VALUE STREAM MAPPING IN CONSTRUCTION: A CASE STUDY IN A BRAZILIAN CONSTRUCTION COMPANY

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ABSTRACT

Since 1993 the ideas of Lean Production have been introduced in construction, creating Lean Construction. Although studies have demonstrated good results from the introduction of Lean Production in construction, these efforts have turned into a specifically isolated implementation, limiting possibilities of improvement along the value flow. A tool that has been widely used in manufacture, as a way to initiate a systemic implementation of Lean Production, is called Value Stream Mapping (VSM). Because VSM represents the main principles of Lean Production, makes it possible to identify throughout the value flow the main problems and process wastes, and to consider action for improvement.

Aiming to introduce the ideas of Lean Production in construction in a more systematic way, identifying its main problems and proposing actions for improvement throughout the value flow, this article describes the modifications and application of the VSM in a Brazilian construction company. Modifications of VSM were necessary due to the difference between manufacture and construction. Through its application it was possible to identify problems and to consider some actions for improvement, turning it into a more fluid production, with fewer stops and increasing the planned flow versus the accomplished one.

KEY WORDS

Value stream mapping, Systemic implementation

LEAN PRODUCTION: PRINCIPLES AND IMPLEMENTATION

As the name suggests, Lean Production aims to make industries' productive process "leaner", so as to produce more (quality, variety, and quickly) with less (costs) and qualify them to compete in markets increasingly characterized by "variety and restriction". To attain this, its main objective is waste elimination, which, because it absorbs resources and does not generate value, causes rise in costs and hides process problems, making it inefficient (Henderson and Larco 1999). The principles which guide this production paradigm are: value, value chain, flow, pulled production, and perfection (Womack and Jones 1998).

Value translates the idea of producing only what the client perceives as "value". So it is important to pay attention to each action necessary to make the product, from the moment of order until its delivery to the client, challenging each step as to its being necessary or not, that is, to identify the product's value chain (or value flow). In addition to permitting to view the productive process in a systemic way (involving clients, firm, and suppliers), identifying the value chain permits one to view three types of action which occur along its extension: actions that create value; actions that do not create value, but at the moment are inevitable, and actions that do not create value and that should be avoided immediately (wastes).

After value has been specified and a certain product's value chain has been identified, and, obviously, the steps that produce waste were reduced and/or eliminated, the objective is to make the remaining steps, which generate value,

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flow. Thus, production will be much faster and the company gains flexibility to answer demands and its variations, even allowing the client to "pull" the production, synchronizing production and sales rhythms (Rother and Shook 1998). To Lean Production there is always a better way to do any activity, because just like the market changes, a firm must change to adapt itself to these new market demands. The search for perfection, or, in other words, continuous improvement, must be something constant for those companies who wish to maintain themselves in the market.

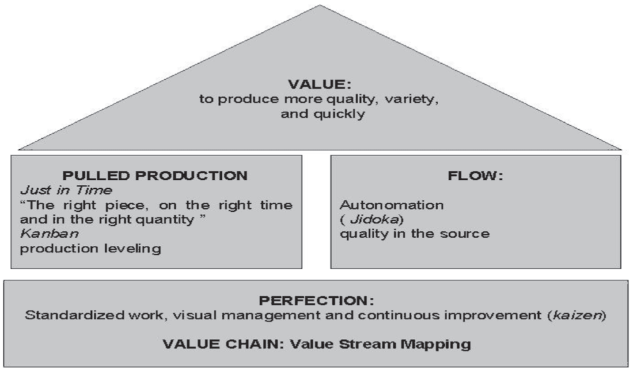

Figure 1: Principles and Tools of Lean Production

The illustration above shows how Lean Production's principles and tools interact. To reach value ("top"), it is necessary to have a pulled and fluid process ("pillars") parting from value chain identification and search for perfection ("base").

LEAN PRODUCTION IMPLEMENTATION AND VSM

According to Rother and Shook (1998), in spite of the fact that the notion of value flow considers all necessary activities to transform raw materials in a product delivered to the final customer, parting from his demand, and thus crosses the company's organizational limits, Lean Production implementation should start inside the company, and afterwards expand itself to the whole value chain. The authors observed that inside the company the first implementation effort must be made at the production process, since this step is responsible for producing the "value" customers buy and interacts with them as well as with suppliers.

Basically, the Lean Production implementation process has three phases: the first phase has a strategic change function, introducing Lean Production principles and transforming the way of "thinking" and "seeing" the company, preparing it for a physical change. The tool used for this is Value Stream Mapping (VSM). VSM is considered one of the gateways for Lean Production precisely because it permits a systemic view of the production process (of the value flow), identification of real problems and wastes and proposition of improvements. Basically, VSM consists of four steps:

1 Selection of a family of products

In the same way VSM should not be started in all company activities (but start in manufacturing), one should not start mapping all industrial plants neither all products sold by the company, but select one plant and one product family from this plant, based on products which pass through similar processing steps and which use equipment common in following processes.

2 Map of the Current State

After selecting the family of products, a Map of the Current State drawing can be started, which, as the name suggests, is a drawing of how the productive process is currently happening. For this drawing to reproduce exactly the current value flow, the information must be obtained directly at shop floor, following the production trail from the customer to the supplier. Considering that in manufacturing it is generally possible to view production from the beginning (product ready to be delivered to customers) to the end (materials supply) in the same day, data collection can be done in one day.

The data to be collected for the Map of the Current State are related to the flow of materials and information about customer demand (for example: amount of products ordered during a certain period; work shifts; if the customer is from another company; packaging necessities; frequency and modes of delivery), productive activities (for example: basic manufacturing processes and key information about each process; number of employees; work period and rest stops; mode and frequency of manufacture programming), and materials supply (for example: main raw material and supplier; amount bought in a certain period; mode and frequency of raw material delivery) (Rother and Shook 1998).

Data relating to customer demand are very important because, in Lean Production, the clients are the ones who "trigger" production, and, in this sense, production rhythm must be synchronized with sales rhythm. This relation (production rhythm x sales rhythm), called takt time, is calculated dividing effectively available work time per shift by the amount (of a certain product) ordered by clients per shift. According to Zawislak et al (2004), time is a key element in VSM, because it helps to transform the whole value flow in a single temporal notion (seconds, minutes, hours, days, weeks, etc.), permitting to evaluate the potential of response to customers' demands. It is in this sense that the "key information" of each production process must be collected, thus obtaining the cycle time (T/C—time it takes between one product and the next to come out of the same process, or, in other words, production rhythm), replace time (T/R—time it takes to change from the production of one product to another), and effective used time of machine operation.

3 Analysis of the Map of the Current State

The Map of the Current State is useful simply for showing how production is currently happening. Its analysis, based on the ideas of Lean Production, is what actually allows to identify wastes and propose improvement actions for the construction of a new flow, more regular, without returns, which generates the shortest lead time, highest quality, and the lowest cost. To develop this new flow, Rother and Shook (1998) point out some propositions to serve as guidelines.

The first proposition is to produce according to takt time. The need to produce according to takt time is related to waste reduction. When production rhythm is below takt, it means that the firm is producing more than the customers are buying, or, in other words, there is overproduction. When production rhythm is above takt, it means that the productive process cannot readily respond to customers' orders, and, for that reason, it must anticipate itself and produce before customers effectively purchase.

The second proposition consists in defining if the company should produce for expedition or for a supermarket of finished products. The third proposition aims to develop a continuous flow where possible. Where the continuous flow is not possible a supermarket should be used to control production (fourth proposition). With this it is possible to establish the fifth proposition and send a customer's programming to a production process only. This point is called pulling process, since it controls production rhythms for all preceding processes. Finally, the sixth proposition consists in a uniform distribution of the production of different items in the pulling process period, leveling the product mix along manufacturing.

4 Map of the Future State

The Map of the Future State is the fourth and last step of VSM. Its drawing is a result of the analysis of the Map of the Current State guided by the above cited propositions, aiming to introduce Lean Production ideas in manufacturing.

It must be emphasized that the Map of the Future State is a drawing of an "ideal state" of manufacturing, the best way it could operate parting from the Current State Analysis. The proposed improvements aim, in this sense, to show the firm where the wastes are and how they can be "attacked" and reduced, and, if possible, eliminated. Obviously that the implementation of the proposed improvements may not occur integrally in the first moment, but start by the most problematic spots until attaining the "ideal" showed by the Map of the Future State.

After VSM begins the second phase of Lean Production implementation, which involves physical change, transforming the company's way of acting. In this phase, the improvements proposed by the Map of the Future State should be put in practice (make this drawing "real"), creating the continuous and pulled flow in the whole productive process, by way of developing a smooth flow and better coordination. Finally, the third phase consists in aiming continuous improvement.

LEAN CONSTRUCTION

Since Koskela's pioneering work, which in the 1990's started to introduce the ideas of Lean Production in construction, originating Lean Construction, researchers in the area and some companies have been trying to implement and adapt Lean Production to construction's specific characteristics, which differ from manufacture from the relation with the market, with suppliers, and even in the production process in itself.

In the theoretic field, Lean Construction evolved significantly in recent years, with studies contemplating different approaches, from technical aspects—which include the development of production control methods along the whole enterprise (Ballard and Howell 2003)—to social and political aspects, such as the identification of barriers to the introduction of Lean Construction (Hirota and Formoso 2003) and the identification of aspects which promote Lean Construction (Alarcon and Seguel 2002). In the practical field, however, its diffusion is still limited. In addition to there being few contractors involved in process implementation, the efforts are directed mainly to the application and/or development of production control tools. Among the most disseminated tools are Last Planner (Ballard and Howell 2003), the use of kanbans (Arbulu et al. 2003), Visual Managing, and 5 S's (Salem et al. 2004).

In spite of the application of these tools showing good results, Vrijhoef et al (2002) as well as Salem et al (2004) emphasize that the isolated and punctual manner with which they are implemented, in addition to limiting the possibilities of improvements along the value flow, are not necessarily "attacking" the main problems and wastes of construction. As a result, the implementation of Lean Production in construction has been restricted, as it has invested more in the "pillars" that "sustain" it, rather than at its "base", jeopardizing its reaching the "top". For Picchi (2003), one way to make possible a systemic implementation of Lean Construction would be through VSM application, precisely because this permits to view the production process as a whole, and so identify existing wastes, showing where improvements should really be searched. This way, implementation starts from "bottom to top" and evolves along the value flow.

VALUE STREAM MAPPING (VSM) IN CONSTRUCTION

With the objective of viewing the productive process in construction in a systemic way, in order to start a systemic implementation of Lean Construction, VSM was used in this study. In spite of VSM having been used with success by different industrial sectors, its application in the productive activities of construction still hasn't been disseminated. Along with there being few studies about VSM in this sector—which refer more to construction supplies than to the productive process in itself (Dos Reis and Picchi 2003; Fontanini and Picchi 2003)—this one has been developed in a manufacturing environment, and considers the characteristics and necessities of this environment, which differ from those of the productive environment in construction. Because of that, some adaptations were necessary, in each stage, for its application in construction.

1 Selection of a construction stage

Considering that VSM should be started inside an industrial plant, in the manufacturing process, and that in construction the manufacturing process occurs on the building site, a construction was selected from a Brazilian building company (contractor) for VSM application. Moreover, mapping should not be initiated in all products manufactured by the company, but a family of products should be selected. In the case of construction, however, because each large stage occurs progressively during a long period of time and has different processes producing different products (which, in the end, result in the product "building"), each one could be considered a kind of "sub-fabric" (or "sub-construction") inside the industrial plant (or construction site). Thus, instead of selecting a family of products to initiate VSM in construction, one should select a stage of the productive process of construction, which in this case was the masonry stage.

2 Map of the Current State

Considering that the Map of the Current State should reproduce exactly the current value flow, it is necessary to obtain information directly at shop floor, and that the time of production in construction is much longer than in manufacturing, it is practically impossible to collect data for the Map of the Current State of construction in a single day. Thus, for the Map of the Current State of construction to reproduce with more exactness how the masonry process was happening, it was necessary to follow practically the whole process, from the first apartment to the last, to obtain, at the end of the process, a global average of this stage for each pavement of the building.

Moreover, analyzing the data collected for VSM in manufacturing, the necessity to make some adaptations to the reality of construction was identified. As for the customers' demands, it was perceived that while in manufacturing the customer makes various orders of a certain product in a period of time, in construction he makes a "single order", which is the purchase of the apartment. From now on, the relation between customer and constructor are based, normally, on a contract, which establishes the mode of payment of the property as well as states the period of construction. This contract, in turn, generates a general schedule of the construction, programming the period of production of each great stage in order to fulfill the contracted deadline. In this direction, the different stages of the construction can be interpreted as different orders of the customers. This difference implied in a new form of calculating takt time for construction, obtained by means of the division of the effectively available worked time for each stage (schedule) by the amount of square meters to be executed for this same stage. As result, takt of the construction will indicate the time in which a square meter should be executed, or the rhythm of production based on customer's demand, stipulated in the contract. Moreover, it was verified that, when the processes that are part of each stage possess different areas (in square meters) to be executed, takt time must be calculated by process.

Referring to the productive activity, some adaptations considering key information of each production process were found necessary. First of all, it was necessary to adapt the cycle time (T/C) to construction, which in manufacturing is determined by the time elapsed between one item and

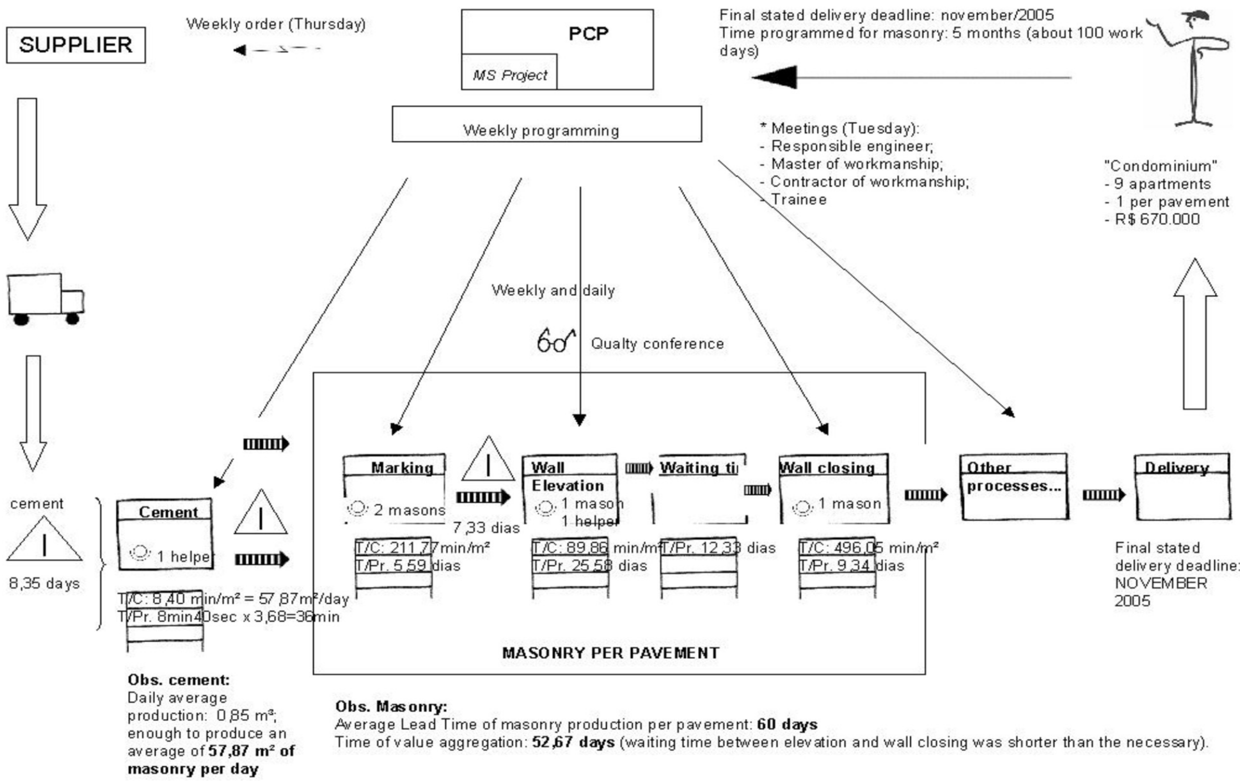

Figure 2: Map of the Current State—average masonry per pavement

the next leave the same process. In the masonry process, the square meter was chosen as a finished item, and the T/C of construction would verify the average time it takes to finish a square meter. It should be emphasized that the choice of the square meter as an item of analysis is due to the fact that the value of the apartments is calculated considering its constructed area in square meters. Because there are no changes in product manufacturing, it was not necessary to collect data about replacement time (T/R) and time used in machine operation. Nevertheless, other key information in manufacturing were identified. Between the end of one process and the beginning of another, there were days of "pause", considered as a kind of supply of finished square meters (from one process to the next) or wip (work in process).
Regarding the raw material supply, it was perceived that the data to be collected are basically the same for VSM in manufacturing, once that the relation between suppliers and company in the construction is practically the same as that of in manufacturing (the company orders the raw material, and the supplier should deliver them in the requested time).

3. Analysis of the map of the Current State

For the analysis of the Map of the Current State, aiming to identify wastes and propose improvements, the propositions of VSM analysis were used. The adaptations consisted precisely of the interpretation of the propositions according to the characteristics of construction.

4. Map of the Future State

In the same way that occurs in manufacturing, the Map of the Future State in construction should be elaborated parting from the drawing of the Map of the Current State and from the analysis based on the ideas of Lean Production, translated in the above exposed propositions.

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Parting from the information exposed above, the Map of the current State was elaborated (see Figure 2).

The drawing of the Map of the Current State makes it possible to view the construction process of the masonry in a systemic way, in which it relates the production process with clients and suppliers, following the value flow, as is briefly described below.

The client bought the apartment after it has been launched by the contractor in the real estate market. As the construction period is long, and the delivery of the apartment will happen in a long time, a purchase and sale contract was established, which should regulate the relation between the client and the constructor. This contract contains, among other information, the value which should be paid for the apartment and the execution deadline. The buyers of each apartment formed a condominium, which, during the construction period, met with the constructor to make general decisions about the building. Nevertheless, each client deals individually with the constructor about personalizing his apartment. From the building execution deadline (stated in the contract), the constructor elaborated a schedule (in MS Project) showing the period of execution of each main phase of the construction, and for masonry the programmed period was five months (about 100 work days). This schedule, however, served only to generally guide the tasks to be done on the site. With the delay in the schedule, it became overdue and was removed from the site.

The masonry started a month after it was predicted and its activities were programmed on a weekly basis in meetings held on Tuesdays, in which participated the engineer responsible for the project, the master builder, the man power contractor and the trainee. The task programming done in this meeting was distributed, weekly and daily, by the master builder to the masons which executed the masonry and to the helper responsible for operating the concrete mixer. The basic masonry processes were the marking, elevation of the walls, and wall closing, and each of these processes happened progressively in each pavement of the building.

The marking was done by in average two masons, always one pavement at a time. The average T/C of marking was 211,77 min/m² and the average T/Pr. was of 5,59 days. Between marking and wall elevation, the average time in which the pavement was in pause (consider work in process—wip) was 7,33 days. Elevation was done by on average one mason and one helper, and occurred in three pavements almost simultaneously. Average T/C of elevation was of 89,86 min/m² and average T/Pr. was of 25,58 days. Between elevation and wall closing, the average time in which the pavement was in pause (wip) was 12,33 days. Nevertheless, this period cannot be considered supply of square meters or wip, because it is a period necessary for the elevation to be ready to receive wall closing (the actual necessary time is 15 days), Finally, wall closing was executed by an average of one mason, also one pavement at a time. Average T/C for wall closing was 496,05 min/m² and average T/Pr. was of 9,34 days. The average masonry production lead time per pavement was 60 days. It can be noted that, in these 60 days, the actual time of value adding was only of 52,67 days.

From the average T/C of each process, it is possible to calculate the daily productivity of masonry. For marking, average daily productivity was 4,59 m², for elevation it was 10,82 m², and for wall closing it was 0,98 m². Considering that the elevation was executed in three pavements almost simultaneously, it can be concluded that the daily productivity of the building was of 38,03 m².

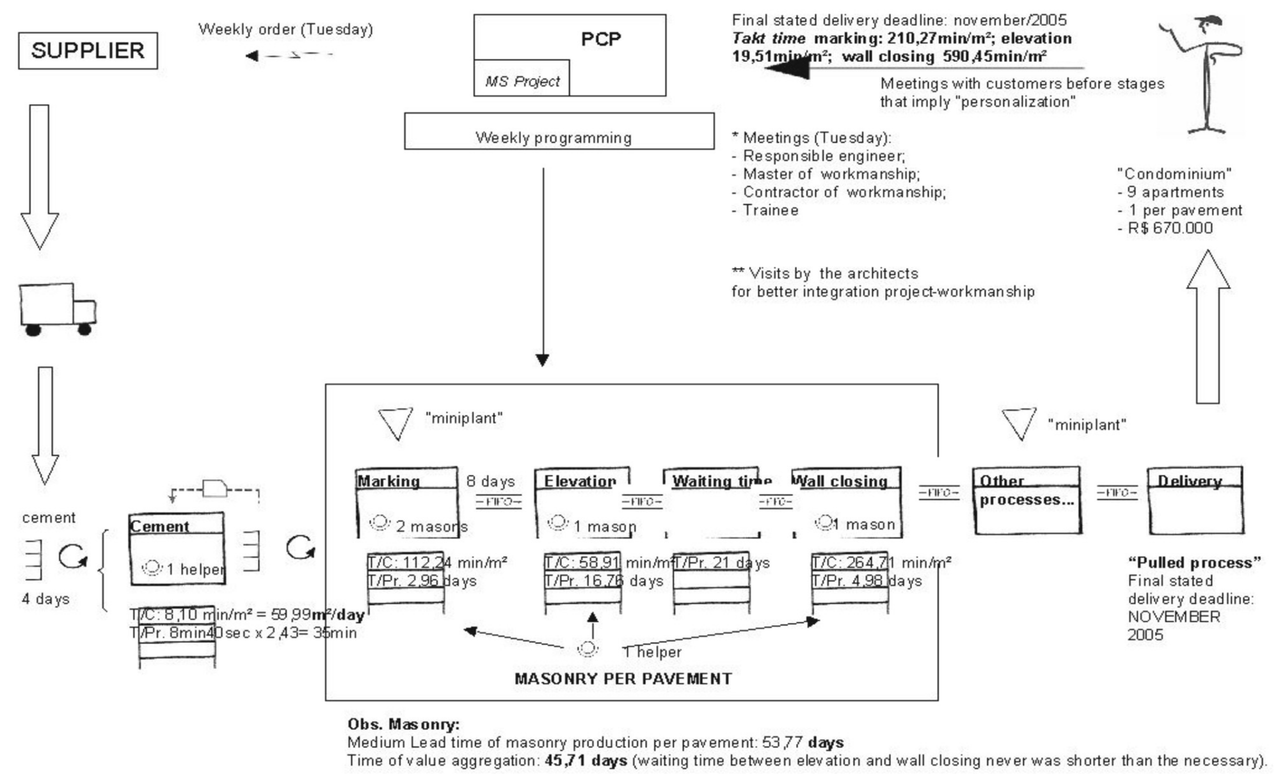

Figure 2: Map of the Current State—average masonry per pavement

Comparing the total masonry production of the building per day (38,03 m²) with the daily production of cement (masonry supply process), which with an average T/C of 8,40 min/m² produced enough to make 57,87 m² of masonry (ceramic block) a day, there is an excess of cement production enough to make 19,84 m² of masonry (ceramic block). This means that each day was produced an average of 0,29 m³ of cement in excess, which is equivalent to consuming 1,26 concrete mixers and 1,26 sacks of cement more than was necessary. In the same way the production programming was weekly (done on Tuesdays), the purchase of necessary materials was also done on a weekly basis (on Thursday), through an Order Form to the main office, depending on the urgency. In spite of the possibility of making weekly orders, the average cement supply was for 8,35 days.

With the drawing of the Map of the Current State and based on the propositions of the VSM analysis, some problems and wastes were identified, as well as improvement proposals, resulting in the Map of the Future State (Figure 3).

In the future state, in the same way it is currently done, the client buys the apartment after it is launched by the constructor in the real estate market. The purchase and sale contract continues to regulate the relation between client and constructor during the construction period, containing information such as the value of the apartment, the execution deadline, etc. The buyers of each apartment continue to form a condominium, which, during the construction period, met with the constructor to make general decisions about the building. What is proposed to change, however, is the individual relationship of each client with the constructor, aiming to narrow communication between them, having them meet more often, mainly before steps that imply in the personalization of the apartments. The objective with this change is to minimize non-compliance with pre-established deadlines of definitions about the personalization of the apartments, and, consequently, the necessity of certain rework in the building.

In the same way, in the Map of the Future the relation between constructor and architecture office (responsible for the building projects) is narrower. For project-related doubts to be eliminated, which result in waiting periods, it is proposed that the architects visit the building site more frequently, to get to know which information are indispensable in the projects, to facilitate the work on site.

The elaboration of the general building schedule (made on MS Project and which contains the time of execution of each large phase of construction, starting from the final deadline, stated in the contract) as well as the weekly program spreadsheets, remain in the Future State. The idea of the "mini-plant", however, should be added, hung in each pavement, working as a signalizing kanban of what, when and by whom should be done in the long and short term. The main objective of the "mini-plant" is to get all persons involved in the process to compromise to what was planned, in order to make production flow (if possible continuously), eliminating stop times between the processes ("supply"). Another advantage of the "mini-plant" is the reduction of the necessity of the master of workmanship to give daily instructions to each employee, since it already shows what should be done. In this way, the master has more time to follow the processes (aiming to have "quality at the source"), analyze where the problems are and think about possible solutions.

In the Future State the day of the weekly production programming meeting coincides with the day of ordering materials. The idea is to verify which materials will be necessary at the same time the weekly activities are programmed, so as not to have problems of lack of material on the site. Moreover, the helpers should pay more attention to the needs of the mason they are helping, in order to prevent the lack of material at the workplace. They may also change places between the masons working at marking, elevation and wall closing, eliminating the need of some masons to use their time to get material or to organize and clean their workplace.

The materials supply registered in the Current Map would be substituted, in the Future Map, by the adoption of the supermarket idea, aiming to reduce the supply of raw materials and also improve its control, indicating when it is time to buy more material. In the case of cement (which was the material analyzed in the VSM), the supermarket of four workdays (average of 16 sacks) was calculated considering the daily masonry production average of 59,99 m²/day (which is equal to 0,88 m³ of cement and 3,83 concrete mixers a day and, consequently, 3,83 sacks of cement per day) and the two workdays the supplier may take to deliver the product. To mark the necessity of orders the idea is to paint on a piece of wood the height of the minimum of cement needed (8 sacks, which, in average, equal two days of work) and also to use two pallets, side by side, for when a new load comes, it can be placed on the empty pallet and only be consumed when the other pallet, with older cement, is finished, so there can be a kind of control (FIFO—first in first out).

With the objective of synchronizing the cement production with the masonry execution and to produce neither less than more than enough, in the

Future Map a cement supermarket is used, which triggers a production kanban. Considering that the average daily masonry production, 59,99 m²/day, needs 0,88 m³/day of cement (3,83 daily concrete mixers), the cement supermarket reaches the number of six carts (one concrete mixer) and when the last cart is consumed the production of the second concrete mixer is triggered (six more carts) and thus successively, until the production of the fourth and last concrete mixer is completed.

The use of a mini-plant, increasing what was actually done versus what was planned, together with better exploitation of the employees and improved communication between constructor and clients and between constructor and architecture office, and also because of better material availability, resulted in an increase of productivity in all masonry processes. Thus, the average T/C of each process are 112,24 min/m² for marking, 58,91 min/m² for elevation, and 264,71 min/m² for wall closing. With the reduction of the average T/C of each process, the T/Pr. are reduced to 2,96 days in marking, 16,77 days for elevation, and 4,98 days for wall closing per pavement. Greater productivity, allied to the "mini-plant" and to better compliance of what was planned versus what was actually done, results in a quicker and more fluid process, without stops (or with few stops). This way, the lead time masonry production per pavement goes from an average of 60 workdays to an average of 53,71 workdays, and, consequently, total lead time of masonry execution in the building goes from about 115 workdays to about 88 workdays. This represents a reduction of approximately 27 workdays, or more than a month.

This reduction in the lead time of masonry permits to reduce the final deadline of the apartment delivery. This reduction can already be established in contract, permitting the company to be more competitive in terms of cost and deadline.

CONCLUSIONS

Through the adequacy and application of the VSM it was possible to visualize in a systemic way a stage of the productive process of construction. This visualization is systemic in the sense that it considers the productive activities, the customers and the suppliers of the process, following the value flow. In this sense, more than simply to identify wastes, the systemic visualization shows the reasons wastes exist, or its origin. Thus, the improvements proposed aim to solve the problem at its source and not only "to cover it up".

Among the results which appeared to be possible are: the production in a continuous (or almost continuous) flow, supplies reduction, reduction of stop times, better exploitation of the workforce, making it possible to reduce lead time in masonry production, executing it in a shorter time than was programmed. This way, the production process in apartment building construction would be possible with lower costs, higher quality and speed, responding to demands of its market (in terms of costs, deadlines and quality).

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