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ORIGINAL ARTICLE

Visilean® application for monitoring and control of pre-fabricated concrete panels

Aplicação do Visilean® para monitoramento e controle de painéis pré-fabricados de concreto

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Abstract: Good design and construction planning are essential to ensure the quality of the final product. To do this, it is necessary to develop an integrated organizational system for production and work schedule control, just in time material delivery, job site layout planning and real-time task management. The main objective of this work is to propose a method to improve process flow planning of prefabricated concrete panels based on the software application that uses Visilean® to monitor the movement of the parts in the factory. Visilean® model was useful for the visual verification of project, production and installation processes allowing suggestions for improvements to operational procedures. Research's contribution is to propose a method for integrated planning that favors scenarios creation to anticipate possible problems that usually occur in both production flow and information flow. In practice, the researchers created a simple interface that allows operators to visualize times, production services and their sequence in real-time. Better visualization of the processes and control has a great impact on the final product's quality, as well as, timely delivery and improved communication between project, production and construction teams. For future research, the inclusion of the Internet of Things for process automation will be an essential complement to the model.

Keywords: Pre-fabricated concrete; Lean construction; Industrialization; KanBIM™; Visilean®.

Resumo: Um bom planejamento de projeto e construção é fundamental para garantir a qualidade do produto final. Para isso, é preciso o desenvolvimento de um sistema organizacional integrado, um cronograma de produção e obra, materiais fornecidos do modo *just-in-time*, planejamento do layout do canteiro e cronograma para gerenciamento das tarefas em tempo real. O objetivo principal deste trabalho é propor um método para melhoria do planejamento do fluxo do processo de painéis pré-fabricados de concreto baseada na aplicação de software que emprega o Visilean® para monitoramento da movimentação das peças na fábrica. O modelo Visilean® foi útil para a verificação visual dos processos de projeto, produção e montagem das peças permitindo sugestões de melhorias para procedimentos operacionais. A contribuição da pesquisa é propor um método para planejamento integrado que favoreça a criação de cenários antecipando possíveis problemas que normalmente ocorrem tanto no fluxo de produção quanto no fluxo de informações. Na prática, a pesquisa proporcionou a criação de uma interface simples que favoreça os operadores visualizarem os tempos

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e os serviços de produção, bem como a sua sequência em tempo real. A melhor visualização dos processos e controle traz um grande impacto na qualidade do produto final, bem como, atendimento do prazo de entrega e melhoria na comunicação entre as equipes de projeto, produção e obra. Para futuras pesquisas, a inclusão de Internet das Coisas para automatização dos processos será um complemento essencial para o modelo.

Palavras-chave: Pré-fabricados de concreto; Construção enxuta; Industrialização; KanBIM™; Visilean®.

1 Introduction

The purpose of the prefabricated industry is rapid assembly due to the pre-fabrication of components. While manufacturing is virtually fully automated and assembly is fast, the speed of process benefits will be affected if there is no design, production, and assembly planning for each part. Problems related to the planning of construction logistics operations, especially information flows, materials, people and space can be classified into three dimensions of sustainability: economic, environmental and social (Bhattacharjee et al., 2016). The economic dimension is the unnecessary cost due to the rework of poorly planned projects. This problem gives rise to the environmental dimension, which consists of the waste of material needed to redo the work and, consequently, the increase of construction work hours. The increase in working hours increases the chance of accidents related to occupational hazards since workers are more exposed in the workplace, which is the social dimension. The deficiency in the flow of information is the source of the problems. When planning is not communicated clearly and continuously with each change it generates all the problems mentioned above resulting in late delivery and loss of money.

Component prefabrication is a concept of industrialized construction that aims to save material storage space at the construction site since most component production is done in the factory, solving the problem of lack of space in the construction site. The use of prefabricated elements reduces the amount of construction waste by up to 52% (Jaillon et al., 2009) because there is greater control of factory production than on-site production. However, to reduce working hours, the prefabrication and construction processes must be performed in parallel, which is why precise coordination between these two groups of activities is required. On the construction site, costly delays are observed if the factory does not provide sufficient building elements in time (Babic et al., 2010). To avoid these problems, the flow must be synchronized in engineering-to-order (ETO) mode, where the customer is the starting point of decisions and production is pulled from the work (Gosling & Naim, 2009).

On the production line, the cycle time that each component spends on each workstation may vary. Variations in cycle time increase the amount of time a component remains idle between stations (Altaf, et al., 2018). Lean tools assist in managing production cycle times, such as the Value Stream Map (VSM), and help provide components for installation without delays with just in time delivery. Luo et al. (2005) applied the lean concept to prefabrication and found that the lean philosophy could contribute to quality and supply chain improvement and waste reduction. However, for an efficient project, production, and site management, technology tools are needed to automatically update and view the progress of each prefab component in real-time, and to share information among all participants. To gain a competitive advantage, the priority of industry management should be the introduction of information technologies (such as BIM, KanBIM, RFID, IoT, etc.) and the use of electronic management tools (eg tablets, smartphones, etc.). According to Scheer et al. (2007), the use of IT has driven advances in the sector's production chain, such as more integrated, objective and flexible processes, enabling the efficient use of capital, labor, and resources.

KanBIM™ fits into this scenario as a tool to facilitate task planning and monitoring, providing a 3D view of the maturity of planned tasks. Utilization of the proposed system will facilitate implementation and systems such as the Last Planner System™, improving on-site workflow and providing a visual representation of the current and future status of production and construction processes (Sacks et al., 2009). Visilean® is a computerized systematized translation of the KanBIM™ tool and fits production, site and project management for control programming with lean construction and BIM interaction. The model incorporates the schedule of tasks from the first site preparations to commissioning and delivery, as well as the 3D model for visualization (Dave et al., 2013).

Noting the need for an efficient method for planning the flow of prefabricated concrete panels throughout their progress using KanBIM™ technologies, the opportunity was created for this research to explore all factors that should be considered when planning the design, production, and assembly of Visilean® optical panels.

2 Industrialized construction

The three main principles that underpinned the industrialization of construction are standardization, prefabrication and quality management (Vrijhoef, 2016). Standardization of building components was a requirement for their production under factory conditions (prefabrication) which, together with dimensional coordination, enabled the growth of construction systems (Crowley, 1998). The industrialized construction approach requires full synchronization in the construction, manufacturing and design processes. There is an emphasis on rationalization, standardization, repetition, collaboration, supply chain partnership, and more effective project planning and management (Kamar et al., 2010). The industrialization process requires that work be standardized so that operators follow the system to manufacture and install product components at the time scheduled to complete each task (Vrijhoef, 2016).

Many researchers have identified as advantages of prefabricated construction: reduced construction costs, faster construction, waste reduction, increased productivity, quality improvement and sustainability (Sacks et al., 2004). A major challenge in managing prefabricated building systems is avoiding downtime and increasing work in progress due to a lack of available components. However, this does not mean that all materials must be sorted as early as possible and stored on-site, but rather that they must arrive precisely on time. To achieve a balance, deliveries must be on the just-in-time concept. Some conditions should be considered: uncertainty and variability in site conditions and upstream flows, distance to supplier, lead time, level of detail in plans and amount of storage space on site (Skjelbred et al. 2015). Also, the delivery of prefabricated building systems have been seen as a means for further productivity advancement (Jansson et al., 2013; Thuesen & Hvam, 2011). Penaloza et al. (2016) explored the implementation of Lean concepts in prefabricated systems to improve the overall design, factory and site system.

2.1 Kanban

Kanban is a lean approach developed in the automotive industry as a mechanism for pulling materials and parts throughout the value stream on a just-in-time basis. “In Japanese, the word kanban means 'card' or 'sign' and is the name given to the stock control card used in a pull system” (Emuze & Tarcisio, 2016, p. 101). The goal of a “pull” system is to produce only what is needed, when needed and in the right quantities (Arbulu et al., 2003).

The kanban strategy is designed to manage the replenishment of certain product types from preferred site suppliers such as personal protective equipment, hand tools, power tools, and power tool consumables. Delivery of other products made for stock (eg bricks, tiles, pipes, etc.) is not included as part of the scope. The kanban strategy has the following objectives. First, giving users what they want when they want it by pulling materials from suppliers. Second, supporting reducing material stocks and paperwork needed to order new products. Third, facilitating product rationalization, reducing times cycle and eliminate acceleration. Fourth, contribute to continuous improvement and act as a catalyst for changing procurement methods. The last is to simplify the site for the procurement, storage, distribution, and disposal of inventory-made products, eliminating waste and reducing processing information (Arbulu et al., 2003).

The kanban strategy has five main tasks: order placement, product ordering, product procurement, shipping, and replenishment. In order placement, suppliers receive an open order which means that the site can pull materials from the supplier up to a certain monetary limit. At the product order, an order from the flowerbed hits the market in verbal or written communication. Obtaining the product includes all actions required to obtain products from the boxes from shipping the bin until the resumption of replenishment. The dispatch operation comprises all the actions necessary to give the products to the consumer. In stock replenishment in the market, transport vehicles follow predetermined routes for collection from each specific vendor, collect empty boxes from each market, arrive at vendor warehouses, and exchange empty reservoirs for full boxes (Arbulu et al., 2003).

2.2 KanBIM™ and Visilean®

The KanBIM™ system is a management information system that includes procedures, software, and hardware designed to support lean workflow control at construction sites. Facilitates the planning and visibility of work processes by providing a clear 3D view of the maturity of planned tasks and the status of work in progress. The term KanBIM™ (Kanban using BIM) refers to lean building principles and building information technology (BIM), which are the major influences on their development (Sacks et al., 2011). Kanban is the Japanese term for cards used to operate flow control on lean production lines (Hopp & Spearman, 1996). BIM refers to the process of compiling parametric 3D object-oriented computer models of buildings and the various technologies used to compile and exploit them (Eastman et al., 2011).

The motivation for system development is threefold. First: facilitating the profound procedural and organizational changes required for a Last Planner System ™ implementation (Ballard, 2000). Second; improving on-site workflows, such as reducing manufacturing and design cycle times, reducing rework, and improving the reliability of material and other information (Sacks et al., 2010). And third, the effectiveness of building model-based interfaces to provide highly-visual representations of the current and future status of process design aspects of construction (Sacks et al., 2009).

Like KanBIM™, Visilean® is a production management system, especially geared towards planning, scheduling, and control operations with lean construction and BIM interaction. It supports the Last Planner ™ pulled workflow, including detailed constraint analysis and task resource allocation. It also allows simultaneous visualization of processes and product by integrating BIM into the same system (Dave et al., 2013). The model incorporates project operations from first site preparations to commissioning and delivery. These operations are modeled at the phase, task, and subtask levels, although a complete project plan is not expected to be created at the beginning of a project. The detailed project schedule can be imported from traditional planning software such as MS Project, Vico or Primavera. Dependencies are defined in the model, both between different operations and between operations and resources required to complete them. These dependencies are employed to determine which operations are ready to be released for weekly work plans to begin. Dependencies are analogous to the seven restrictions of the Last Planner ™ system, with all constraints on an operation being classified before the operation is classified as ready for work (Dave et al., 2011).

There are a few evidences of case studies on Visilean® in the literature. However, the authors Dave et al. (2013) performed a pilot deployment on a UK highway construction site. The project was to install automated traffic control gantries. The client was the UK State Agency, which was also the project's main sponsor. The total project duration was approximately 26 months starting in January 2012. The main objective was to reduce congestion and improve traffic flow. This implementation was critical to receiving customer feedback to identify requirements on the processes, training, and technology that needed to be met to evaluate Visilean® (Dave et al., 2013).

3 Method

The Visilean® model starts with user registration on the company website. The administrator license was provided by Visilean® CEO, dr. Bhargav Dave, for academic purposes. After this step, you create the BIM model, import the task schedule, create the organizations and users who will be responsible for each task, perform the tasks (planning, tracking, approving, and reporting) and finish the project. The steps are in Figure 1.

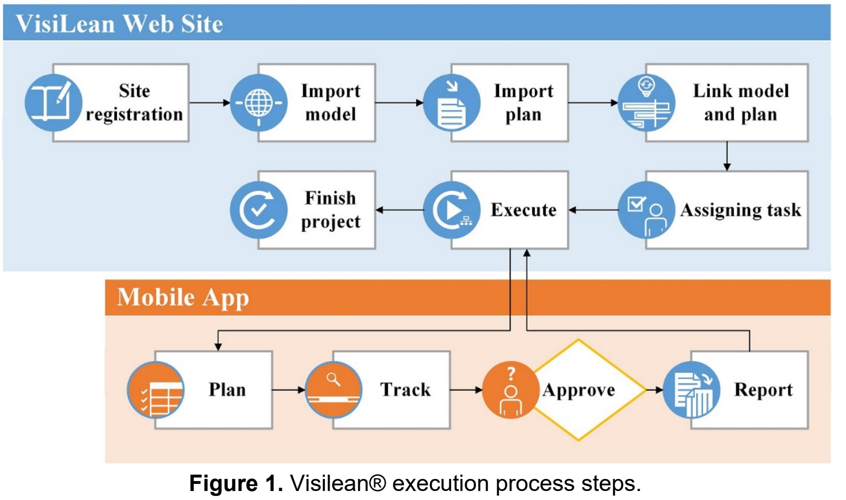

Figure 1. Visilean® execution process steps.

With the BIM model, you can view the project in 3D, rotate, hide and move, but you cannot edit it. The site allows the Ifc2x3tc1 and Ifc4 formats of BIM templates: The schedule can be edited, change the task times, task status and the worker assigned to the task. The allowed formats for the schedule are Microsoft Project CSV, Microsoft Project XML, Vico XML, and Primavera XML. Although Vico and Primavera software have BIM concepts of information sharing among other users and more detailed tasks (cost, vendor information, etc.), the authors chose Microsoft Project for the convenience and agility of scheduled execution. In addition to the schedule, you can view the hierarchy of activities and their relationship through the Gantt chart.

The model and schedule will be developed and imported into Visilean® from the website on the computer and tracking will be done by the mobile app as shown in Figure 2. During task tracking through the app, the user will be able to rate them as follows: not ready when the task cannot be started yet; ready when the task is ready to begin; forced ready when the task is done but there is an unmarked prerequisite; started when the task starts; warning when there is an alert or the job is in disuse; stopped when the task has stopped and cannot continue due to some problem to be solved; complete when the work is complete.

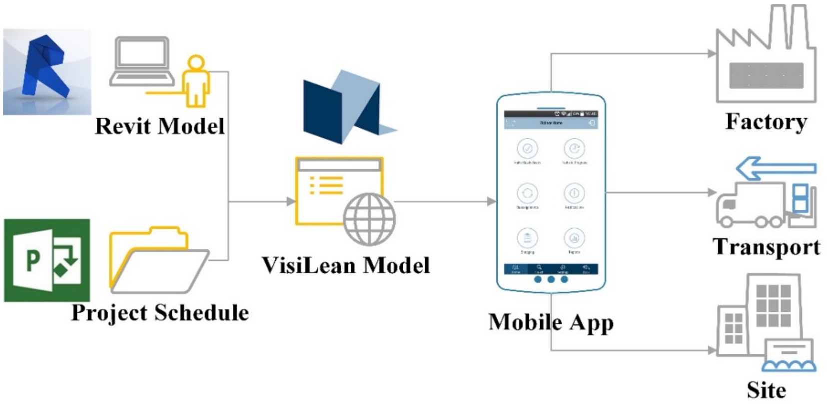

Figure 2. Prefabricated panel monitoring scheme.

To register on the site, the authors sent an email to Visilean® COO and requested authorization for academic purposes. The COO asked for the author's email to register as an administrator on the site and the name of the project that the author intended to execute. Subsequently, an email from Visilean® was sent to register the password and to confirm the registration email. Every time a user accesses the site, they need the login (which is the email) and the password registered at the time of registration.

The second step of importing the 3D model in the IFC format was done in the “Settings” item in the upper right corner of the home screen. In the left column, in top-down order, you have Basic Info, Parameters, Organization, Users, Model, Plan, Locations, and Calendar. In this column, click on “Model” and then “+ Add New Model” to add a new model. A field will open to add the template in the “Browse File” item by clicking on “Choose a file” and remembering that in the item “IFC Schema” you must enter the format in which the template was saved (Ifc2x3tc1 or Ifc4). This field can include the model identification number (under “Model ID/Number”), the model name (under “Model Name”), importing plan information (by selecting the “Import plan information” item) and import 4D links (by selecting “Import 4D links”) if the template is made with this information.

To add the schedule, you need to enter the settings tab as you did to add the template, but in the left column click on “Plan” and then “+Import a project plan from another application”. A field will open to add the schedule in the “Browse File” item by clicking “Choose File” and selecting the format in which the file was made. As the schedule was made in Microsoft Project XML, in the item “Date format” was typed “dd-MM-yyyy” to indicate the format of the dates. The schedule used depends on the scenario in which it is applied. The schedule chosen was from a realistic scenario.

In the fourth step, you must select the part in the 3D model, select the task that refers to the part, and click the link button shown in Figure 3. After clicking the link button, a message appears if you want to create this link, so click on “Yes”. Then a message appears that the link was successfully created. This procedure was done for each schedule panel. This way, whenever the task is selected, the 3D model will indicate which part it is and will bring the screen closer to the part. This will make it easier for the site engineer to locate where the part should be installed.

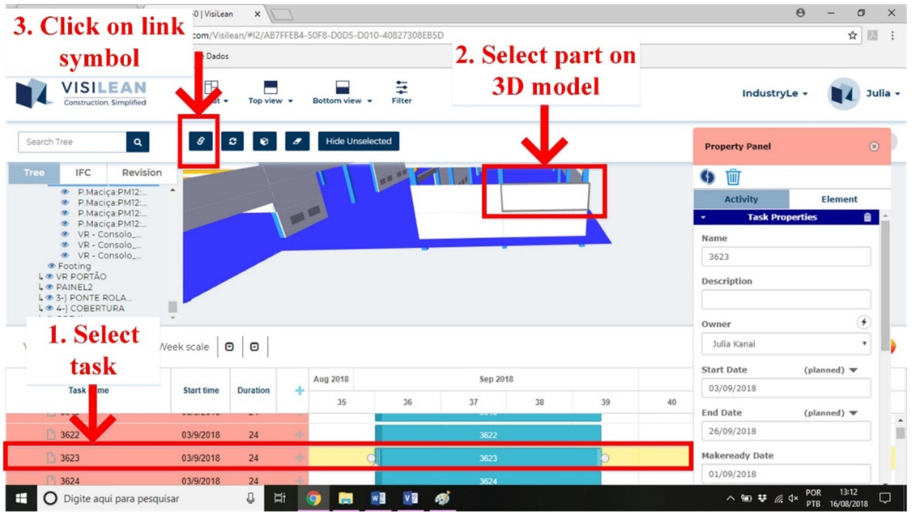

Figure 3. Link formation between the 3D model and schedule.

To assign a task to a team member, you must select the scheduled task and select the team member from the Property Panel under the Owner item as shown in Figure 4. All tasks have been assigned to the author because only she has the registration on the site so far. If the company decides to sign the contract with Visilean®, there will be more administrators to assign tasks. When the task is assigned to a person, only the person can make changes through the mobile app.

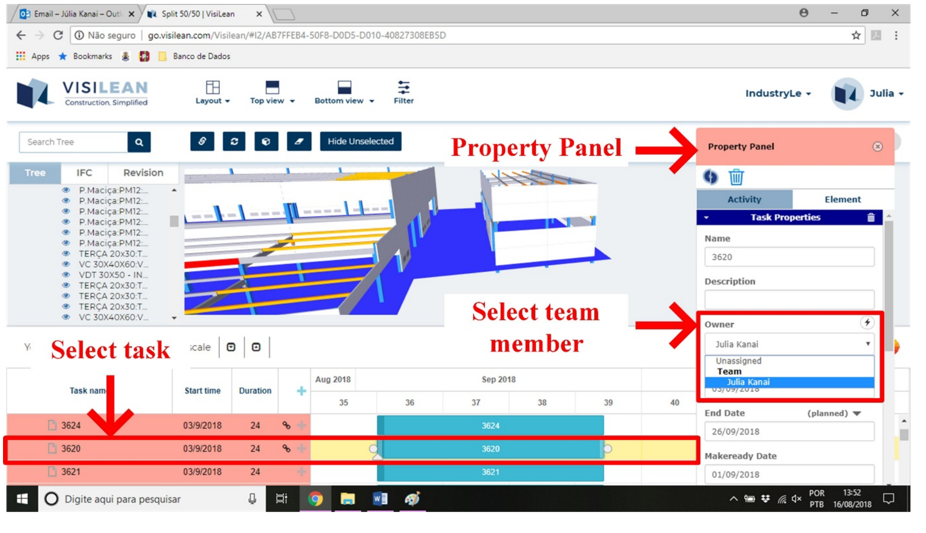

Figure 4. Assigning tasks to a team member.

4 Results

The method was applied to a specific work of the company located in Ribeirão Preto (Brazil). The work consists of 4 sheds, but the design, production, and assembly of the panels were only carried out in shed 3. The 3D model in IFC format (Revit) of the shed was provided by the company as can be seen in Figure 5, as well as the 2D plan, the sections, the number of panels, the location of each panel, and the characteristics of each panel (weight, volume, length, name, etc.). The land has slopes on the north and west sides of the work, the west side is bordered by another company. The work was approved in mid-June 2018 and is due in December 2018. Shed 3 specifically must be completed by October 19, 2018. Figure 5 shows the 3D model of shed 3 from various angles. Shed 3 consists of two parts: a larger shed and an attachment. The largest shed is 90 meters long, 63.05 meters wide and 12.50 meters high. The annex is 14.90 by 56.60 meters and 11.40 high. The distance between the two is 13.05 meters.

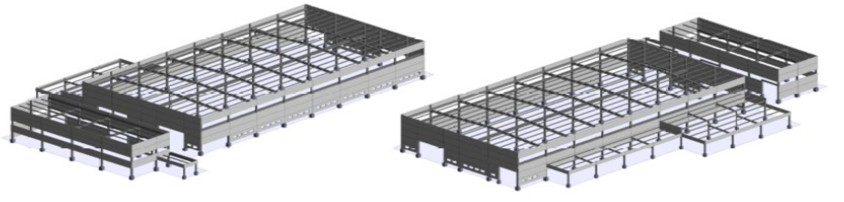

Figure 5. 3D model of shed 3.

The project flow shown in Figure 6 begins upon receipt of the customer proposal. The design team does the Revit design model and structural calculation for TQS load verification. These steps are done simultaneously in 2 days. After modeling, the material quantity table is extracted for the budget that is made in 1 day. The budget is then presented to the approving customer or requests a review within 7 to 15 days. After approval and due adjustments requested by the customer (if any), the project is delivered to production. The production manager interfaces with both the work and the project. The production team studies the best assembly sequence with the construction team and prepares the production schedule according to this definition. It then requests the detailing of each part in the same order as defined for production and assembly.

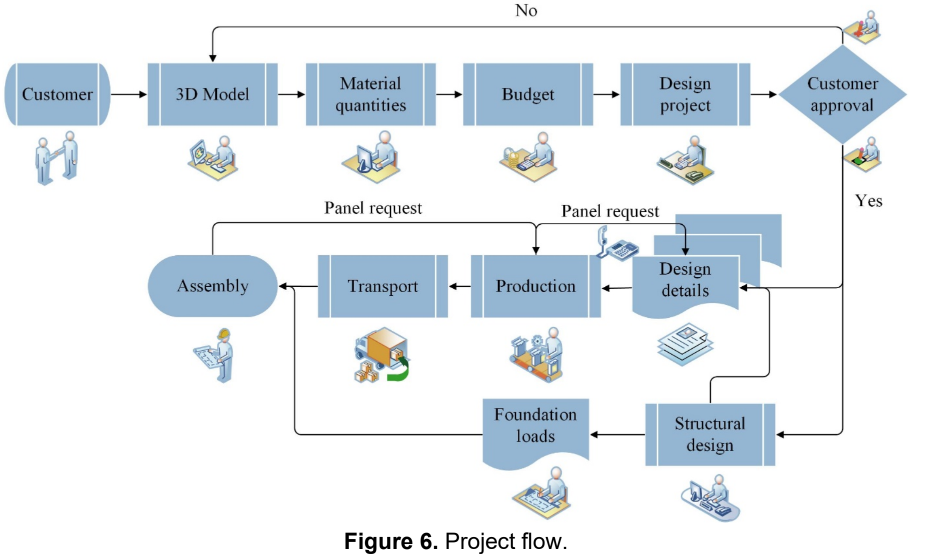

Figure 6. Project flow.

The production sequence consists of framework, pallet cleaning, formwork assembly, putting the framework on the formwork, concreting, finishing, polishing, taking formwork out, curing, withdraw and shipping. The production flow is in Figure 7.

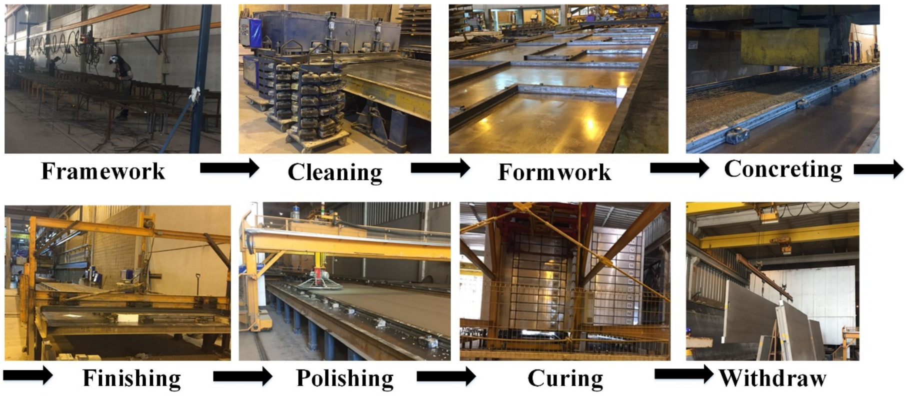

Figure 7. Production flow.

The frame should be made 2 to 3 days before the other steps because the amount of assembled reinforcement per day is less than the number of pallets cast. There are 4 frame tables, 1 assembler, and 4 welders. The assembler places the longitudinal irons and stirrups in the proper spacing defined in the project. Then a welder passes the weld at each of the joints to fix the irons together.

Pallet cleaning begins with the removal of the thicker dust through a dry cleaning machine. Then pass the waxing machine, the demolders, a cloth to remove the excess of demolders, put the rulers and magnets to advance the next process of assembly of forms.

When assembling the form, the responsible engineer transfers the panel properties to the System Analyze Automation (SAA) which projects the panel into the form using a laser to guide the formwork assembly. After mounting, you must screw the strips, wipe the dust with a cloth, and put the inserts, sheaths and lifting supports.

In the process of leasing the frame, the armature is hoisted to the form. Then the workers make the proper adjustments, put the starters, the spacers, and wire them up.

The concreting is done automatically by the SAA, the same system that projects the laser into the formwork. This software identifies the exact location of the panel on the form and moves the machine by casting concrete on the form. The concrete volume is predefined and posted to the system. In this way, only the defined volume is thrown over the form, with no waste.

After concreting, the pallet goes through the vibration process. Then the pallet (where the panel moves through the factory) goes to the finishing where the part receives a leveling before polishing. Finishing is like the trowel straightening process, but more quickly with the aid of a machine.

The polishing is a finer smoothing process that leaves the panel surface like a wall ready after fishing. The concrete must be firm but not dry. If it is too dry, the machine will not remove surface imperfections and may damage the machine blade. If the concrete is too wet, the concrete will spread as the machine rotates, thus damaging the surface of the part.

After polishing, remove the magnets before placing the pallet in the greenhouse, where it is overnight. After 24 hours of concreting, remove the formwork pieces. When removing the pieces, it is necessary to apply demolders on them to remove the remnants of stuck concrete. To store the formwork pieces, 2 people are required to load from the pallet to the formwork assembly location.

The panels are withdrawn with the aid of an overhead crane and placed the pallet on a truck to be taken to stock or directly to the job site. Before the panel is lifted, the operator removes the isopores from the workpiece and clears the lifting fittings that contain concrete debris. The fittings are holes for attaching the lifting hook.

In Visilean®, when starting a task on the scheduled day, you only had to select the task from the "Make Ready Tasks" list, click to start, and then select the task from the "Task in Progress" list as shown in Figure 8. Panel 3411 was scheduled for September 17, 2018, and effectively started on the same day. Since this panel was started on the scheduled day, there was no need to establish delay reasons at the top of the mobile app display. So this step of getting the job done was simpler. The date each task should be ready to start is in the "Make Ready Tasks" list above the list of tasks to be done on that date. The app is set to get tasks ready 2 days before the scheduled date. For example, on schedule, panel 3411 should start on September 19, 2018, but the "Make Ready Tasks" list prompts you to get tasks ready to start 2 days before it is ready, September 17, 2018.

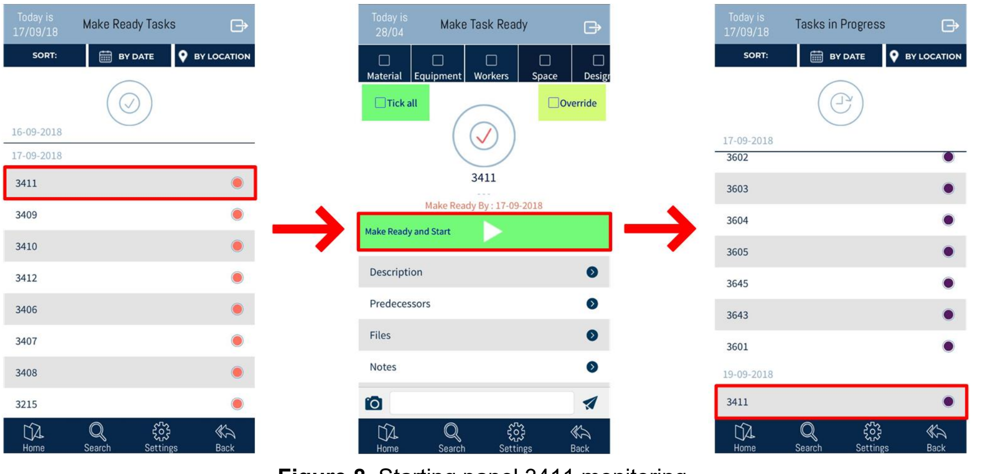

Figure 8. Starting panel 3411 monitoring.

After starting panel 3411, progress is tracked through the mobile app following the caption in Figure 9, where each percentage means the end of a step: 0% is the start, 10% is the detailed project, 20% is the frame assembly, 30% cleaning and formwork assembling, 40% is the lease of the frame in the form, 50% is concreting and finishing, 60% is the polishing, 70% is deforming, curing and withdraw, 80% is the shipment, 90% is the transportation of the panel to the site, and 100% is the arrival of the panel on site. Figure 9 shows the mobile app display in each percentage of progress with the red caption below.

An important detail is that the detailed design start date is September 17, 2018. The production start date is one day after the detailed design (September 18, 2018) with frame assembly, cleaning, and form, location of the frame, concreting, finishing and polishing. The deforming, curing and withdraw was one day after the polishing (September 19, 2018). Shipment, transportation, and arrival at the site were 8 days after the withdrawal (September 27, 2018), which means that the panel was in stock for 8 days before being taken to the site.

Upon arrival at the job site, to complete the task you must select the approving person, select the task from the "Snagging" list and click "Complete". Thus, panel 3411 was received and checked for quality in the work, there was no problem, so it was not necessary to mark to redo.

Figure 9. Panel 3411 progress control.

5 Discussion

The site allows you to add more than one 3D model and more than one schedule per project. The site facilitates 3D visualization of the building, presents the report with percentages of completed tasks (Figure 10), reasons for stoppages (Figure 11) and reasons for warnings (Figure 12), and has an automatic update on the mobile app and in the site. When it forms a link between the model item and the task in the schedule, clicking on the task, the model approaches the part in the 3D model. This makes it easier to find the part in the 3D model.

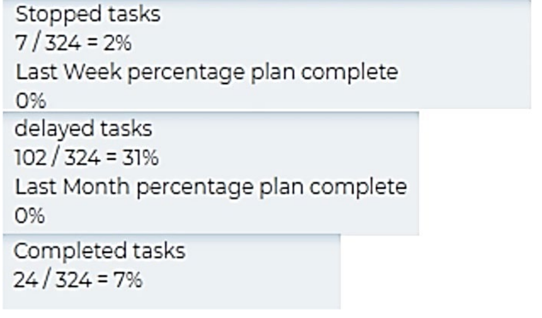

Figure 10. Report data on the site.

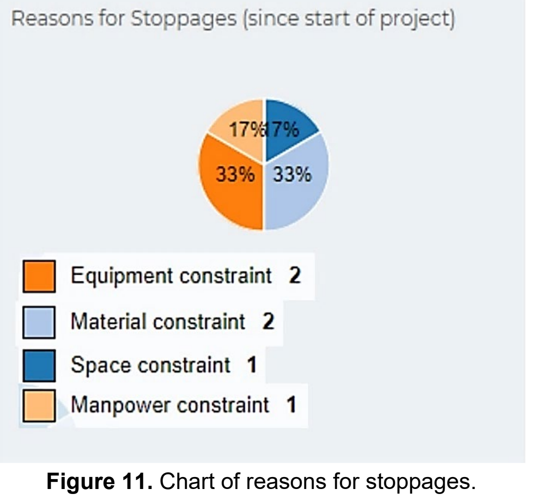

Figure 11. Chart of reasons for stoppages.

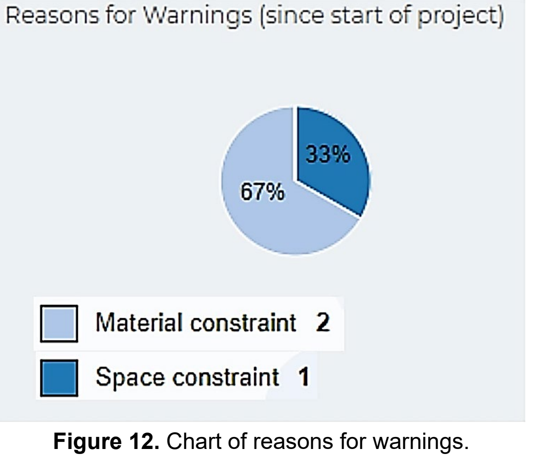

Figure 12. Chart of reasons for warnings.

The mobile app does not have 3D model visualization, it is only used for schedule visualization and for handling the progress of the tasks (in progress, complete, stopped, alert, etc.). The mobile app also shows the report, but only the percentage of completed tasks, delayed tasks, and the to-do list. The advantage of the mobile app is that it facilitates the flow of task progress status information and, being on the mobile phone, is easier to carry than a computer. Another problem is that when you put more than one schedule in the project, the tasks all appear together in the app unless you put different subtitles for each schedule.

At first Visilean® is in English and there is no Portuguese version, but the developers of Visilean® said they would program a Portuguese version if there were demand in any Brazilian company. One suggestion is to receive a notification on the mobile for each task started, alerted, paused, or completed. This would make it easier to receive real-time information between design, production and assembly teams. Another point is that Visilean® does not yet have connectivity to other technologies such as RFID, QR code or Internet of Things. This would make it difficult to implement other technologies in the factory.

6 Conclusion

The research contributed to integrated planning that favored the control and monitoring of the production flow and information flow of prefabricated concrete panels. Visilean® provided better process visualization and improved communication between design, production and construction teams. In practice, operators were able to view production times and services as well as their sequence in real-time. Better visualization of processes and control has a major impact on the final product quality, as well as cost reduction, waste reduction, timely meetings, and improved communication.

Although the factory studied is remarkably automated, there must be continuous improvement, as seeking new updates will ensure that the company is always modern and in a good position of competition in the market. Visilean® has proven useful for flow management of precast concrete panels, but updates are still lacking to compete with other equally useful technologies in the market.

For future research, the suggestion is to include RFID or IoT for greater control of flow management. Enterprises should consider, when possible financially, new upgrades of Industry 4.0, where there is a greater logical connection of all devices and media related to the production environment in question, sensors, transmitters, computers, production cells, productive planning, industry strategic guidelines, government information, climate, suppliers, all being recorded and analyzed in a database. In this new productive reality, industries must prepare for new modernizations to gain competitive advantages in the market.

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To our group of researches in LABTEC.

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