Value Stream Mapping of the Design Process in a Design-Build Firm

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Abstract –

With a scenario of intense difficulties faced by the construction industry, improvements of the productive processes are demanded in order to make them more efficient, optimizing resources such as human, materials and financial ones, aggregating quality to the delivered product. Thus, this study aims the application of a methodology of improvement in the design process, under the lean approach, in a design-build firm, including the usage of the tool Value Stream Mapping (VSM). The VSM is initiated from the first contact with the customer to the final design and construction documents delivery. As a result, high levels of interruption and waiting for information have been detected. It has been verified a total lead time of 50 days, with only 21.28% corresponding to the effective execution time of activities. The analysis of the negotiation phase indicates a consumption of 32% of the total cycle time and in the design phase it was observed that just 30.68% of the time is utilized on activities which generate value for the customer. Besides, there is a loss of €84.93 in materials and services. With the implantation of kaizens, it is proposed to lower the total lead time in half of the initial amount. Therefore, the simple usage of lean tools contributes to reduce waste.

Keywords –

Lean Thinking; Lean Design; Value Stream Mapping; Design Management; Design Process; Architectural Executive Design; Private Sector.

1 Introduction

Low productivity is one of the biggest challenges facing the construction industry in the world economy. Brazil and the European Union, for example, play about 15% and 75% of United States productivity respectively, indicating that there is a gap between them (Mello and Amorim [1]).

Therefore, it is more and more necessary the adaptation to new technologies and way of production from the industry making the processes more efficient, increasing in the optimization of human resources, materials and financial, but also aggregating quality to the delivered product.

In this context, there are some studies that aim to improve construction processes. Generally, these researches seek to adapt theories, methods and tools originated from manufacture to the construction sector. Lean Construction, originated from the Lean Thinking, which aims to gain quality and productivity through the reduction of waste in the construction sector. This approach has generated positive results and stabilization of the constructive processes, but there are not many studies on the application of the Lean within the administrative scope of the design firms. Thus, the gap of the knowledge that this paper seeks to fill is the application of the VSM tool in a design firm.

Studies like Lima et al. [2], Tilley [3] e Melo et al. [4] prove that problems with the design quality and documentation in the construction industry have a significant impact on the efficiency of the construction sector and are the main factors for the rework in design and projects phase.

This paper consists on the application of a methodology of improvement of the design process, adapted from Freire and Alarcón [5], in a design firm based in Natal, Brazil. The firm develops design activities, budgets, licensing and consults. The team is composed by two engineers and an intern, being this one responsible for aiding the engineers.

2 Theoretical reference

2.1 Lean Thinking

The Lean Thinking is a generalization of the Toyota Production System (TPS) (Womack et al. [6]). Idealized by the engineer Taiichi Ohno, the TPS emerges as an application of a new manufacturing technology at the Toyota Motor Company, automobile industry, after the Second World War. Its principle is based on increasing the productivity through the complete elimination of waste, defined as everything that does not aggregate value, structured in two pillars: The Just in Time and Autonomation. In this system one item is only produced when it is necessary and in the correct amount (Ohno [7]).

In the battle against the waste, main principle of the Lean Thinking, Rother and Shook [8] created the Value Stream Mapping (VSM), based on the maps of material flows and on information utilized by Toyota. The VSM is considered the most important tool in the fight against waste.

2.2 Lean Thinking Application

Freire e Alarcón [5] proposed a methodology to improve the design process and applied on 4 designs of a design firm specialized in the civil engineering, mining and industrial area. The suggested methodology by the authors is based on the Lean Design approach, which considers the application of the conversion models, flow and value to the processes of design elaboration, seeking to identify and eliminate the waste and activities which do not aggregate value.

Tilley [3] analyzed, through a literature review, that if the implementation of the Lean Design has the potential to reach the necessary quality improvements. He concluded that a Lean Design Approach has the potential to improve significantly the way the design process is managed, aggregate value to the internal customers and to the final customer and minimize the waste in the construction process through designs and documentation of better quality.

Koskela et al. [9] points out that the design management is chaotic and improvised. The authors applied the Lean approach in the design management of construction of a building with 7.600 m^2 in Finland, through the usage of the Last Planner system, method that used to be applied only in construction phase. The design was compared to another similar design, previously carried out by the same planners and at the same location using the conventional way of planning. The results indicated a decrease of 30% in the design time comparing to the traditional planning method, the process of the design as a whole was more disciplined in comparison with the design managed in the conventional way. Koskela et al. (1997) observed that the application of the Last Planner generated a superior process of design in all aspects and that all the involved parties saw the approach as something really positive and everybody wanted to use the method in future designs.

Lee et al. (2010) proposed the application of Lean concepts in the elaboration of proposals of megaprojects of infrastructure. The research is a case study concerning the development of a proposal of a Design-Build-Operate-and-Maintain (design, construction, operation and maintenance) project of US$ 500 million in the public sector. The study discusses the concepts of Design Constraint Analysis Choosing by Advantages (CBA), set-based design, cross functional teaming, colocation, and Target Value Design (TVD). The results indicated improvements in the collaboration between teams and in the integration between the process of design and cost estimate, and by consequence, a better performance on the conception of megaprojects and delivery of a more competitive proposal.

3 Research Method

The research method used in this paper is an adaptation from the method used by Freire and Alarcón [5] to achieve improvements in the design process. Based on concepts and Lean Design principles, the authors consider the design process composed of three models: conversion, flow and value. According to the researchers 4 stages are necessary, such as:

1. **Diagnosis and evaluation**: It aims to determine the current conditions of the process under the perspective of flow and value. At this stage Freire and Alarcón (2002) consider necessary and complementary the application of five actions to a complete comprehension of the design process. They are: the obtainment of performance indicators, the value mapping stream, execution of interviews, the achievement of the time distribution in the process, the identification of waste and opportunities of improvement.
   In this research the utilized performance indicators are based on Lima et al. [2]: Processing Time (PT), Lead Time (LT) and PT/LT percentage. Adapted from Freire and Alarcón [5] the time percentages are defined according to the distribution of activities in the process: Data collection, design, consultations, exception or rupture, time of waiting for information and time of inactivity. The study also proposes indicators for the analysis of the negotiation time compared to the time of project and to the total time.
   The Value Stream Mapping (VSM) was performed according to Tapping and Shuker [11], focusing on the information flows. The data utilized to produce the map were obtained from direct observation,

interviews and analysis of documents (through the observation of the date and time of emails and app messages, and the notes from the team's reports as well) within 3 months of follow up. Divided in 5 meetings which add up approximately 13 hours of data collection with the team of the design-build firm. It has been obtained the time distribution in the process by the VSM interpretation and analysis, the identification of waste and opportunities for improvement. Through the interpretation and VSM analysis it was obtained the time distribution in the process, the identification of waste and opportunities of improvement.

2. **Implementation of changes:** based on the stage of diagnosis and evaluation it suggests the implementation of changes in the process depending on the types of waste and problems found. In this stage the authors proposed the usage of 7 tools of improvement, classified according to the 5 areas of improvement (customer, administration, design, resources and information - CAPRI): interactive coordination; intranet; checklists before the design; checklists after the design; Quality Function Deployment (QFD); value stream mapping and training.
   It is not mandatory the application of all suggested tools by Freire and Alarcón [5], but those compatible with the company's necessities, according to the areas of improvement (CAPRI). In this study just some of the aforementioned tools were adopted.
3. **Control:** It aims to control and assess the effects of the changes made in the process. It consists on following control measures such as the time distribution and performance indicators, verifying the effectiveness of the improvements.
4. **Standardization:** It aims to introduce permanent improvements on the working methods of the company, through the formalization of changes, as well as implementing the ongoing improvement to design process through the reapplication of the methodology.
   In this study the stages 3 and 4 will not be applied because they do not fit the purpose of the research.

4 Findings and Discussions

4.1 VSM Current state

This phase comprehends the diagnosis of the current situation of a design-build firm which has as an external customer an owner of a supermarket with 382.50 m^2 of built area. Figure 1 illustrates the value stream mapping of the design package and complementary documents for purposes of legalization, atypical situation of the firm. The initial contact with the customer was via an instantaneous message app with the engineer, followed by a visit to the site. Next, due to the need to consult the appropriate procedures to legalize the project after built it, it is done a visit to SEMURB (Environment and Urbanism Department). From that, it is set up and proposal and sent to the customer.

After waiting some time for the customer to reach out, there is the negotiation phase, with adjustments of the values, payment method and, lastly, contract signing at the supermarket. The team visits the project to data collection for the architectural executive design (AED) sketch, after some mishaps. Ultimately, with all the measures of the building collected in the field, the intern begins the digitalization of the data collected and the location of the points for the drainage design. When the file is received, there is the first review of the architectural executive design.

In the next phase, there is the sewage and drainage design sizing and respective specifications. In the drainage design some doubts about the position of the water tank on the roof came up. Therefore, there is a waiting time for information, due to other ongoing activities and the engineer just reaches out on the next day to obtain the answer from the customer and next, an interruption of a working day because of external factors not related to this VSM. The architectural executive design is resumed, followed by another interruption.

The engineer starts the draft of the drainage design from the data collected during the technical visit and, once it is concluded, it goes to the intern in order to finalize the design. For the execution of the RIV (Neighborhood Impact Report), the engineer consults with the SEMURB to eliminate doubts and requests the customer data such as: Schedule of the garbage truck, data of the sanitation in the area and public transportation; and, the property title. After receiving them, they can be included in the RIV.

The team schedules another technical visit for the approval of the architectural executive design, with a wait of 2 days due to incompatibilities of schedules among the team, and other data for the RIV: working schedule of the supermarket, number of employees, way of solid waste packaging and water table level. On this visit, the customer decides to incorporate one more floor in the architectural executive design. Afterwards, there are two working days with no activities connected to the customer's design. Coming back, the team works in parallel: the intern proceeds with the architectural executive design, the engineer works on the elaboration of the schedule and the other engineer finishes the RIV, designs the fire design and continues the architectural design from the last update from the intern.

The intern includes some architectural design changes demanded by the customer, corrections on the

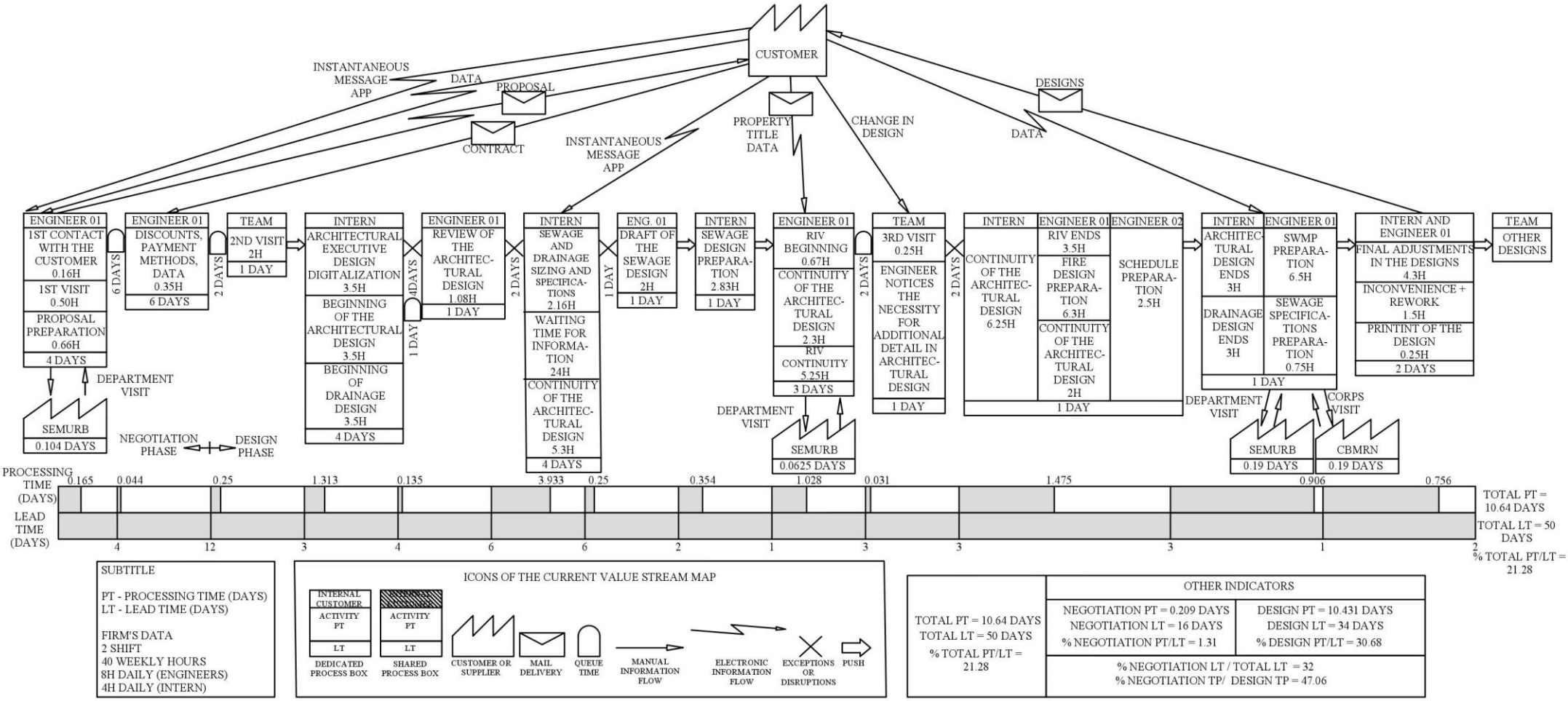

Figure 1. Current State Map.

drainage design, then conclusion and organizes the layout of printing of the architectural design. In parallel, the engineer consults with SEMURB and the CBMRN (Military Firefighter Corps of Rio Grande do Norte State), through the Engineering Technical Service (SERTEN) about the access stair on the fire design of the first floor. With the data which were requested from the customer, it is done the solid waste management plan (SWMP). The engineer requests the sewage memorial already finalized by the intern, but to avoid the waiting for information, elaborates a new sewage memorial.

Together, the engineer and the intern make final adjustments on the designs and plot the boards and reports, but because of the lack of colorful printer cartridge ink, the boards of AED are not printed and because of this they decide to send them to a print shop. Having the printed designs, the engineer delivers to the customer, however noticing some flaws on the printing of the architectural boards, this is corrected and plotted again by the print shop. Lastly, the designs, reports and specifications are delivered in person to the customer.

Summing up the lead time of each activity results in the total lead time of the process. In the study, it was verified a lead time of 50 days, from which only 10.64 days correspond to a processing time. Therefore, the activities do not aggregate value correspond to a total of 78.72% of the process.

The process can also be divided in two sub processes: the negotiation phase and the design phase, after getting the contract signature from the customer. The negotiation phase presents a lead time of 16 days, from which just 1.31% represent the actual time of value aggregation. In the design phase, the lead time corresponds to 34 days. From these days, only 10.431 equals the lead time of each activity. In other words, the only activity which adds value to the process is the design process, but only 30.68% of the cycle time is used for that. It is important to point out that the established deadline by the parties on the contract for execution of the activities was 30 days, surpassing in 4 days what had been previously defined. On the feedback the design-build firm cites modification in the architectural executive design as a motive.

Facing the expressive time of lead time negotiation, this value was compared to the total LT and design LT. As a result, it was obtained 32% and 47% of the time, respectively, indicate the negotiation percentage. This shows the high time consumption with the customer, which could have been done by another professional.

There were identified activities which do not aggregate value to the process: Wait of information from external or internal customers, wait for updated designs and documents

On the system, computer lagging, interruptions due to other customers (conversions of the digital file versions or plotting). And routine tasks of the technical room such as: plotting, folding the site plans, signature collections, stamps, answering the telephones (Lima et al. [2]). It also identified how much cost the wastes indicated in Table 1 and Table 2.

Table 1. The cost of the 3rd technical visitation (unnecessary)

Waste	Cost (€)
Transportation	5.14
Hourly cost of team work (1h25)	30.78

Table 2. The cost of the printings with errors

Waste	Cost (€)
Material	14.80
Transportation	5.14
Engineer's rework cost (1,5h)	17.44
Engineer's work hourly cost (1h)	11.63

The total cost of these wastes result in € 84.93 (Adjusted according to the currency exchange rates on January 7th, 2018), the current year.

By the time this research was conducted, the design team had other 7 ongoing designs, shifting the priority of other activities between parallel designs.

4.2 Future state map

Aiming to reduce the waste, the suggested value stream modifications are next, illustrated on the map of Figure 2.

1. **Technician assistant of engineering:** The time wasted by the engineer could be minimized if the first contact with the customer for negotiation goals (such as visits and elaboration of proposals) were through a technician assistant of engineering. Besides, the technician would be responsible by the consults with external institutions, when requested.
2. **Reducing the validity of the proposal:** The reduction of the validity of the proposal from 30 to 10 working days pressures the customer to return to contacting the firm as fast as possible, reducing the answer time from the customer.
3. **Communication optimization:** In the negotiation phase, it is suggested the contact from a phone call and confirmation via email with the with a deadline established in the proposal.
4. **Interactive coordination:** It is proposed the possibility that many subjects are designed simultaneously, providing more interaction among the team, in order to avoid interferences as much as possible, allowing a parallel correction, reducing

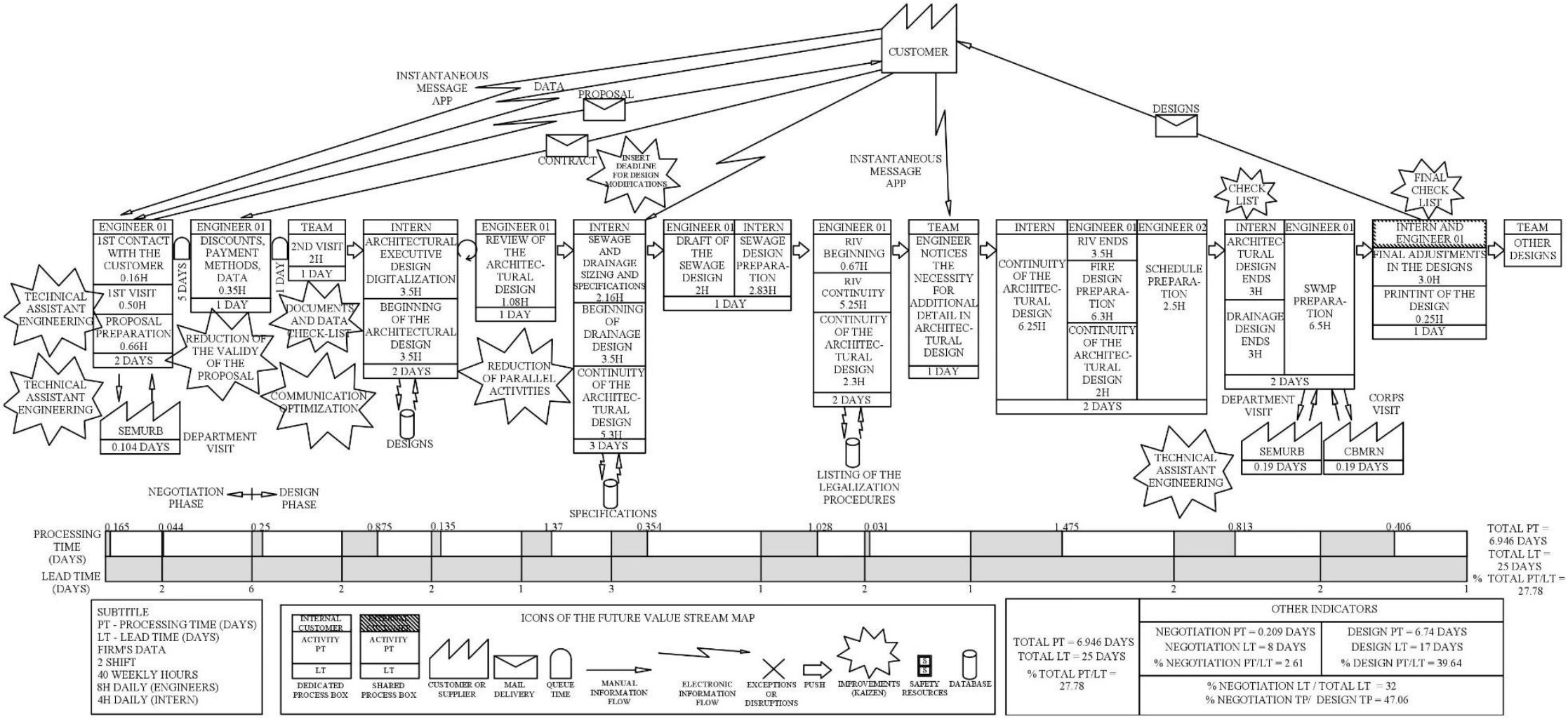

Figure 2. Future State Map.

the time of wait for information and reducing the cycle time of the drawings. It can be adopted through the implementation of auxiliary software, in BIM platform.

5. **Creation of a database (designs, sizing spreadsheets, memorials, legalization procedures and checklists):** The use of a database, with designs and documents templates, speeds up the process of digitalization and helps to reduce the PT. Analogously, it is suggested the creation of pre-programmed sizing spreadsheets, calculation specifications and legalization procedures for the daily situations. It is also proposed the usage of checklists to verify which documents and data will be necessary throughout the design process, as well as a final verification after the project is finished.
6. **Reduction of parallel activities:** It is suggested to prioritize the current design, avoiding this way the interruptions in the elaboration and corresponding documents.
7. **Use of task manager:** The software aids in the analysis of invested time in the performance of the activities. It is possible to create tasks, attribute tasks and count automatically the time effectively used in each activity. This way the team can oversee itself.

As a result of a future VSM, the total lead time of the process is reduced in half, 25 days. The total PT is also reduced, 6.946 days. In other words, the activities which do not aggregate value correspond to 72.22% of the total process time.

The negotiation phase presents a lead time of 8 days, being less than the proposed time of 10 days. In the design phase, the lead time corresponds to 17 days, from which 6.74 represents the time of execution of each activity. Thus, it is reduced the time of waste on activities that do not aggregate value in 8.96%, resulting in 60.36%. This change contributes to deliver the design within the deadline. Regarding the indicators related to the negotiation time percentage, it was kept constant in 32% of the total PT and was elevated to 47.06% the design PT. The time spent per discipline is illustrated in Figure 3, before kaizens.

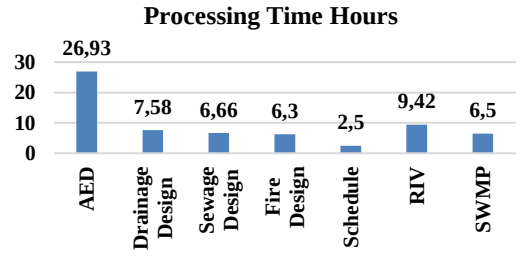

Figure 3. Processing Time Hours per discipline.

4.3 Implementation Plan

Many improvements were suggested to the design-build firm in study, and with the intention of applying the same, a plan of implementation was created. This plan targets the gradual integration of changes to the work procedures, providing the best way of team adaptation to the new techniques.

Under the supervision of the engineer, the insertion of the interactive Coordination through the use of BIM tools is divided in two stages: acquisition of the computational tool and team training. It is estimated a duration of 1 month for the first stage, which involves a cost-benefit research to choose the *software* and purchase. The team training stage lasts 3 months, divided in 1 month for each member of the team. This one was escalated in a way that the activities of the firm were not interrupted.

The *checklists* can be elaborated in 1 month, being 15 days for each list. It is necessary, for this activity, the internal data gathering of the firm about essential information for the elaboration of documents and designs of recurrent typologies at the company, under the shared responsibility between the engineer and the intern. The modifications of the proposal validity and insertion of deadlines in the contract must be done within 10 days by the engineer.

Concerning the creation of a database (designs, memorials and legalization procedures) it is expected 2 months of activity, assigned to an external consultant (a *freelancer* engineer). Regarding the hiring of a technician assistant of engineering it has been established a deadline of 6 months to the engineers. This extended time is due to the priority of the aforementioned improvements, besides the current limitation of physical space and the company's budget organization.

Among the suggested changes, just the alteration of the validity date and the hiring of a *freelancer* engineer were not deemed valid by the firm's engineers. Some of the attributions that were suggested to the technician were vetoed, as well as negotiation and elaboration of proposals.

5 Conclusions

The use of the VSM *lean* tool is essential in the identification of value adding and non-value adding activities to the selected processes flow. In this study, the VSM indicated that the lead time in the activities is fairly elevated if compared to the execution time, for the total cycle time as well for the negotiation and design phases. The study points out as reasons the long waiting time for information from the external and internal customers and interruption of the activities to deal with activities related to other customers. To minimize or eliminate the waste is did a plan of implementation of improvements and just part of it is validated by the firm, due to costs originated

from these changes.

The biggest obstacle reported by the engineer to count the time spent by the team members on the execution of the design. On the one hand, they not only worked in the design-build firm, but also on the outside, making it harder to establish the actual time spent on the design-build project. On the other hand, there is no linearity in the activities due to other needs: technical visits, consultation with public institutions, possible future clients and reception of phone calls regarding the projects of the company (clients and others), shifting the focus of the ongoing activities. Another important reported challenge is to make the team adopt the changes made, despite the results and observations from this study. The fact that the team is neither Lean nor expert at this philosophy imposes difficulties to the adoption of new techniques and mainly the change of attitude in the organization. The engineer notices not only the need to show the losses and offer solutions, but also to transform the culture and organizational thinking of the company; the training of the current and the new members about the Lean approach also stands out.

At first the firm was reluctant to recognize that the design lead time surpassed the established deadline of 30 days. Thus, the results of the VSMs were eye opening so the team could accept that there was room for improvement in their production process. As future perspectives, the engineers decided to hire an intern of engineering and initiate a software course to BIM architecture concept. Due to the fact of not being a lean firm, the suggested changes have some barriers at first, but ones that decrease as long as the team lives their benefits (Leite and Neto [12]).

Overall, the Lean Design approach provides gains of quality to the design process. With proven improvements in the reduction of the cycle time, waste and rework, besides the delivery of more value to the customer in less time and with less cost if compared to the current design techniques.

As a limitation of the paper, there is not a mapping of activities done during the interruptions of the studied flow and other current processes in the firm in the same period of this research. For future studies, the paper suggests executing the same method of research at other bigger firms, with the performance of similar activities and mapping the current state, developing the future VSM and comparing the results.

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