different teams working in the same location.

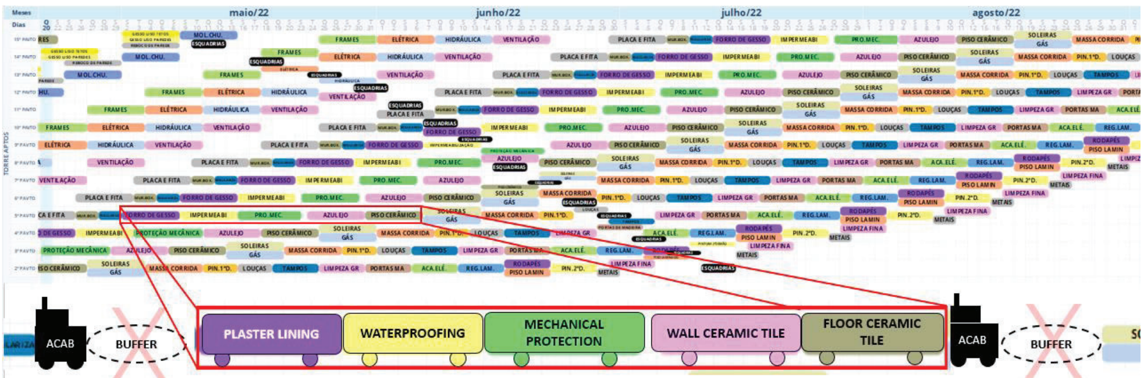

Figure 1: Master Plan and the set of critical interrelated activities selected

Figure 2a and 2b compare the initial plan and the projection of the production pace, based on existing performance, for the set of critical activities. The following problems were detected: (a) the actual production paces were different from the master plan; (b) there was a 24-day delay in the starting day of the set of critical activities; (c) waterproofing and plaster lining were being executed in parallel which caused some interferences between crews; (d) wall and floor ceramic tile actual cycle time was 16 days, i.e., longer than the 10-day planned duration; (e) wall and floor ceramic tile were planned to be executed in sequence while executed in parallel, and based on the projected production pace tendency it was not going to finish within the established deadline (September 1st 2022).

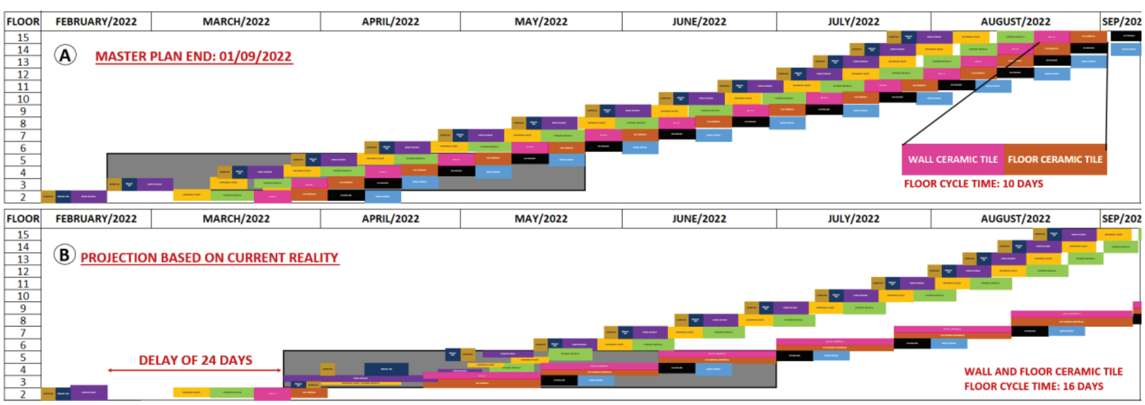

Figure 2: (A) Master plan and (B) Projection based on current reality

Standardized Work Proposal

Based on the identified delay trend, mostly related to the execution of the wall and floor ceramic tile, a future state plan was proposed considering ideal cycle times (Figure 3). The five critical interrelated activities were merged into three activities: (1) ceiling plaster lining; (2) waterproofing and mechanical protection (3) wall and floor ceramic tile. For these three critical interrelated activities, a 5-day floor cycle time was considered as well as a new crew size definition. This research paper focused on the wall and floor ceramic tile activity, as this was the one that had the highest impact on the existing delay. By implementing these improvements the new projected conclusion of the set of activities was August 19th 2022, which represented a reduction of two weeks' duration compared to the master plan.

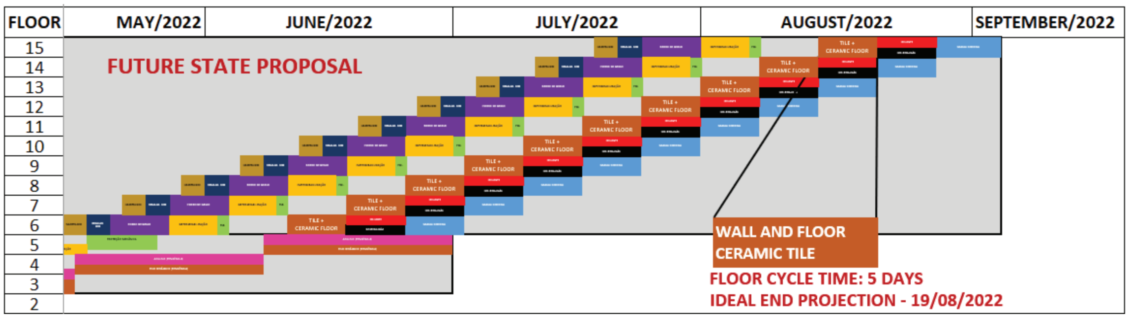

Figure 3: Future State Proposal

In order to implement SW, the future state proposal needed to be detailed, observing actual cycle times, necessary production and setup times, execution alternatives and good practices informed by workers. The aim of this stage was to balance the amount of work among crews to reach the takt time of five days per floor and synchronize the processes. Figure 4 shows the current state of the wall and floor ceramic tile, which makes the number and distribution of workers into work zones (Y-axis), durations (X-axis) and location flows explicit. It highlights that the actual floor cycle time is sixteen days, while it was planned for ten days.

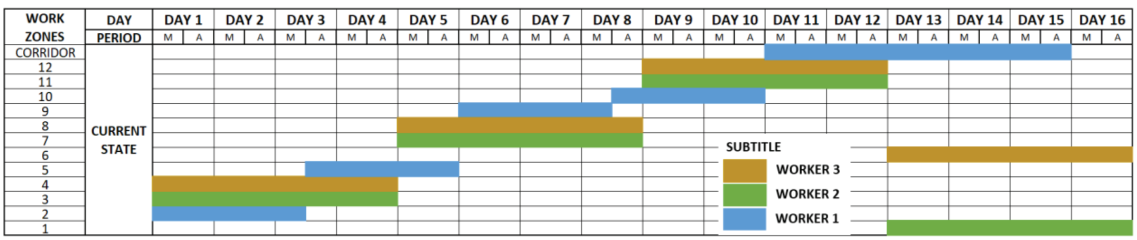

Figure 4: Current State – Wall and floor ceramic tile

The current state of each critical activity was initially discussed with the site manager and the subcontractor. Based on that, a new crew size was established. After that, the distribution of work was discussed with the workers involved in the task, resulting in the proposal of the first version of the SW. This proposal comprised the elements: takt time, worker cycle time, standard floor location flow, followed by workers and standard sequence of operations in each apartment. In the second version of the SW proposal, some types of slack were included. Figure 5 presents the SW sheet for wall and floor ceramic tile.

In order to commit workers to the implementation of SW, managers and researchers promoted a meeting with all of them to discuss the plan and explain the benefits to all parts. It was emphasized to workers that they would benefit from better working conditions, increase in the learning effect and production predictability, and consequently, raise their earnings.

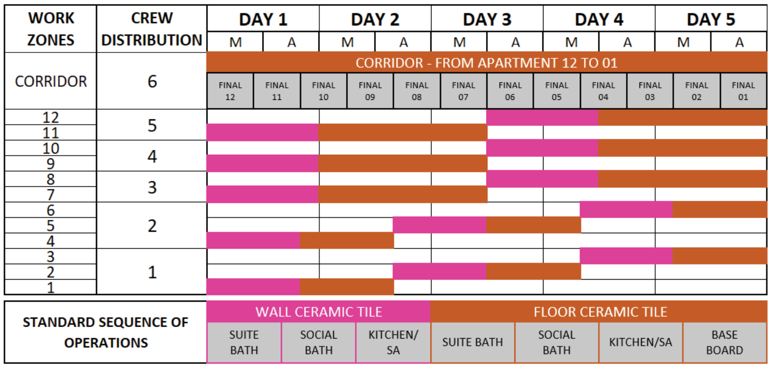

Figure 5: First Standardized Work Proposal – Wall and floor ceramic tile

INTEGRATION OF STANDARDIZED WORK AND PRODUCTION STATUS CONTROL

After defining the SW, control routines were proposed to achieve takt time and synchronize interrelated activities. The LBS played an important role in defining production control cycles. The company was used to allocate crews to floors. However, it was decided to reduce the production batch size to one apartment to make it easy to control each operation flow of each apartment (12 apartments per floor) and perform quality inspections. Nonetheless, the production pace control was still being controlled per floor (13 floors total) so that it could be compared to floor takt time. Reducing the batch size was important to improve the commitment of crews to the location flow and to encourage them to take proactive measures to achieve the proposed apartment cycle time. This was named hierarchical work zone control, as different work zone levels enabled different location-based controls.

The inclusion of different types of slack was due to the need to cope with the variability in workers' productivity, as teams used to work in a fragmented way. The main types of slack adopted were: multifunctionality of some subcontracted crews, time buffers, and space buffers, e.g., apartment and corridor areas to be produced which had no worker assigned by the one that finished their assigned apartments before the floor takt time.

With all these decisions, visual devices, digital technologies and control routines were implemented to promote transparency and increase understanding and commitment to plans and standard working routines. Figure 6 shows a visual device used on each floor to make production goals explicit for each worker of ongoing activity (apartment takt time, time and buffer, location flow and standard sequence of operations). Other visual solutions were also adopted: workers' names were written close to the entrance door of the assigned apartment, and spray was used to mark the best sequencing of ceramic installation to encourage repetition in operations.

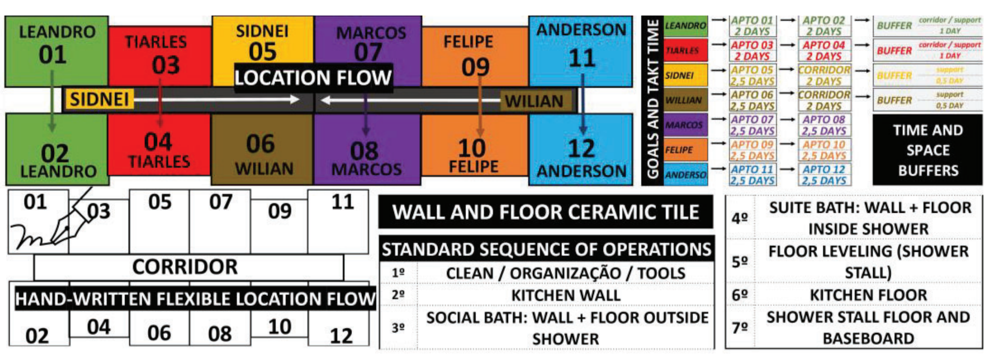

Figure 6: (1) Visual device that displays batch sizes, workers allocation and location flow, apartment takt time, time and space buffers and standard activity sequence; (2) Example of flexible allocation visual device.

An LBPC software was used to produce the plan, support control routines and allocate workers. A key step in allocating workers to work packages was following the planned floor location flow and prioritizing the execution of the same apartment typology to promote the learning effect in order to increase productivity. After some production cycles, the need for flexibility in assigning workers to their activities in work zones was observed due to workforce turnover, variation in production pace and work absence. This was done by using a visual device that allowed some degree of flexibility in the allocation of labour, as shown in Figure 6.

SUPPORT OF DIGITAL TECHNOLOGIES TO CONTROL THE PRODUCTION STATUS

The production status control matrix was devised to control the amount of WIP while assigning activities and work zones to workers. It can be considered as an application of the pull production concept proposed by Hopp & Spearman (1996): activities are triggered by the status of the system. The aim of this visual device was to improve communication between trades, and enhance data accuracy and traceability of process status. The source of data was the check-in and check-out control process, which allowed the start and finish times of different operations to be obtained. Three different mechanisms were used (Figure 7). Initially, paper tables were already adopted by the company, producing a daily manual report on activities status – besides the lack of automation, that solution resulted in inaccuracy for start and finish times, as data collection was performed generally once a day and sometimes not in all work zones. Then, two other mechanisms replaced it: a cloud-based electronic spreadsheet with mobile data collection, which produced a reduction of data collection and processing times, increased data accuracy and provided an overview of the production status in each work zone (Figure 7a); and a semi-automated status registration using an andon system (Figure 7b).

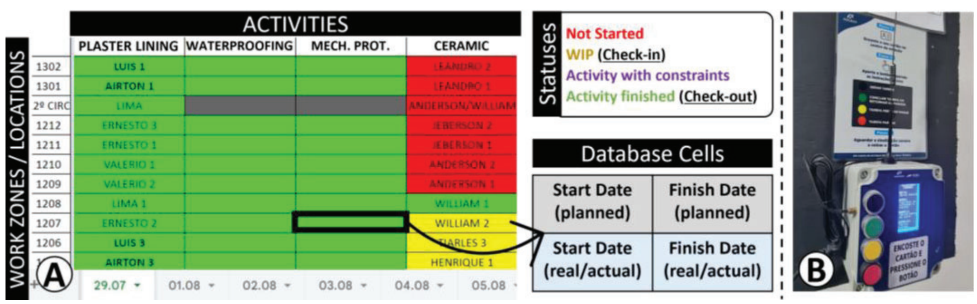

Figure 7: (a) Production Status Control Matrix and database that originates the statuses, and (b) electronic device to self-register actual start and finish (e.g., Andon).

Workers allocation was done in a mobile app which automatically updated the LBPC software, and workers received a message about the updated assigned activity and work zone. This information was also updated to the andon system, enabling workers to use their tags to obtain their assigned activity and update its status. This app was used to improve WIP control, as workers should follow the assigned location flow. The managerial team started anticipating allocations 1-2 weeks before activity should start accordingly to the production status. To some extent, this system lacked the flexibility to allocate workers and change locations flow. But the check-in and check-out mechanism automatically updated a database that stored planned and actual start and finish dates. This information allowed the production status matrix to be updated in real-time and provided an overview of the status of each location, represented by different colours (Figure 7a). Also, this database was the source of information for all production performance graphs (see the following topic). The 360-photo database, located on a cloud-based platform, was useful to support tracing WIP, work completeness and production cycles by location. It was also used to assess start conditions, site organization and stocks. Some constraints and the need for additional logistics work were identified, resulting in the assignment of new tasks for managers and crews. All the analyses made through this platform were triggered by the production status control.

DISCUSSION

Several different production metrics resulting from LBPC were used in this project: cycle time (per apartment and floor), batch adherence (per floor) and production pace deviation (per process). Figure 8 presents graphs generated for wall and floor ceramic tile. Figure 8a shows that, even though this process had not started at the initially planned start date, it finished on time. In fact, balancing the amount of work among employees allowed the floor delivery pace to be lower than it was initially planned. Figure 8b indicates that this was achieved, i.e., actual cycle times ranged from six to seven days per floor. On the 12th and 13th floors, there was an increase in cycle time due to sharing the resources with the 2nd floor. Hierarchical work-zone control was fundamental to this process, as it enabled different location-based controls: even though apartment cycle times (a lower control level) varied inside the floor production cycle, floor takt time could be accomplished (a higher level of control).

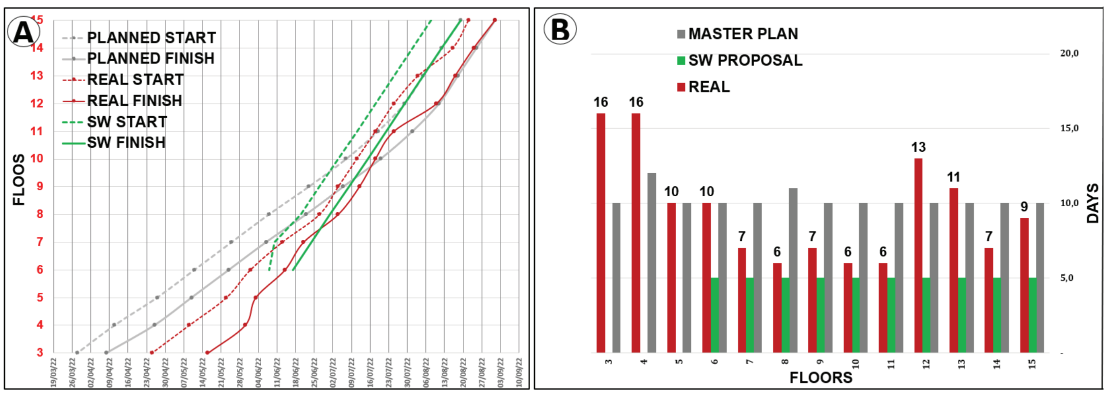

Figure 8: (A) Batch Adherence and (B) Cycle Time – Wall and floor ceramic tile

Two graphs were created to analyze the impact of SW on the set of interrelated activities (Figure 9). Figure 9a plots the production pace deviation by process, showing a trend of process synchronization. Figure 9b shows the evolution of cycle time, indicating a trend of reducing both duration and variation. This confirmed that the combination of SW and production status control was successful in terms of implementing production improvements towards process synchronization.

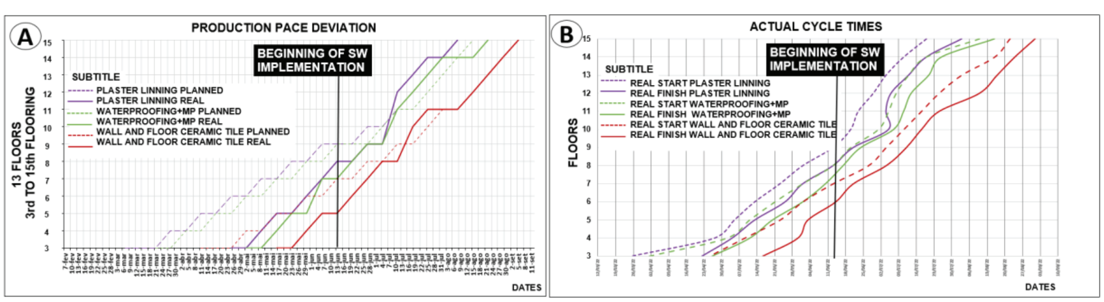

Figure 9: (A) Production Pace Deviation and (B) Actual Cycle Times-Interrelated Processes

Implementing SW enabled stabilizing processes' cycle time, reducing work zones congestion and displacements. The focus on the execution of the same apartment typology generated learning and increased the crew's productivity. The effects of the SW and production status control combination enhanced subcontractor trust and the prediction of the amount of work ahead and monthly incomes. These reduced workforce turnover, a problem identified during the first production cycles. Monitoring production status successfully supported work allocation, based on the pull production principle, which increased WIP control and helped crews to anticipate initial conditions and problems and report them to managers, so they could solve them before starting their activity in that location. Digital technologies also provided a key support in quickly obtaining accurate, traceable and transparent construction progress data, which was used to make production adjustments when needed. Visual devices, such as the production status matrix and metrics report, supported weekly meetings with subcontractors to have a production overview, detect rhythm deviations, align goals to follow the proposed plan and make the necessary adjustments. The need to adopt slack was endorsed during production cycles to cope with productivity variability. However, this mechanism was not enough. Anticipating the requirements to perform an activity beforehand was also important to eliminate constraints, but this was not fully explored in this investigation. This was made evident by some problems identified, such as the unavailability of crews to execute the 2nd floor, which increased the cycle time of the wall and floor ceramic tile on the 12th and 13th floors, as the same crews had to execute these in parallel. Also, problems with pipe leveling on the slab surface were not identified in advance and did not allow the installation of the kitchen floor on time and generated additional activities. Therefore, using digital technologies to analyse ideal conditions to perform activities and controlling task completeness while considering quality standards play a key role in the successful implementation of SW and process synchronization.

INTEGRATED CONTROL MODEL AND EVALUATION

The proposed model for integrating SW and Production Status Control is presented in Figure 10, being divided into five main steps. The model was evaluated accordingly to its utility and easiness of use. Regarding the utility construct, the model contributed to the implementation of collaborative processes in LBPC and the level of standardization, promoting team engagement and increasing the reliability of the production system. By encouraging participation and work autonomy, SW provides a suitable balance of standardization, flexibility and continuous improvement. In fact, workers provided feedback on their learning, and productivity increased along standard production cycles. The model also increased workers' autonomy by providing a clear scope of flexibility bounded by the standardization of operations: location flows and apartment cycle time were part of the standards, while workers could change operation sequencing during execution. Consequently, the model provided mechanisms to increase the stability of processes' synchronization and production cycles. Regarding the ease of use construct, it was observed that the model enabled the understanding of LBPC practices and concepts, as well as made information available to support decision-making effectively and transparently.

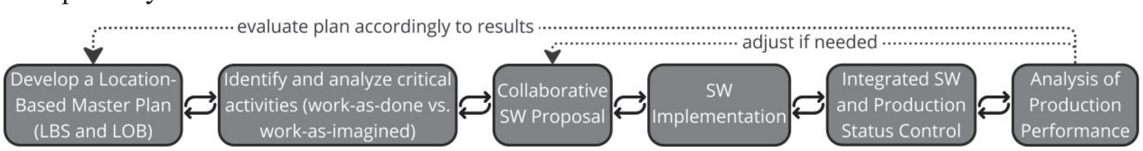

Figure 10: Integrated Control Model of SW and Production Status to support LBPC

CONCLUSIONS

The main contribution of this investigation is extending the use of LBPC to the very operational level, by adapting the SW approach, developed in manufacturing, into the construction industry. This study has also explored the use of production status control by using digital technologies. This model is based on the assumption that the implementation of the Lean Production Philosophy in construction must emphasize the management of variability, rather than simply trying to eliminate it. Collaborative processes involving the workforce, and the use of visual management supported by digital technologies play a key role in the model. This results in a set of lean metrics and concepts that are effectively used in production management: takt time, cycle time, slack, standard floor location flow, standard sequence of operations, production status, and work-in-progress control. Therefore, the model can be understood as a mechanism to systematically manage variability and uncertainty in LBPC (workforce and processes) and increase the degree of standardization of processes while having short feedback cycles to promote adjustments while monitoring the construction progress. The control model must seek an equilibrium between standardization, flexibility and autonomy in production processes. The proposed model still needs to be refined to provide a robust decentralized management system. Further studies should consider: (a) implementing the model in projects with lower levels of repetitiveness; (b) investigating other digital technologies for monitoring production; and (c) further investigating requirements (standard kits) and slack to avoid the negative impact of variability.

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