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Implementation of standard work in the construction industry
Implementación del trabajo estandarizado en la industria de la construcción

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Abstract

Standard Work (SW) focuses on reducing variability and waste based on three conceptual elements: takt-time, work sequence, and work-in-process. Considering the importance of SW implementation in the Construction Industry, there is a need for adapting the conceptual elements due to differences between the production systems. This paper discusses the singularities of SW concepts adaptation in construction processes and proposes four implementation rules. A participatory case study was conducted aimed at the implementing SW in the construction of the reinforced concrete structure of a 26-floor residential building developed by a Brazilian construction company. This process is characterized by long cycle time, a great number of interrelated operations performed by workers with specialized skills who traditionally have autonomy in organizing their work. The singularities refer to the adaptation of the conceptual elements to the context investigated and resulted in four rules to implement SW in the construction industry: (a) define daily work packages as a control parameter due to the long takt- time; (b) focus the specifications of standard work sequences on the team, allowing space for autonomous decisions; (c) establish batches' size prioritising the sharing of resources between work packages; and (d) define specifications for transporting and storing resources since there are constant modifications of the workstations.

Keywords: *Standard work, standardization, takt-time, variability, reinforced concrete structures*

Resumen

El trabajo estandarizado (TE) busca la reducción de variabilidad y desperdicio en base a tres elementos conceptuales: *takt-time*, secuencia de operaciones y trabajo en proceso. Considerando la importancia del TE en la Industria de la Construcción, existe la necesidad de adaptar los elementos conceptuales debido a las diferencias entre los sistemas de producción. Este artículo discute las singularidades para la adaptación de los conceptos a los procesos de la construcción y propone cuatro reglas de implementación. Se realizó un estudio de caso participativo fue realizado para la implementación del TP en la construcción de la estructura de hormigón armado de un edificio residencial de 26 pisos, desarrollado por una constructora brasileña. Este proceso se caracteriza por un largo tiempo de ciclo, un gran número de operaciones interrelacionadas, realizadas por trabajadores con habilidades especializadas que tradicionalmente tienen autonomía en la organización de su trabajo. Las singularidades se refieren a la adaptación de los elementos conceptuales al contexto investigado y resultaron en cuatro reglas: (a) definir paquetes de trabajo diarios como parámetro de control debido al largo takt-time; (b) enfocar las especificaciones de la secuencia de trabajo en los equipos dando espacio para decisiones autónomas; (c) establecer el tamaño de los lotes priorizando el recurso compartido de recursos entre los paquetes de trabajo; y (d) definir especificaciones para el transporte y almacenamiento de recursos, ya que existen constantes modificaciones en las estaciones de trabajo.

Palabras clave: Trabajo estándar, estandarización, *takt-time*, variabilidad, estructuras de hormigón armado

1. Introduction

The building construction process is characterized by a high level of variability, which negatively impacts its performance in terms of time and cost (Cruz et al., 2018). There is a waste of manpower production capacity and an increase in the inventory levels of semi-processed products due to the variability (Tommelein et al.1998); (González and Alarcón, 2003). What also stands out are the fluctuations in production rates due to the time it takes to prepare and mobilize the workforce, the irregular distribution of the workforce between jobs, difficulties in making resources available in the various workplaces of the building, and the recurrent rework (Brodestkaia and Sacks, 2007); (Vrijhoef, 2016).

These difficulties have prompted the Construction Industry to seek concepts and management practices in Manufacturing aimed at the stability of production. Stability is a condition in which there is predictability "to produce consistent results over time" (Liker and Meier, 2005). Standardization in one of the most important principles in the Toyota Production System (TPS) and it has received the attention of the Construction Industry due to its benefits which promote process stability.

Standardization is a principle that is widely used in mass production (Womack and Jones, 2003). In that context, standards have been established by using time and motion studies developed by industrial engineers, based on the idea that there was one best way to execute a job (Hopp and Spearman, 1996), (Mlkva et al., 2016). In the TPS, standardization has a different meaning. It is not focused on the process or the product, as in quality management systems, but on the operations, that is, on the workers' activities. Therefore, in this context, it has received a specific designation – Standard Work (SW).

SW includes the specification of a work routine that meets customer demand by maintaining low quantities of

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inventory. It consists of three conceptual elements: (a) takt-time, or the rate of demand for production; (b) the work sequence; and (c) the standard inventory, which corresponds to the limited amount of semi-processed products needed to keep the process operating and to achieve an appropriate cycle time for takt-time (Monden, 2015); (Ohno, 1988); (Dennis, 2007)

Although the literature presents many different descriptions of the three SW elements and their applications in manufacturing (Puvanasvaran et al., 2018); (Kumar and Kumar, 2014); (Martin and Bell, 2011); (Chan and Tay, 2018), studies applied to the Construction Industry are scarce. There remain theoretical and practical gaps as to the applicability of SW in the Construction Industry.

The research presented in this paper was developed based on a participative case study aimed at implementing SW in the erection of a reinforced concrete structure of a high-rise residential building. This process is characterized by long cycle time, and a great number of interrelated and diversified operations, performed by a large number of workers with specialized skills who traditionally have autonomy in organizing their way of working.

The results of this study showed significant benefits for the stability of production, but the three SW conceptual elements had to be adapted to fit the context. This paper discusses the singularities of implementing SW in the process studied, thereby contributing to define four rules to implement SW in the construction industry.

2. Standard Work

One of the characteristics of SW within TPS is to maintain the pace of production linked to market demand by using the concept of takt-time, the first conceptual element of SW (Monden, 2015); (Ohno, 1988). Thus, the work assigned to each workstation that makes up the production line is associated with a standard time. However, this time is not associated with the maximum productivity for the task performed in isolation, but rather with the time that reflects customer demand (Liker and Meier, 2005).

Takt-time is the result of dividing the time available for production and the number of units to be produced in that period to meet customer demand (Chan and Tay, 2018). After having determined the takt-time, the production process should be structured so as to seek a slightly shorter cycle time. Cycle time refers to the time elapsed between one product and the next one leaving the same process, ie, the frequency or rhythm with which a part or product is completed by a process (Liker and Meier, 2005); (Hirano, 2009).

All workstations are subjected to takt-time, but in order to deal with differences in pace, the inventory of partially processed products between these stations is controlled at a standardized level (Liker and Meier, 2005); (Productivity Press Development Team, 2002). This amount of intermediate inventory in the production line is called Work-in-Process (WIP) and represents the second conceptual element in SW (Monden, 2015); (Dennis, 2007).

The concern with inventory levels in SW stems from the constant search to reduce waste. The inventory of partially finished products is classified as a waste because it consumes time, thus increasing cycle time, and does not add value to the production system (Shingo, 1981). Defining standard amounts of WIP enables variations to be identified quickly and therefore to see what problems this has caused. The occurrence of larger or smaller quantities than those set as standard will be evidence that there is a mismatch among the workstations, which may result in overproduction or idle time within a workstation (González and Alarcón, 2003); (Whitmore, 2008). Producing within a cycle time appropriate to takt-time and with a low amount of WIP requires a set of specifications with regard to work operations and their sequences. These specifications make up a standard work sequence, the third conceptual element of the SW (Monden, 2015); (Productivity Press Development Team, 2002).

The work sequence is described as the order of actions that each worker must perform within a given cycle time, consistent with the takt-time (Monden, 2015); (Ohno, 1988); (Productivity Press Development Team, 2002). In TPS, the activities are specified in detail in terms of their content, sequence, time to completion and expected results either for a single worker performing all operations at a workstation of a group of workers required in the same workstation (Hirano, 2009); (Spear and Bowen, 1999).

3. Standard Work in the Construction Industry

Previous studies point to the need to adapt SW concepts to the construction context (Fireman et al., 2018); (Bulhões et al., 2006); (González and Alarcón, 2009).

With regard to takt-time, for example, although, in the context of building construction, deadlines are highly valued, production at the construction site is not usually influenced by changes in market demand. Projects have a contractual deadline supported by a schedule that specifies the duration of the main processes. Thus, each process will take up a specific takt-time, the calculation of which consists of the ratio between the production time available for the process and the number of repetitive units of the process (eg. floors, apartments.) (Bulhões et al., 2006).

In relation to WIP, while in TPS its determination is valued and well defined, in building construction the control of inventories between activities is not a widespread practice (González and Alarcón, 2009). The WIP in construction can be identified when observing two consecutive and dependent activities or processes, as the number of work units (houses, floors, structural elements) that have not yet been processed, but will be (González et al., 2011).

Managers should consider how much importance they attribute to WIP and the productivity rates of teams. In high-variability environments, such as in the production process of construction, if there is insufficient WIP between workstations, interruptions in the flow can be very frequent (Hajifathalian et al., 2012).

As for the work sequence, a study carried out aiming at standardizing the production of industrialized walls indicated that standard work sequence should encompass the specification of team size, production batches, tasks allocated to daily shifts and their sequence of execution, the forms of organization and the transportation of the inputs to the floors, as well as the demarcation of the inventory areas in the work area. (Fosse et al., 2014)

Specifically, in relation to the production of concrete structures, (Memarian and Mitropoulos, 2012) report that the standard work sequence focused on the division of labor *between teams and the distribution of tasks among workers according to their skills, on seeking greater reliability in the supply of the main inputs and on a plan for the shared use of the transport equipment (crane) between the different teams, thereby setting priorities for its use during each day of the week.*

In Brazil, (Fazinga and Saffaro, 2016) have discussed the level of detail of standard work sequences for individual workers allocated in the service of a reinforced concrete structure and reported difficulties in estimating cycle times and defining work sequences for each individual worker. The authors suggested that when there are difficulties in detailing the work sequence, it may be advisable to encourage teams to coordinate the workflow autonomously, based on internal negotiations so as to adjust the rhythm of the work and to assign tasks.

It is understood that a certain degree of autonomy for the work teams can promote a broader understanding of the content of the work and workers developing a greater repertoire of skills, thus favoring proactivity and mutual help vis-à-vis the uncertainties and variability of the production (Kent, 2006); (Pais, 2010); (Tremblay, 2003). However, allowing self- regulation among teams can lead to problems such as irregular and unexpected occupation of work areas, an increase in WIP, disordered flows of resources between workplaces, and delays due to the interdependence between activities (Brodestskaia and Sacks, 2007).

According to (Annosi and Bruneta, 2018), the adequate approach for team management consists of granting autonomy in addition to management control. Control parameters (e.g, cycle time and product quality goals), constantly provided by managers, allow team performance comparisons over previous production cycles and targets. This practice supports the internal team monitoring and learning and highlights good experiences that must be replicated.

The examples given of applying SW in the construction of buildings point to the importance of understanding the particular characteristics of production on construction sites so as to define a work standard satisfactorily.

4. Research Method

This research was based on a participative case study undertaken at the construction site of a 25.776 m^2 residential real estate 26-floor building. The study investigated the application of SW to erecting the reinforced concrete structure, for which prestressed ribbed slabs and metal shoring were used, a construction system widely used in Brazil (Figure 1).

The construction system consisted of using prestressed ribbed slabs supported by a metal shoring system (Figure 1a). Plywood panels were used to support plastic molds (Figure 1b). A crane, allocated exclusively for this activity, was used for vertical and horizontal transport. Prefabricated concrete beams were produced on the construction site. The prefabricated beams were made until they reached approximately half the height of their cross-section (Figure 1c) and thereafter, they were positioned on the columns, while the other half of this height was complemented with lateral plywood molds and they were concreted together with the slab. The columns were erected using plywood panels supported by a steel frame (Figure 1d) which required the assistance of a crane for handling and positioning because of the dimensions and weight of the panels.

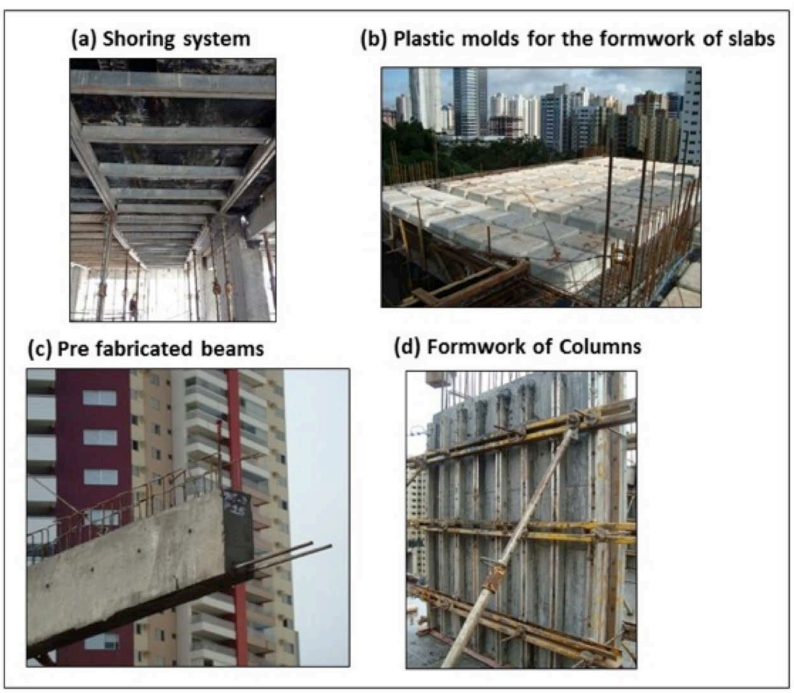

Figure 1. *Reinforced concrete structure construction system*

Three different contractors were responsible for erecting the reinforced concrete structure: one assembled and positioned the steel bars (6 workers), the second was responsible for pre- tension (3 workers) and the third produced prefabricated-beams, the formwork for columns and slabs, the shoring and concrete (18 workers). The contractors were co-ordinated by a front-line supervisor.

The research followed the protocol presented in (Figure 2). It started with a meeting involving the production manager and site engineers. The objective of this meeting was to disseminate and discuss the main concepts and procedures for implementing SW in addition to which the research protocol for data collection and analysis was presented. The next step was to examine the architectural and structural designs, the project master plan and the companies' quality management standards and procedures in order to understand the construction process and its degree of standardization.

ACTIONS						
Meeting to present concepts to the company	Study of site projects and Quaity Management System documents	Observation of production on the site	Series of Meetings with the engineer and the team of workers	Training the workers	Observation of production on the site	Meeting with the engineer and the team of workers
		6 weeks			7 weeks	
PURPOSES						
Disseminating the concepts studied	Understanding the construction process	Understanding the content of the work, the team's activity and manifestations of variability	Defining and documenting the standard work (version 1)	Communicating the standard work to the team of workers	Evaluating the repercussion of the specifications of the standard work on the stability of production	Defining and documenting the standard (version 2)

Figure 2. *Research Protocol*

The subsequent step was to observe and record what the workers did day-by-day. This observation lasted six weeks during which the second, third and fourth floors of the reinforced concrete structure were built. Throughout this period, a better understanding was gained of the construction process, the organization of workstations and the work sequences that would be incorporated into the SW. Also, it was possible to identify sources of variabilities in production, such as interruptions in processes, changes in sequences, unnecessary movement and transportations, cycle time variations. Data were collected by observation, interviews with the site team, and by compiling photographic records.

The data were processed and analysed by the researchers and then presented and discussed with the construction manager and front-line supervisors. After a series of meetings, the first version of the SW was established and visually represented, using worksheets and sketches. These consisted of the sequence of work operations and sketches representing the work over time and in physical space (buildings floors). A training session was scheduled in order to communicate the SW to the workers.

Over a period of seven weeks, the researchers observed and recorded in detail how the SW had been implemented. During this period, the reinforced concrete structure from the fifth to the eighth floor was built. The deviations from SW were annotated and improvements in production performance were measured, in order to identify to what extent standardization had improved production stability in terms of the availability of resources, work organization and adherence to takt-time.

In the final meeting with the construction site team, the results were discussed, and a new version of the SW was proposed. However, at this moment the reinforced concrete structure was in its final stage of execution and it was not possible to implement this new version.

Although only one case study has been conducted on site, several data sources were employed in favour of the evidence reinforcement, such as the analysis of company's planning and quality management documents, participation in several meetings with the site manager and the production team leaders, direct observation of the production for thirteen weeks and reports of workers informal conversations. Besides, the observation of seven production cycles (floors) has allowed researchers to compare data in order to confirm or falsify the results presented.

5. Results

5.1 Analysis stage

From the analysis of project documents, it was observed that each floor of the reinforced concrete structure was executed in two stages, named Phases A and B (Figure 3). According to the master plan, the cycle time for each concrete structure floor was defined as ten days. Phase B of the concrete structure for each floor started 3 days after the start of Phase A, as some of the formwork and shoring components were shared between these two phases.

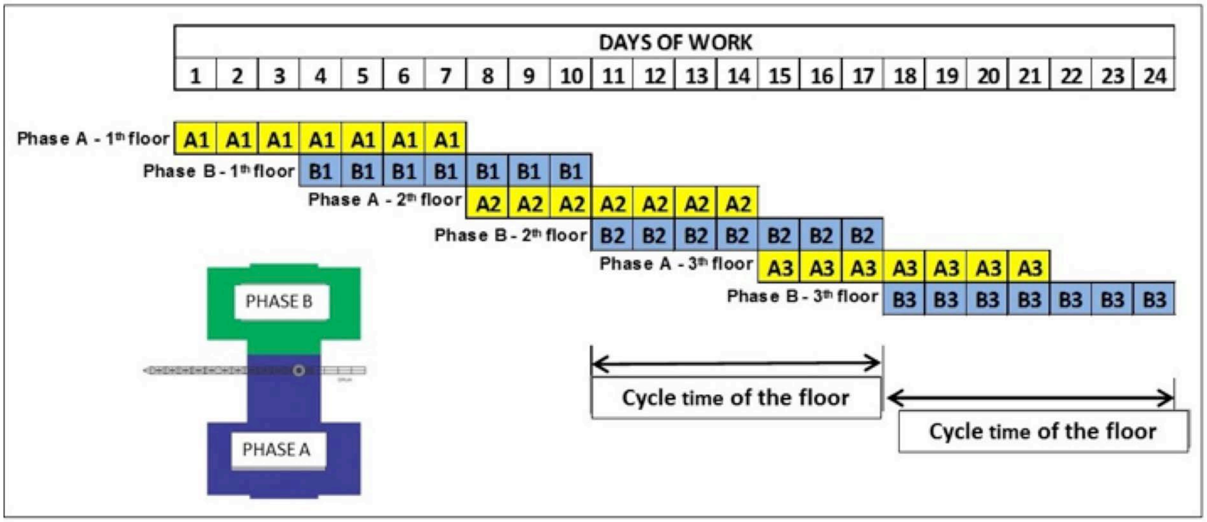

Figure 3. *Cycle time*

Based on the schedule for the reinforced concrete structure in the master plan and considering the contractual deadlines defined by the client, the takt-time was calculated as 7 days. This was calculated by considering the ratio between the total time available for building the reinforced concrete structure (182 days) and the number of floors in the building (26 floors). The takt-time was considered to be the most important information in the SW to be communicated to the workers. The contractors were aware that meeting this deadline was a commitment made in the contract with the client.

At the beginning of the study, the work sequence was specified by the construction manager using a scheduling worksheet where he determined, in very general terms, the tasks to be performed each day. The workers had great autonomy to organise themselves as to how to do different tasks throughout the cycle time.

The researchers' observation on site proved that this schedule was incomplete and insufficient to define a standard for the sequence of operations. (Figure 4) shows the work sequence developed based on the researchers' observations and interviews with workers. The blue boxes represent tasks that were not included in the first schedule used by the company.

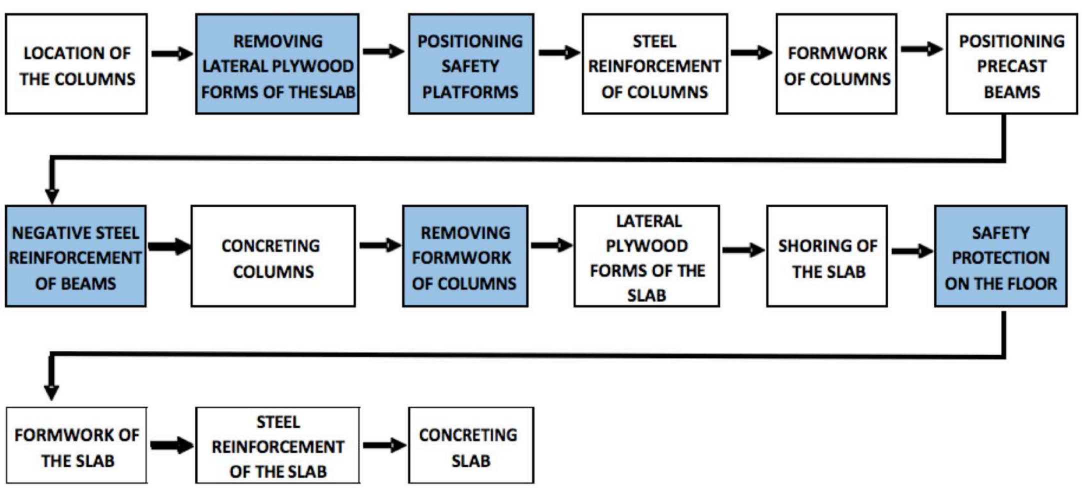

Figure 4. *Standard Work sequence*

Even though there was a general work sequence, it was observed that when comparing one cycle to the other, the time allowed for performing the same task and the number of workers involved varied; individual workers alternated between tasks; the formwork and shoring components were transported in random ways between floors and therefore improvisations caused by the lack of supplies to perform the task was frequent; the work was constantly interrupted to fetch components; and there was not a standard layout for storing these components on each floor.

The interviews with the workers, the site manager, and the front-line supervisors showed that they did not favour the idea of each of them having a standard work sequence because it would go against the autonomous and collaborative way of working they were used to. They argued that they mutually helped each other whenever necessary, no matter their specializations. But, it was also observed that some more difficult or time-consuming tasks were always designated to the same workers, as they required specific skills that these workers could perform with greater precision and quality.

Therefore, it was proposed that the SW should consider the segmentation of the work into small production batches, limited to one physical space so that the work could be conducted in one working day. For instance, the 32 columns that made up the floor of the concrete structure were divided into two smaller production batches of 14 and 18 units, each of which the workers could complete in one working day. The standard procedure specified which columns should be assembled and the number of workers involved. These small batches of work were called work packages and were allocated daily throughout the cycle time.

The teams had the autonomy to define the best way to organize themselves so as to complete each work package, but some pre-conditions were specified, such as completing a specified number of structural elements; maintaining the number of workers in each work package and obeying the sequence between these packages.

The daily work packages served to ensure takt-time was not exceeded. Even though the team had the autonomy to define the work sequence, the work packages established a daily deadline goal that would guarantee the takt-time to be achieved. Therefore, controlling this daily would allow time deviations to be identified so that corrective measures could be applied.

Another important restriction for establishing the work sequence and work packages was the need to share resources between the two reinforced concrete structure phases, e.g. shoring components and columns formwork. Also, the crane had to supply simultaneously the work in both phases. The levelling of resources and the synchronization between equipment and tasks determined the specification of a standard work sequence and the daily work packages.

The observation of the work also showed the need to define a standard procedure for transporting and organizing supplies, such as tools and formwork or shoring components. Usually, they were spread over different floors, thus demanding a great deal of the workers' motion time, and generating job interruptions. Supply kits were created in order to improve workflow. Moreover, the preferred form of transport was determined for each supply kit: manually or using the crane; using carts or wooden boxes. The supplies were also organised on the floor on adequate conditions and delimited spaces. (Figure 5).

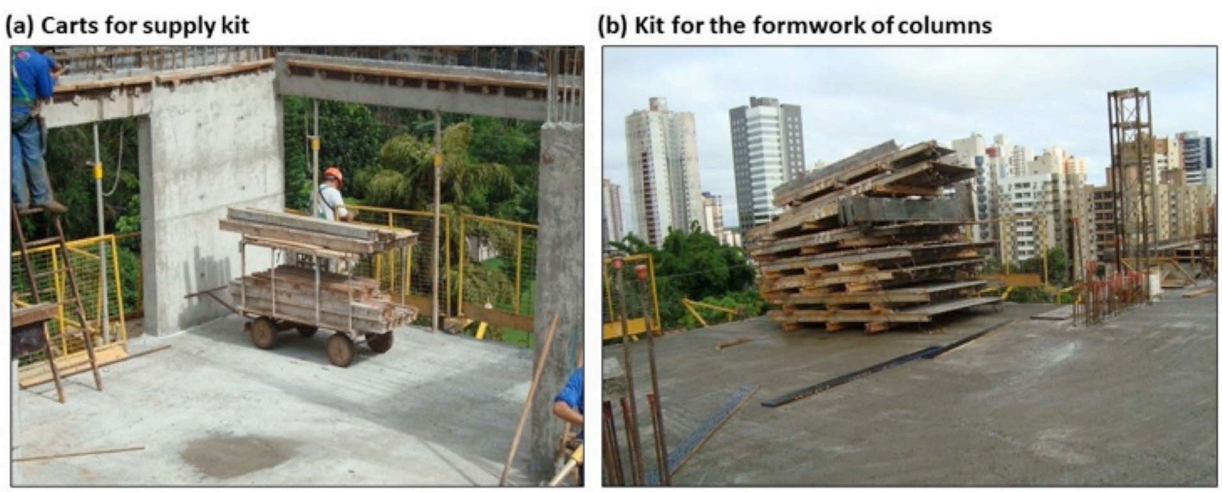

Figure 5. *Organization of supplies*

As for the standard inventory, there was a need to synchronize the process of column formwork and assembling the prefabricated beams, between phases A and B. In the first SW proposed, it was suggested that assembling the pre-fabricated beams could start as soon as a batch of 9 formworks of columns was ready, thereby reducing the WIP. But the workers did not follow this standard, as they preferred to conclude all the 18 formworks of columns before starting to assemble the pre-fabricated beams. This amount of work also proved to be necessary given the need to share the crane between the formwork of columns and the assembly of prefabricated beams. This was adjusted in the standard procedure to conform to the workers' preferred work sequence, although it implied increasing WIP.

The first version of the SW was developed containing: (a) the daily work packages distributed throughout the cycle so as to achieve the takt-time; (b) the synchronisation of the crane routine with the operations; (c) the ways to transport components; and (d) the layout for storing them on the floor.

5.2 The implementation stage

During the training session that presented this first version of the SW, the site team was prompted to comment and suggest changes. One important comment made by the workers was that they agreed with the work sequence, but they did not feel confident about completing the amount of work established for each work package.

They proved to be right because the takt-time was not achieved in any of the reinforced concrete structure floors that were followed-up after implementing the SW. (Table 1) shows the cycle-time of the reinforced concrete structure before and after implementing the SW. A significant reduction in the cycle time was observed. This was from 13 days for the last floor completed before the SW was implemented to 10 days for the next three floors when the implementation was followed up. It can also be observed that SW resulted in reducing the variability of the cycle-time whenever processes were repeated.

Table 1. *Evolution of the cycle time*

Floor	***Cycle time (days)***
2	17
3	16
4	13
5	10
6	10
7	10
8	11

This decrease in variability could be associated with establishing a standard work sequence and daily work packages, but also with eliminating waste in the process by organizing the transport of supplies and the floor layout; by reducing the time spent on transporting components and on workers' motion times; by optimizing the equipment (crane) time; and also due to some improvements made in the operations, such as developing an easier and more precise way to fit the pre-fabricated beam into the column and other improvements.

In the second version of the SW, the researchers, together with the production manager and the front-line supervisors, revised and detailed the work packages so as to make them fit better into the way the workers organize themselves, and the sequences of some operations were standardized to reduce workers and equipment's motion time. There were also improvements in the visual representation of the SW to facilitate communication and adherence to standards (Figure 6).

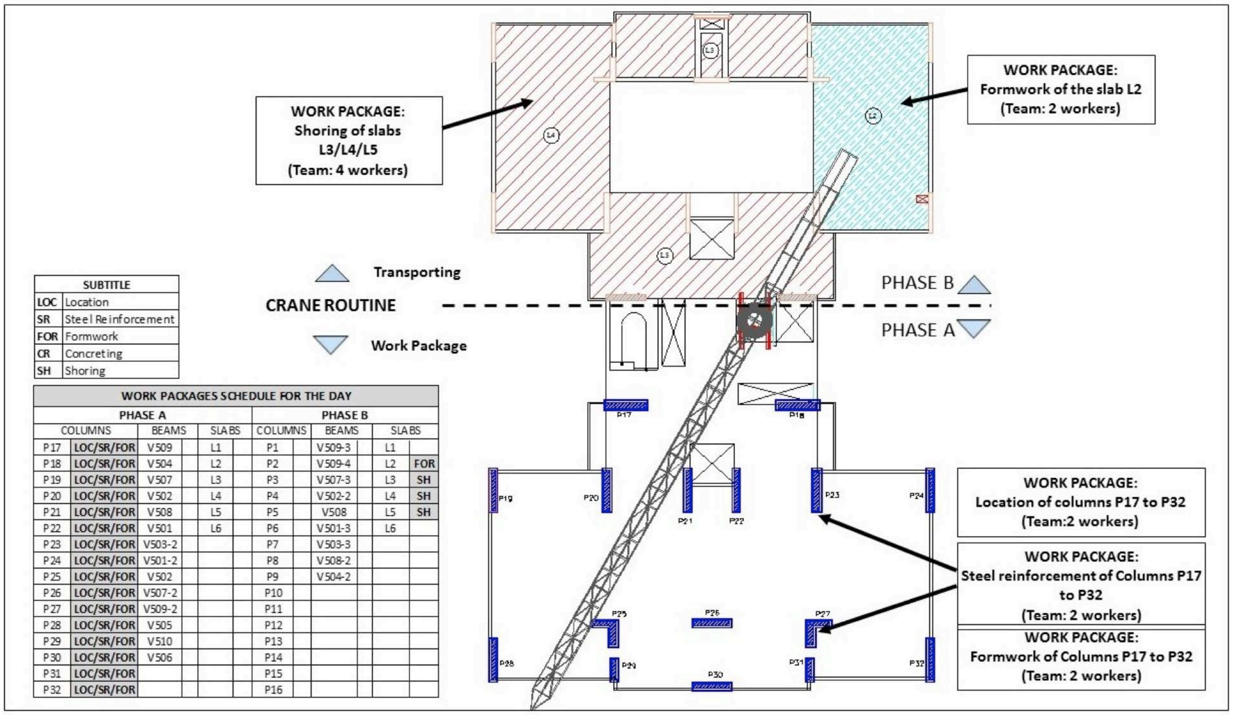

Figure 6. *Standard Work visual representation*

Reports from the site manager as well as previous studies carried out on two other sites of the company (Fazinga et al., 2016) showed similar difficulties, such as sharing the crane among various demands on the floor, frequent changes in team size, constant interruptions in workflow, lack of material in the work area, and oscillating cycle time.

In this research, quantitative data have demonstrated the reduction and stabilization of the cycle time (Table 1). Qualitative data from direct observations and managers' reports have given evidence of improvements in resources organization, teams' decisions regarding transporting components (crane, manually), more clarity about which workers should be responsible for a particular work package and a better perception of the team about which work packages demanded longer execution time.

6. Discussion: singularities and rules to implement SW

It can be assumed that the application of SW in the specific process studied presents some singularities when compared to its implementation in manufacturing. These singularities are related to the characteristics of the work observed.

The first singularity of implementing SW in such a context was the determination of the takt-time. It was observed that the long process cycle time imposed a new approach for controlling the takt-time. Therefore, takt-time was not used to monitor production, but it stood for a deadline goal to be achieved by the contractors. Daily work packages were defined by segmenting the process into smaller batches, considering the teams' production capacity and shared resources (equipment and space).

A second singularity is related to defining work sequences. Defining the detailed work routines and tasks was strongly dependent on the workers' knowledge and implied that the researcher had to spend a long time on observation and the need for a high level of workers' participation and involvement. As the workers were organised in semi-autonomous groups, specifying work standards had to be focused on the teams and not on individual workers. The decisions about work sequences was an autonomous decision of the different teams, who decided how to organize themselves while taking their abilities and specializations into consideration.

The third singularity is the need for resources to be shared among work packages, which limited the reduction of WIP.

A fourth singularity is associated with the fact that in the construction industry, workstations change constantly. This fact demands that some of the resources needed for production had to be transported from one place to another. In order to reduce waste due to transporting resources and to workers' movement, it was important to specify resource kits for each work package as well as to define the best way to transport them from one workstation to another. These specifications are not common in manufacturing as, generally, workstations are fixed and the necessary inputs are available at the place they are needed.

Based on these singularities a set of four rules (Table 2) could be proposed to guide SW implementation in the construction industry, mainly considering processes with similar characteristics of the reinforced concrete structure observed in this research.

Table 2. *Rules for SW implementation*

Conceptual Elements of SW	Singularities	Rules
Takt-time	Is a deadline goal, but not used as a parameter control	Define work packages by segmenting the process into batches, considering both the teams' production capacity and shared resources (equipment and space). These work packages are distributed throughout the cycle so as to achieve the takt-time.
Work Sequence	Is an autonomous decision of the teams, who decide how to organize themselves, considering their abilities and specializations.	Focus the specifications on the team with the space for autonomous decisions. Work sequnce should not focus on individual workers.
Standard Inventory (Work-in-Process - WIP)	The need for resources to be shared among work packages limited the reduction of WIP.	Establish batches' size prioritising the sharing of resources between work packages.
Transporting and storing resources	Is not specified in TPS as workstations are fixed. In construction, waste due to transporting resources and to workers' movement is quite large since there are constant modifications of the workstations.	Define specifications for transporting and storing resources.

7. Conclusions

The application of SW in this context studied implied the need for adaptations in the definition of the three SW elements. In the case studied, the takt-time calculated was very long and so the cycle time had to be divided into daily work packages that allowed takt-time to be controlled. The work packages were defined considering not only the teams' production capacity but also some constraints characteristic of the production process of the concrete structure, such as the need to share resources and storing space.

Thus, identifying and dimensioning the daily work packages played a decisive role in defining both the WIP and the work sequence. In this case, the work packages assumed the same role that takt-time represents when implementing SW in manufacturing.

Due to the organizational characteristics of the workers, divided into groups with semi- autonomous characteristics, the work sequences were not standardized for each individual worker. The teams were responsible for defining the best way to organize and carry out the activities, although there was a delimitation in relation to the amount of work to be performed each day and its sequence of execution.

It is observed in this case that the worker's involvement in defining the standard became even more relevant, since part of the work sequence was not standardized, but should be defined by the teams in an autonomous way.

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