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IMPLEMENTING LEAN PRACTICES AND A MODERN CONSTRUCTION METHOD IN A SOCIAL HOUSING PROJECT

Sergio Kemmer[1] and Leonardo L. Marin[2]

ABSTRACT

The paper aims to explore the implementation challenges and advantages of utilising lean practices along with a modern construction method, i.e. timber frame prefabricated system, to accomplish a challenging goal in a social housing project in Brazil.

It presents a case study on the construction of 518 housing units, which were built in a short period to help victims of a climate catastrophe relocate. Data was collected through semi-structured interviews, participant observation, site visits, and documental analysis. The findings suggest that relying on a single lean practice or a modern construction method may not be enough to achieve demanding project objectives, such as completing a construction project within a tight deadline. Instead, it is the appropriate combination of these initiatives that will result in a better outcome.

Moreover, the study contributes to a particular issue that has not been adequately addressed by the lean community. Specifically, it sheds light on the connection between a project objective, lean concepts and managerial tools that can be used to accomplish it.

KEYWORDS

Lean practices, Last Planner® System, off-site construction, prefabrication, prototype.

INTRODUCTION

In February 2023, during the Carnival festival, the coastal city of São Sebastião in the state of São Paulo, Brazil, experienced the worst rainfall ever recorded (G1, 2023). Within less than 24 hours, approximately 600mm of precipitation fell resulting in dozens of fatalities, extensive damage to local highways, and hundreds of people left homeless (Figure 1).

After the disaster, the local government quickly relocated the affected population to sports arenas and provided temporary housing. They worked on a permanent solution and decided to construct 518 housing units within a short period of 10 months to allow the displaced people to move into their new homes and begin rebuilding their lives.

In order to achieve this challenging goal, the local government decided to utilise a modern construction method to ensure quick completion of on-site work. The modern construction methods promote a shift from fragmented project delivery methods to a more controlled environment. (Taylor, 2010). Specifically, the timber frame prefabricated system was chosen, which is one of the methods outlined in the Modern Methods of Construction Definition Framework (MHCLG, 2019). To minimize waste and add value to the population affected by such catastrophic climate event, lean practices were also applied in the design, planning, and

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construction processes. The project was led by Brazil's top company in efficient and sustainable social housing.

Figure 1: The damage caused by a catastrophe resulting from heavy rainfall. (G1)

This study explores the challenges and advantages of using lean practices and a modern construction method to complete the construction project within a tight timeframe. Moreover, it highlights the relationship between a project goal, lean concepts (i.e. conceptual ideas related to the lean construction philosophy), and managerial tools.

LEAN AS A SYSTEM

The key to successfully applying and sustaining Lean Construction concepts and tools lies in a thorough understanding of the fundamentals and consistent practice (Koskela et al, 2002).

The Toyota Production System (TPS) has served as an inspiration for the development of the Lean Construction theory (Koskela, 2000). It changed the paradigms of production management, bringing to light simple and innovative ideas based on a common goal: increasing production efficiency by eliminating waste consistently (Ohno, 1997). The following figure, known as the TPS House, shows the basic elements of the system.

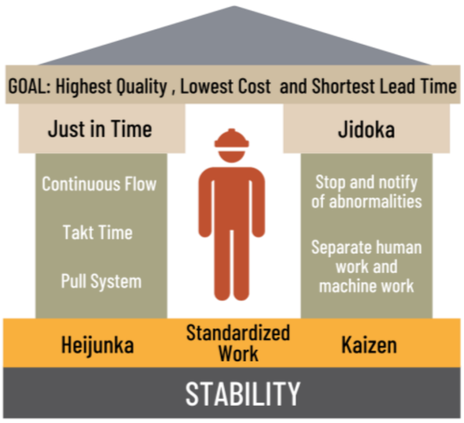

Figure 2: Toyota Production System House (Adapted from Lean Enterprise Institute).

On the roof of the house are the TPS goals (highest quality, lowest cost, and shortest lead time). Just in Time and Jidoka are the system's support pillars. Stability is the foundation. The person at the centre represents respect for people. Understanding the meaning of each of these elements is a mandatory task for anyone who wants to embark on a Lean transformation journey. It is also worth highlighting the idea of a system brought by the TPS House, that is, for the expected results to be achieved, all parts need to be applied. Systems thinking is essential.

Furthermore, the TPS House (Figure 2) indicates the initial step in a lean implementation, namely, the achievement of production stability, which is represented as the foundation of the house. The creation of a stable workflow is a prerequisite for the deployment of more advanced lean concepts (e.g. continuous flow) that will enable the achievement of project objectives (e.g. compression of lead time).

The Last Planner System® (LPS) is a well-known lean tool in construction for production planning and control (Ballard and Tommelein, 2021). LPS aims to promote stability in production flow and facilitate rapid learning (Ballard, 2000). Therefore, it is advisable for construction companies to start their lean journeys by implementing LPS (Koskela et al., 2002).

It is worth mentioning that the LPS is not the only lean practice available for supporting the creation of stability. There are many other initiatives that can be employed during design and planning processes with the purpose to remove uncertainties associated to the product and its production process such as the early involvement of cross-functional teams (Ballard et al., 2002; Laurent and Leicht, 2017; Laurent and Leicht, 2019), Design for Manufacturing and Assembly (Rankohi et al., 2022), Building Information Modelling (Sacks et al., 2018), First Run Study (Saffaro, 2007; Hackett et al., 2015; Aslesen et al., 2023), and Production System Design (Ballard et al., 2001; Barth et al., 2020). The literature on these management practices is extensive and it is assumed to be well-known and thus omitted from this section.

THE PROJECT

This paper presents research conducted as part of a project to reconstruct housing for those affected by landslides. The construction involved 518 housing units, which were distributed across 30 four-story blocks. Each floor of the blocks contained four apartments, with an average area of 47.29m². In addition, there were 38 houses, each averaging 44.16m². In total, the entire project spanned over an area of 24,377m².

Three companies were hired by the São Paulo State Government to undertake a project. Each company was responsible for a specific aspect of the project, which was divided into infrastructure, assembly and installations, and finishes. The industrialised timber frame panels were manufactured in a city located 500km away from the site. A total of 6,124 panels were then transported by truck to the assembly location. During the 10-month operation, approximately 450 people worked on the project, which covered the period from the beginning of the first excavation and manufacturing to the delivery of the housing units to the residents.

In addition to the challenges related the tight timeframe, the project attracted significant media attention due to its status as a public work contracted by the government, employing a construction method considered innovative in the country.

RESEARCH METHOD

A case study was carried out to investigate the implementation issues and benefits of utilising lean practices along with a modern construction method, i.e. timber frame prefabricated system, to construct 518 housing units within a short period of 10 months. The research was structured in three phases: diagnostic, training, and implementation. The objectives set for each phase along with the methods used in this investigation is presented in the following table.

As shown in Table 1, the first phase of the study was exploratory. Data was collected prior to the commencement of works on site through semi-structured interviews (engineering manager, production planning and control coordinator, head of operations, process engineering coordinator, quality manager and site agents), direct observation of works on the prototype built offsite, and documental analysis (production plans, production rates, and problems faced in previous projects).

Table 1: Research process.

Items	Phase 1 (Diagnostic)	Phase 2 (Training)	Phase 3 (Implementation)
Objectives	(a) understanding the characteristics of the project and typical issues faced in previous projects (b) discussion on which managerial tools should be implemented to compress project lead time	(a) raising the awareness on lean fundamentals (b) practical application of lean concepts and tools such as Takt Planning, Production System Design, Last Planner System	(a) discussion on the implementation issues and the benefits reaped through the application of lean practices
Research methods	Semi-structured interviews, direct observation, documental analysis	Training sessions delivered to the project team	Participant-observation in planning meetings, documental analysis

The second phase involved training sessions on lean fundamentals such as value, continuous flow, and continuous improvement. Besides, production system design, takt planning, Last Planner System® were also addressed throughout the sessions through practical exercises.

The deployment of the lean practices was conducted in a collaborative fashion during the third phase. A cross-functional team involving the the engineering and innovation director, project manager, design representatives, procurement manager, site agents, safety coordinator and planners were engaged to promote collaboration in order to ensure a successful implementation. Follow-up meetings were led by the production planning and control coordinator on a fortnightly basis to discuss the implementation issues, project progress, opportunities for improvement and the benefits reaped through the application of lean practices.

Due to the objectives set for this study, the findings reported in this paper are focused on phase 1 (i.e. discussion on which managerial tools should be implemented to compress project lead time) and phase 3 (i.e. discussion on the implementation issues and the benefits reaped through the application of lean practices).

ON THE INITIATIVES TO COMPRESS PROJECT LEAD TIME

Several initiatives were taken to shorten lead time as this was the aim of this project. The first decision made in this regard was the selection of a construction method appropriate for a project with a tight timeframe. The timber frame prefabricated system was chosen because it increases the efficiency of the construction process as opposed to the artisanal process traditionally used in Brazilian construction sites. The timber frame panels are produced off-site in a controlled environment with the support of an automated production line, thus increasing the levels of quality, safety, and productivity. The panels are sent to site fitted with electrical and plumbing installation kits and windows, hence simplifying the construction process by reducing the number of steps to be done on site.

Besides the choice of a suitable construction method, lean concepts and tools were deployed across project phases (Figure 5) to ensure that works on site was completed as quickly as possible. To achieve a design solution that would help the production teams to avoid stoppages on site as well as increasing product quality and safety during installation, the DfMA (Design for Manufacturing and Assembly) approach, BIM (Building Information Modelling) and a physical prototype were adopted. In the planning phase, a Production System Design was conducted by a cross-functional team with the support of BIM Models to remove uncertainties in order to promote a stable production workflow. Takt Planning was also applied to create a continuous flow that would help shorten production lead time. In the construction phase, the

Last Planner System® was implemented to ensure works on site were conducted as planned along with Visual Management and a Continuous Improvement approach to enable agility in dealing with deviations from the original plan. The following figure summarises the lean practices implemented across the project phases. Further details on the implementation of these initiatives are provided in the next sections.

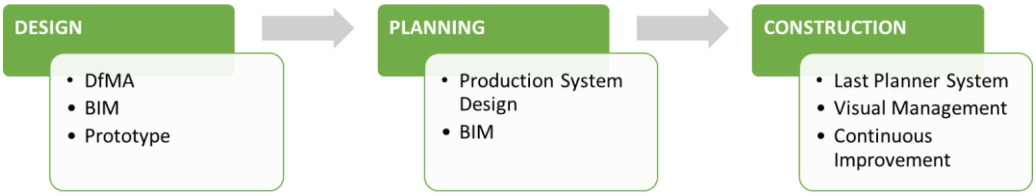

Figure 3: Lean practices implemented across project phases.

DFMA

The DfMA principles, which DfM involves minimizing the number of components whereas DfA focuses on streamlining assembly (Gao et al., 2018), were introduced to the engineering teams after the conclusion of the conceptual design phase and prior to the creation of detailed drawings. This collaborative effort involved design engineers, the safety manager, as well as production and assembly coordinators and analysts. The primary objective was to streamline and optimize production and assembly operations with a focus on safety.

During this phase, two four-hour meetings were conducted, engaging all team members. The initial focus was on defining the manufacturing and assembly sequencing to ensure the most efficient operational utilization. Subsequently, following the initial planning, 15 new subproducts were identified and categorized as potential project risks. This identification prompted the necessity to prototype these elements, encompassing 2 structural components, 2 roof-related elements, 5 installations, and 3 external finishes.

BIM

The application of BIM was undertaken with a focus on industrialisation, with a view to achieving a high level of detailing and fidelity to reality through the use of a specified Level of Development (LOD). The resulting model was then analysed to validate solutions and interfaces, providing the basis for informed discussion and decision-making involving people, technology, processes, and policies to ensure the achievement of business objectives, during the production process. – as it is common when BIM is applied as a working methodology.

As highlighted by the Engineering Manager, "developing a design for an emergency project that requires rapid delivery demands a high level of decisiveness in engineering decision. There is no room for error during construction, which makes decisiveness even more crucial when it comes to industrialisation and repetition of the same typology. Even a minor error can easily become a systemic problem, which is why the use of BIM is essential. By utilising BIM models, clashes between different disciplines can be detected at an early stage, design solutions can be better assessed and discussed, construction stages are properly defined, training sessions can be delivered in a higher quality in order to get the operational team ready in the best way possible. This ensures that there are fewer issues due to design omissions or project failures". Also, the information contained in the modeled objects allows for an accurate quantity takeoff, thus making it easier to achieve assertive purchases and providing better on-site inventory control.

PROTOTYPE

To validate design and engineering solutions as well as reducing the risk of unexpected issues (e.g. time waste) on site, a two-story prototype with a roof was erected within two weeks. It was an accurate full-size mock-up of the building. All electrical and plumbing installations were executed, and a complete dwelling was finished. Figure 4 shows results from the prototype implementation.

Figure 4: Two-Story Prototype built off-site.

The development of the prototype was a collaborative effort involving the engineering manager, operations manager, project coordinator, manufacturing and assembly teams, and the electrical and plumbing subcontractors. Upon its completion, a thorough assessment of the prototype revealed the existence of 16 non-conformities. These issues were attributable to either flaws in the product definition or errors during the execution process. A depiction of these non-conformities is illustrated in Figure 5. Subsequently, measures were taken to address and mitigate these issues before commencing the mass production phase.

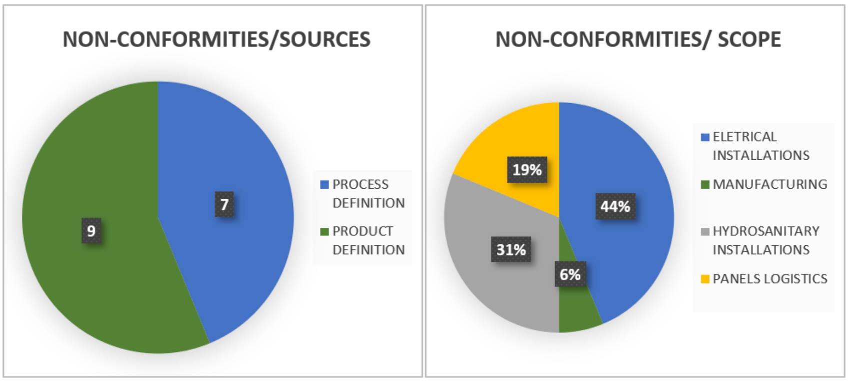

Figure 5: Number and type of non-conformities.

The oversight conducted by the project team facilitated the validation of the hourly schedule for the execution of electrical and plumbing installation activities. These activities were deemed critical due to the significant number of non-conformities identified. The project coordinator emphasised that the prototype provided valuable insights such as the importance of carrying out all activities until their completion and ensuring the precise measurement of parameters such as production rates and materials.

PRODUCTION SYSTEM DESIGN AND TAKT PLANNING

The Production System Design aimed at organizing the production system by establishing a structure that served as a reference for production planning, control, and improvement. The scope of decisions involved: definition of work packages, production sequence and activity durations, analysis of the workflows of crews on site, definition of the project execution strategy, capacity analysis of production resources, site layout and logistics planning. The Takt principle was also applied with the purpose of enabling continuous flow, hence allowing the compression of project time. The engineering and innovation director, project manager, design representatives, procurement manager, site agents, safety coordinator and planners were involved in this phase.

Four meetings of four hours each were necessary to conclude the work. They were structured according to the scope of works abovementioned, namely, the first and second meetings focused on work structuring and sequencing as well as production flow analysis whereas the third and fourth meetings addressed the definition of project execution strategy, capacity analysis of production resources, site layout and logistics planning. These collaborative sessions were held in the headquarter of the general contractor prior to start of works on site. The main outcome of this work was the development of the strategic production planning, which was represented in a line of balance. The work packages and resources (labour and equipment) required to carry out the production tasks were also sorted by the team.

LAST PLANNER SYSTEM®

The Last Planner System® was deployed with the purpose to stabilize production workflow to allow the implementation of continuous flow as well as promoting a culture of continuous improvement. Two pull planning sessions were carried out to specify handoffs and conditions of satisfaction of two key processes defined by the team, namely, electrical installation and plastering. Lookahead meetings were conducted on a fortnightly basis. Weekly meetings were held for assessing production progress as well as learning from mistakes. Daily huddles were also implemented to allow front line supervisors to share commitments completed as well as making clear what commitments need help with or cannot be delivered. These daily meetings happened at the end of the day and lasted 30 minutes approximately.

VISUAL MANAGEMENT

Visual tools such as line of balance and charts displaying attributes related to production planning (e.g. Percent Plan Complete, reasons for task non completion, countermeasures, etc.) were deployed on site to increase process transparency and allow the project team to quickly identify deviations from the plan. Furthermore, a Big Room was set up on site to foster communication and collaboration among project participants as well as supporting management routines such as daily huddles and weekly meetings. It is worth mentioning that visual aids such as BIM Models and wallcharts with sticky notes were also used during the development of the production system design and takt planning.

CONTINUOUS IMPROVEMENT

A continuous improvement approach was implemented by identifying and analysing the root causes of problems. The 5 Whys technique was used for this purpose. The project team applied countermeasures to promote stability and improvement in processes, which were reviewed daily during huddles at the end of each workday. Weekly meetings were held to assess project progress. The continuous improvement approach was also applied during the design and planning phases of the project, with management practices such as DfMA, prototyping, and production system design prompting changes to improve performance.

DISCUSSION

In this section, the authors describe the implementation challenges and advantages of utilising lean practices and a modern construction method, i.e. timber frame prefabricated system, to accomplish the construction of 518 housing units in 10 months. This analysis is structured according to the project phases, namely, design, planning, and construction. Furthermore, the connection between project objective and the lean concepts and managerial tools that can be used to accomplish it are also discussed by the authors of the paper.

DESIGN PHASE

A relevant issue faced in this phase was the short time available for developing and validating the design. As this project had a particular feature, namely, it was a response for a catastrophic event where people had been displaced from their homes, the engineering team had to develop the design solution faster than what they usually do in traditional projects in order to releasing the production of prefabricated panels to be shipped to the construction site. According to the Engineering Manager, the design development for a new building normally takes 60 to 90 days. However, due to the tight timeframe, the engineering team decided to use a design solution that had already been tested before. Consequently, only a few minor enhancements were made, therefore reducing the design lead time to less than 30 days.

Another important challenge was to start the production of prefabricated panels as soon as possible to meet the on-site demand. The ideal approach would be to produce a prototype first, validate its components, and then proceed with further production. According to the project coordinator “it's important to fully validate each component of the prototype, including time, execution processes, and materials used, before moving on to further production. If any component is only partially validated, it may result in waste generation”. However, it was not feasible to produce all the required timber frame panels within the given timeline due to the limited production capacity of the factory. As a result, some of the panels were manufactured beforehand and kept in storage offsite. This led to rework on site due to technical problems discovered only at the end of the prototype evaluation phase.

It is important to note that despite the challenges mentioned earlier, the virtual model created using BIM, along with the physical prototype, proved to be effective in helping the team to evaluate potential issues, refining solutions and ultimately achieving a high level of precision and accuracy throughout construction. Besides, it helped validate some key factors for the project. This includes the validation of engineering assumptions and the production rates for electrical and plumbing installation activities. These activities were found to have a higher number of inconsistencies in design specifications and constructability, and were identified as the most critical, making them the focus of special attention during the planning and construction process.

PLANNING PHASE

The main issue faced during the planning phase was the lack of collaboration between the three main contractors hired by government to undertake the project. The company responsible for carrying out the infrastructure services, which was a basic requirement for allowing the assembly of timber frame panels, did not participate in the meetings held to carry out the production system design. There was no commitment to the dates considered in the strategic production planning hence affecting the work conducted by company responsible for installing the prefabricated timber panels.

Another relevant issue faced by the project team was the lack of reliable data on production rates to perform the Takt Planning. Without a sound database it was difficult to adjust the level of work to achieve the production pace set for the project. Although some data were gathered during the execution of the physical prototype (e.g. electrical and plumbing production rates), there was no information available for all services required to be carried out on site. Besides, the data collected in the prototype did not consider the site conditions where material logistics was more difficult to be handled than what was faced during the simulation conducted in the prototype built in a controlled environment. Hence, adjustments had to be made on site after the construction of the initial blocks, but this exposed the project to a risk of having to allocate extra resources to cope with the production pace originally planned. Hiring additional crews in a timely manner to work in an underway project located in a remote area was not an easy task. This issue ended up having a negative impact on the works on site due to the dependencies among services. The delay in one task affected the start of the next and this created an undesirable effect, namely, deviation from the original plan.

The production system design meetings prompted the early involvement of cross-functional teams from the company hired to install the timber frame panels. People from different departments such as engineering, supply, quality, safety, production (factory), operation (site agents), besides the engineering and innovation director worked in a collaborative fashion to create an effective production plan. The presence of a senior-level leader along with a multidisciplinary team improved the quality of the discussions as well as the commitment to the plan because people felt appreciated to take part in its development.

Another benefit noted during the production system design meetings was related to the use of BIM models to speed up the process of quantitative take-off. This information was required for calculating the amount of work that needed to be done by the crews on site. These quantities are an important input for Takt Planning, hence calculating them in an automated manner saved time and increased accuracy.

CONSTRUCTION PHASE

The lack of consistency in conducting the routines established by the Last Planner System® (LPS) was one of the main issues faced during the construction phase. According to the production planning coordinator, this was due to the lack of training on the fundamentals of LPS for the subcontractors engaged later in the project. This problem was tackled by a three-day training session held on the construction site to raise awareness on basic lean concepts with a focus on the implementation of LPS. As a result, the engagement of the subcontractors increased and their behaviour during the planning meetings improved, i.e. they became more collaborative. Another important action taken to improve the commitment to the planning process was the provision of a financial incentive for achieving goals. The team received a bonus when production targets were achieved. It is noteworthy that the LPS training was not carried out for the three main contractors hired by the government. Only the company responsible for installing the timber frame panels and its subcontractors were involved in the lean implementation.

The application of LPS resulted in a more stable production flow. This condition enabled the implementation of the takt principle and allowed construction processes to be carried out in a nearly continuous flow, hence contributing to the accomplishment of the project deadline. The daily huddles had an important role in in providing agility in the resolution of issues found out on site. The use of visual aids in the Big Room displaying the production targets against the actual performance was also instrumental to enable the rapid identification of deviations from the original plan, hence prompting improvement actions in a timely manner. Equally important was the use of a software tool for modelling the line of balance as it allowed a more agile approach to project control during the weekly planning meetings.

THE LINK BETWEEN PROJECT OBJECTIVE AND THE LEAN CONCEPTS AND TOOLS

The compression of lead time was the main goal of the project investigated in this research due to the context mentioned in the introduction section of this paper. Therefore, the selection of lean practices aimed at achieving that specific objective. The following figure summarises the rationale applied by the authors.

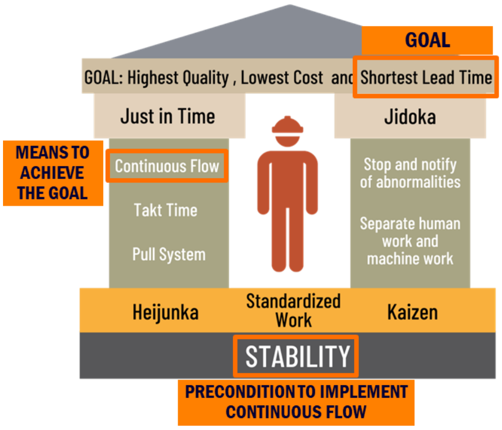

Figure 6: Connection between the elements of the TPS House.

Based on Figure 6, it can be argued that there is a logic behind the sequence of actions taken to achieve the project goal. If one wants to compress lead time (goal), then applying the principle of Takt is an effective way to attain continuous flow (means to achieve the goal), which in turn will lead to the achievement of project objective. However, there is an important precondition to implement continuous flow, namely, stability. Therefore, the selection of lean practices to be applied in the project aimed at creating a stable workflow on site to enable the implementation of a continuous flow and, hence, the compression of lead time. Visual management and continuous improvement practices were also adopted to support the identification of deviations from the original plan, project stabilisation, and rapid learning.

CONCLUSIONS

This study demonstrates that the application of lean practices across different project phases (i.e. design, planning, and construction) coupled with a modern construction method (i.e. timber frame prefabricated panels) can be an effective approach for delivering an emergency construction project in a tight timeframe. It leads to efficiency gains, waste reduction, and value to the customer. The main evidence of such benefits was the achievement of the challenging goal set by the government, namely, the delivery of the 518 housing units in 10 months.

Among the implementation issues described in the paper, it is highlighted the lack of integration between the three main contractors responsible for undertaking the project. Only the company responsible for installing the timber frame prefabricated panels and its subcontractors engaged in the lean implementation whereas the other two main contractors had not adhered to that. This undermined a better performance of the project as a whole since there were dependencies between those companies.

Another key issue noted in the study was the lack of a reliable database on production rates, which have impacted the quality of the production system design and exposed the project to unnecessary risks. Prototyping was an important initiative for helping with this issue and the knowledge on site status was deemed as critical for adjusting the data collected offsite.

Finally, regarding the selection of lean practices to be applied in the project, an important lesson was learned by the managers of the company. Lean should be seen as a system. Thus, having a solid understanding on the relationship between the lean concepts and choosing appropriate lean tools is crucial to achieving project objectives. Systems thinking is vital!

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