ACHIEVING A LEAN DESIGN PROCESS

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ABSTRACT

An improvement methodology is proposed for the design process in construction projects. Based on concepts and principles of Lean Production the methodology considers the design process as a set of three different models: conversion, flow, and value. Four stages are necessary to produce improvements and changes: (1) diagnosis/evaluation, (2) changes implementation, (3) control, and (4) standardization. The methodology suggests the application of seven tools in accordance to specific needs (detected and desired) on five potential areas of improvement (CAPRI): Client, Administration, Project, Resources, and Information. Results of an application included: an increase of 31% in the share of value adding activities, 44% reduction of unit errors in the products, up to 58% decrease of waiting times in the process, and an expansion of the utilization in the cycle times. In this manner, not only did the efficiency and effectiveness of internal engineering products improve, but also the whole project, by improving one of the main suppliers of construction.

KEY WORDS

Lean design, design process, flow, value, value stream mapping, CAPRI, improvement methodology, design management.

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INTRODUCTION

The influence of the design stage on the outcome of construction projects both technically and economically is extremely important. It is precisely in this phase where the customer's ideas and speculations are conceptualized into a physical model; defining his needs and requirements into procedures, drawings, and technical specifications. However, the administration and engineering of design has been barely explored and exemplified. In fact, numerous authors (Cornick 1991; Austin et al. 1994; Koskela et al. 1997; Ballard and Koskela 1998; Formoso et al. 1998) indicate that planning and control are substituted by chaos and improvising in design, causing: poor communication, lack of adequate documentation, deficient or missing input information, unbalanced resource allocation, lack of coordination between disciplines, and erratic decision making. The design process fails to minimize the effects of complexity and uncertainty, to ensure that the information available to complete design tasks is sufficient, and to reduce inconsistencies within construction documents (Tzortzopoulos and Formoso 1999). Even if the nature of the design process justifies some of these problems, this reality cannot be viewed as satisfactory.

Design management has attempted several responses to solve the problems mentioned above like: project management, concurrent engineering, process models, value management, new organizational forms, and information technology support (Ballard and Koskela 1998). Even though these "state-of-the-art" design management approaches contain many interesting and seemingly effective new features, they are fragmented and lack a solid conceptual foundation; thus becoming a barrier for progress. Huovila et al. (1997) proposed a conceptual framework for managing the design process in which three different views of this process are considered: (1) design as a conversion of inputs to outputs; (2) design as a flow of information; (3) design as a value generation process for the clients. This set of perspectives allows a more solid conceptual foundation of design and engineering, which can be comprehended as the simultaneous juncture of the three views.

This paper proposes an improvement methodology for the design process, based on concepts and principles of Lean Design. The results from an application of the methodology in a design firm are shown, emphasizing the potential improvements that are possible with this new approach to the design process.

IMPROVEMENT METHODOLOGY FOR THE DESIGN PROCESS IN CONSTRUCTION PROJECTS

INTRODUCTION

The basic objective behind the methodology is to consider the design process not only as a conversion model, but rather as a flow and value model. This great difference allows the process to be seen from another perspective, different from the traditional one, enabling us to discover and analyze aspects commonly veiled. The methodology is schematically summarized in Figure 1.

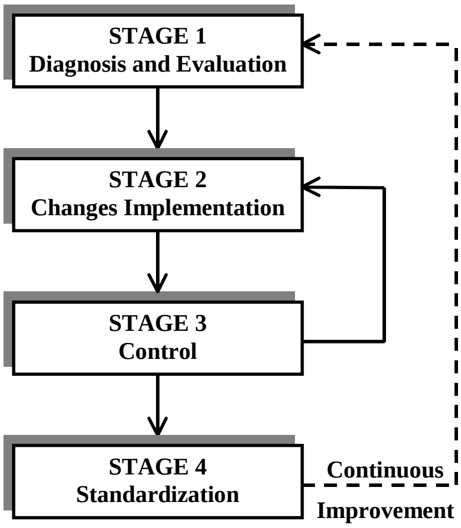


Figure 1: Improvement Methodology

In general terms, the methodology includes four phases for the improvement of the design process in projects:

1) Diagnosis and evaluation

The main objective is to determine how the process is performing according to the concepts of flow and value. Basically, in this stage diverse tools are used in order to obtain the categories of waste in the process and their respective causes, the time distribution used in the process, cycle time with its respective categories, and different performance indicators.

2) Implementation of changes

This stage considers the results of the previous phase in order to implement different changes according to the categories of waste and problems identified, with the improvement tools suggested. The methodology makes it possible for improvements to be based on the specific needs of each case, granting flexibility in its application. Furthermore it discriminates between several areas of improvement, in order to facilitate the implementation not only according to the technical requirements, but also considering the availability of resources and specific strategies of each company. The areas of improvements are the following (CAPRI): C= Client; A= Administration; P= Project; R= Resources; I= Information.

3) Control

This phase consists in the control and evaluation of some parameters in order to determine changes in performance; essentially controlling measures obtained during the diagnosis and evaluation stage, such as the time distribution and performance indicators.

4) Standardization

The objective is to introduce permanent improvements in work methods that support the design process. Also, the methodology seeks to implement continuous improvement of the process upon reiterating the methodology.

STAGE 1: DIAGNOSIS AND EVALUATION OF THE DESIGN PROCESS

A diagnosis and evaluation model of the design process was created in order to fulfill the objectives previously defined and to facilitate the use of the improvement methodology. Figure 2 graphically shows the five elements that participate in the diagnosis and evaluation of the design process in construction projects. The elements of the model focus on flow and value aspects of the design process. There is no specific order for carrying out the evaluation, but the five actions are necessary and complementary to obtaining complete understanding of the process.

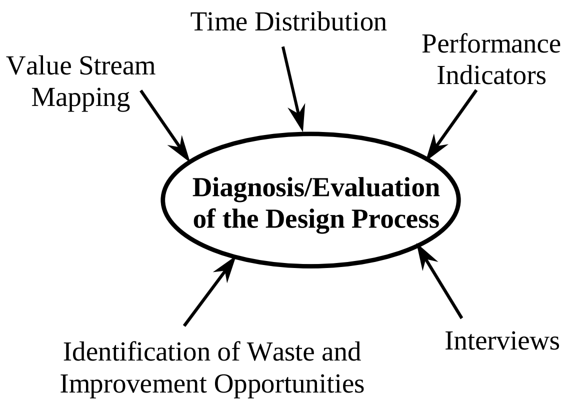


Figure 2: Diagnosis and Evaluation Model of the Design Process

(a) Performance indicators

In order to obtain an objective measurement of the quality of products in the design process, two performance indicators were defined:

1) Changes in design = number of changes/ total number of drawings (or documents);

2) Errors/ Omissions = number of errors/ total number of drawings (documents).

The first indicator delivers the magnitude of changes in projects. A change was considered as "any deviation of the original specifications and bases from design that harm and/or modify the drawings or documents in execution". The second indicator measures the quality of the drawings and documents in the design process. Errors and omissions were considered equally by being "any non conformance to requirements of the specifications and design criteria in the drawings or documents." It is necessary to emphasize the importance in the control of the information in order to be able to compile the required data. However, since the objective of this methodology is not only to improve the internal design process but also to facilitate the construction and start-up of the project, it is necessary to be a good "supplier" for the construction process. This means that it is convenient to group these indicators for drawings and documents of several areas for construction, called “design packages”. In general, designs have identification numbers for specific areas of the project that can be used to measure performance. In this way, the variation is obtained of the quality of the drawings and necessary documents in order to physically advance in the project.

Special attention should made when measuring and comparing these performance indicators in different environments. Even though most drawings are produced in computers, the total number of drawings generated varies greatly with those that are hand-made (usually fewer), thus changing the values of the indicator. As a general rule, one should use the performance indicators for products created in similar conditions.

(b) Time distribution in the process

It is essential to obtain the time needed for the design process, but even more so to discover its distribution. The concept of characterizing the distribution recognizes the entire process according to the flow view, with the activities that add and do not add value to the product.

Most design companies strictly control the release dates of drawings or documents. However, the internal design process that is generically composed of: data recollection, design, review, correction, and release is not quantified. One could observe that the only activity that adds value is design, all the other activities are waste and should be reduced or eliminated. In order to calculate the duration of the design process, it is necessary to determine the cycle time defined as the "number of work days elapsed between the beginning and end of the drawing (or document)".

(c) Methodology to identify waste and opportunities of improvement

In order to obtain an appropriate notion of the categories and causes of waste, with their frequencies and relations, a methodology created by Alarcón (1997) was adapted for the area of engineering and design.

(d) Value stream mapping

Using value stream mapping (Rother and Shook 1998) for the design process is vital to 'visualize' the process in "lean" terms.

(e) Interviews

Interviews are used to detail and clarify results. Interviews also serve as a brainstorming tool to define problems and create cause-effect diagrams to analyze processes. In addition, they incorporate the human aspect in the methodology, allowing the acknowledgement of the reality of the process.

STAGE 2: IMPLEMENTATION OF CHANGES - IMPROVEMENT TOOLS

The improvement tools are classified based on five areas (CAPRI): client, administration, project, resources and information that interact as shown in Figure 3. Specifically, the design process is a part of the project, which at the same time is linked with the client inside the administration. The categories of resources and information are present in all areas, emphasizing the appropriate management of these systems. This means that flows of resources and information occur between the client, the administration, the project and the design process.

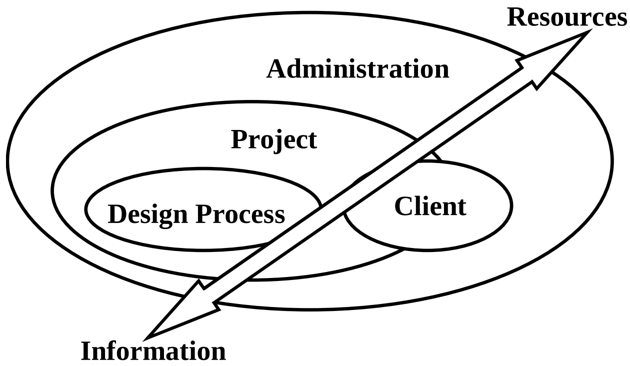


Figure 3: CAPRI (Client-Administration-Project-Resources-Information)

The following improvement tools are proposed: (1) Interactive coordination; (2) Intranet; (3) Checklist before design; (4) Checklist after design; (5) QFD – Quality function deployment; (6) Value stream mapping; (7) Training. Tools are selected so that they will work in specific fields of improvement that are appropriate to the particular needs in every case, but also according to the resources and individual strategies of each company (Table 2).

Table 2: Focuses of the Improvement Tools

Improvement tools	**Area of Improvement**				
	C	**A**	**P**	**R**	**I**
(1) Interactive coordination			X	X	X
(2) Intranet					X
(3) Checklists before design		X	X		
(4) Checklists before design		X	X		
(5) QFD	X				
(6) Value stream mapping				X	X
(7) Training				X	

(1) Interactive coordination refers to the possibility of simultaneously designing a product with the different disciplines in the project (in real time). The idea behind the coordination and parallel correction is to avoid interference and to reduce the cycle time in each drawing. Many auxiliary computer programs are available for this purpose.

(2) Intranets are ideal for expanding the uses and benefits of distributing information inside the organizations. Also, since the main flow of design firms is information, this tool becomes vital. Its use will largely diminish the time required in search of information from several sources.

(3) Checklists are one of the most fundamental tools of quality management, mainly designed as reminders and guides for workers. Nevertheless, in the best of cases, they indicate some of the important aspects to consider during the process (they almost always indicate the characteristics of the final product). In this form, using checklists before designing "shields production" (a lean strategy developed by Ballard and Howell 1998), forcing the designers to obtain a minimum of necessary requirements and information in order to begin their work and avoid costly rework.

(4) Checklists to revise the documents and drawings during their development (and at the end of their execution in order to verify their main aspects) help control the characteristics and variations of the products. In spite of the fact that the checklists of revisions collaborate to the standardization of products and reduction of errors, they are reactive tools that correct the errors after executing the activity. For this reason, it is important to emphasize the use of the checklists prior to work, that is, to use them proactively.

(5) QFD is a very useful methodology in order to determine the requirements and needs of the client (Akao 1990).

(6) Value stream mapping is an aid in improving the flow of information in the design process, by suggesting alternative methods to manage the flow. This tool creates a basis for future actions and value generation incentives.

(7) Training is essential in all productive processes. The human resource is the most valuable one of the company, and it should be trained. In the design process, engineering

is very dependent of the experience of the people, frequently used as an indicator to determine the quality or minimum requirements for tenders. Several types and degrees of training that depend on the type of company, projects, goals, strategies, etc. should be focused on knowledge of lean design principles, use of design programs, general computer skills, concepts of quality, concepts of safety.

To successfully implement changes it is advisable to consider the following suggestions.

a) Teamwork: teamwork is one of the most important features in the success of a good design (and of the project). It is essential to support the work of multidisciplinary teams, where one should incorporate representatives of design, construction, client (construction and operation) and sometimes suppliers to facilitate decisions and realization of activities, consider constructibility and quality issues, etc.

b) Continuous improvement and organizational learning: continuous improvement is necessary in order to maintain competitiveness. Generally, during the design process projects are managed based on informal experience thus typical errors are repeated by several people. Know how is not systematically shared inside the organizations. Companies need to improve the measurement of parameters in engineering and also the exchange of information (with quick feedback).

c) Flexibility: the set and environments vary from project to project. Thus, a decision of one project could be inappropriate in another. This means that the system (of work) needs to be able to adapt to these changes, having flexibility to adapt to new conditions.

d) Importance of preliminary phases of design: it is necessary to emphasize the early design phases. An early participation of construction personnel in engineering could influence a better result. Also, possible changes in the design are cheaper in the preliminary stages of the design. Changes in later phases frequently lead to extensive re-works in engineering.

e) Introducing control in the flow of activities: planning and control should be focused on the flow of activities. This is the easiest way to introduce changes and improvements (the Last Planner is ideal for this purpose, see Ballard 1994).

STAGE 3: CONTROL

The purpose of this phase is to determine the effects of the changes made in the previous stage, either from the use of the improvement tools or of the recommendations in order to implement them.

Control consists of the measurement of the performance indicators and time distribution in the process, observing variations of these values and acknowledging the effectiveness of the changes. In order to carry out control it is necessary to document the data corresponding to the errors and changes of the products (drawings and documents).

STAGE 4: STANDARDISATION

This last stage represents a formalization of the changes and total integration to the work methods of the companies. The objective is for improvement tools to be used to introduce new work methods that support the design process and permanent improvements. In other words, to create practices that promote the principles of the flow and value models. Also, each company is able to implement continuous improvement of the process upon reiterating the methodology and according to their specific necessities at a given time.

THOUGHTS ON THE NATURE OF THE DESIGN PROCESS

No engineering company is identical to another. They have different strategies, goals, organizations, procedures and work methods, resources, experience, size, etc; including diverse market segments like building design, civil or industrial works, mining and metallurgy, etc. For these reasons, the methodology must provide flexible support to design firms. Its application grants the freedom so that each firm can make the appropriate choice according to the basic concepts behind the methodology: lean design. For example, a company that has ISO 9001 certification as an objective could adapt the checklists as support tools. Also, control of the indicators and cycle time is useful in the statistical control of the process and products, which also is in agreement to the ISO normative. In the same nature, if a firm wants to completely fulfill all the requirements and needs of their client, it could opt for the QFD methodology.

Even though it is recommended to rigorously complete every aspect of the methodology in order to improve the entire process, and not just part of the process, this is not mandatory. For example, in stage 1 (diagnosis and evaluation) the methodology to identify waste and opportunities of improvement is sufficient to begin the elimination of activities that do not add value and implement actions of improvement on the causes of these waste categories. Nevertheless, this is the first step to a detailed analysis of the process (time distribution, value stream mapping, etc.). Also, in stage 2 (implementation of changes) it is not mandatory to apply all of the improvement tools; in fact the reason for the division according to areas of improvement (CAPRI) is to have the autonomy of choosing any tool based on the specific requirements of each company.

Finally, it is necessary to add that an immediate implementation of the concepts of lean design is not easy. In general, like all changes in operational methods and systems, it is a gradual process with many possibilities of failing with false beginnings. Therefore, the authors recommend beginning the implementation with everything related to the elimination of waste (kaizen on process improvements). This area shows immediate results due to the great amount of activities that do not add value in the processes and subsequently begin with value generation in the processes, mainly in relation to the client.

APPLICATION OF THE IMPROVEMENT METHODOLOGY IN A DESIGN FIRM

GENERAL DESCRIPTION

The methodology was applied in four projects of a design company mainly dedicated to the engineering of civil, mining, and industrial projects, for a period of approximately one-year. All the projects were in the detailed engineering phase and used a design-bid-build format. The company’s products were classified into two groups: drawings and documents.

The diagnosis and evaluation stage, which lasted three months, allowed the acknowledgement of the entire process. Value stream mapping was extremely useful for visualizing how the process worked, and to recognize the different activities involved. It was possible to draw a map (Figure 4) of the initial situation and categorize the time in each production stage: data recollection, design, review, corrections, release, and distribution.

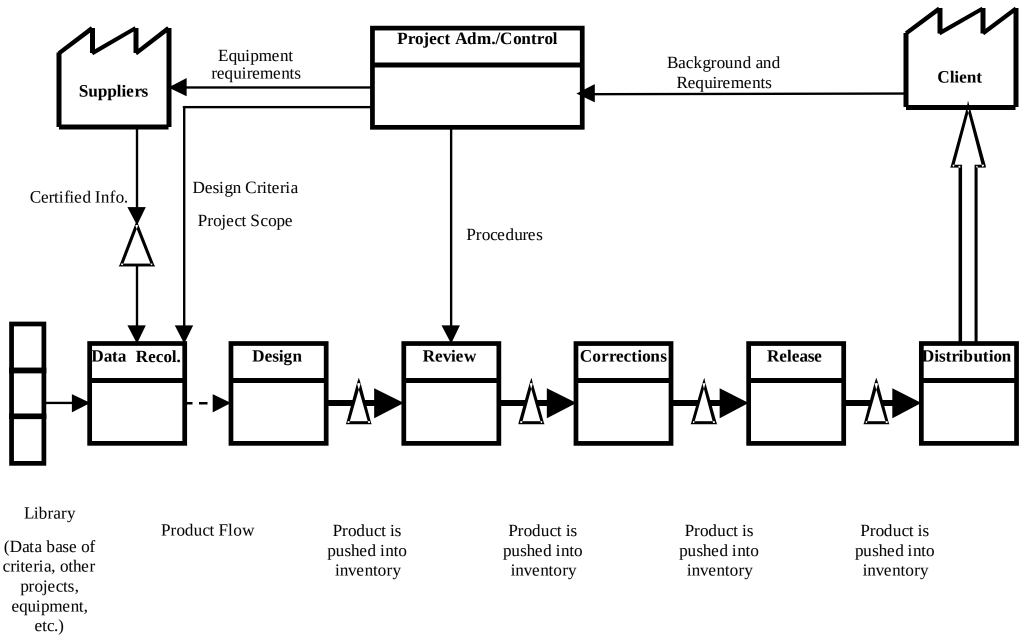


Figure 4: Initial Value Stream Map of Design Process

The principal finding was that there is a great amount of work in progress or inventories between the different stages in the production of the drawings and documents. This means that the actual time used to design was only a small fraction of the total cycle time to produce the products. Documents and drawings were, spending most of their time in inventories waiting to be worked on. As shown in Figure 5, the utilization (simply defined as the percentage of hours effectively worked in the cycle time) in the case of drawings is 31.7%. Here, it is important to emphasize the low values in the utilization and in the design stage; according to lean principles the only value adding activity in the process is design, but only 16.2% of the cycle time is used for it. However, the utilization for the documents tends to be higher, generally in the range of 45%.

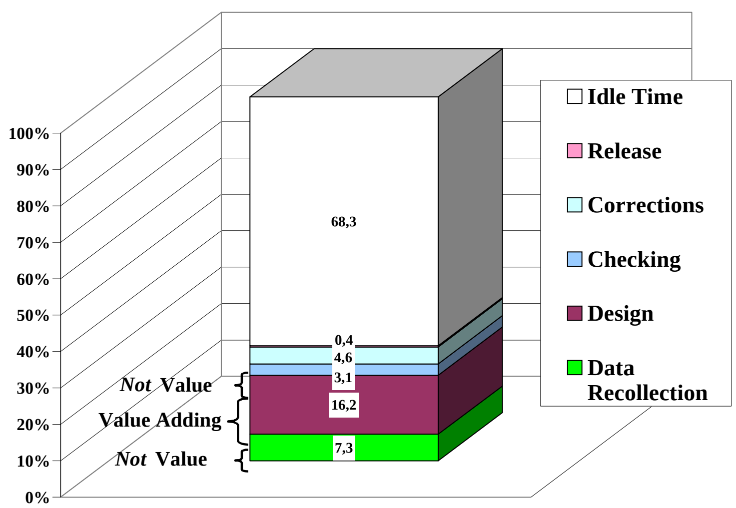


Figure 5: Cycle Time Distribution in Drawings

The results from using the methodology to identify waste and improvement opportunities (Alarcón 1997) allowed us to develop a comprehension of the main problems in the process with causes and categories of waste. An example of our analysis is depicted in Figure 6, which shows the waste frequency in the engineering process and the relative importance of each type of waste. From this same type of analysis, the following causes of waste were determined as the most important ones to reduce: lack of knowledge of client requirements, interdisciplinary coordination, bureaucracy, and information (not available).

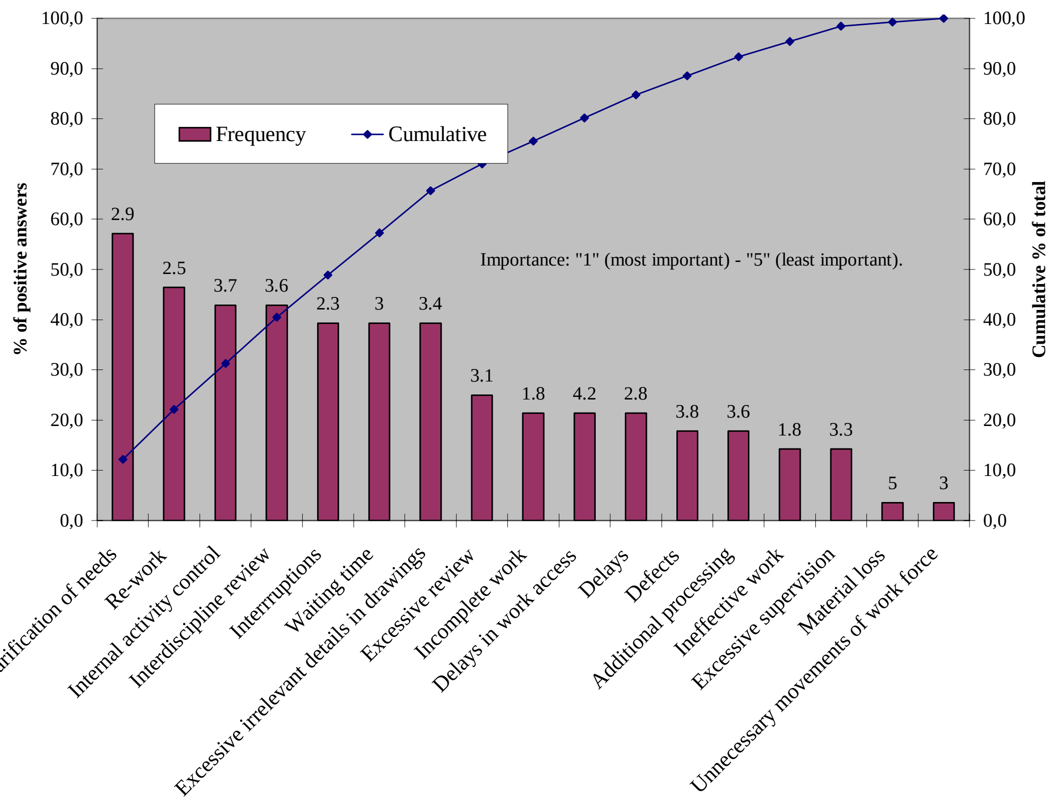


Figure 6: Waste Frequency

Improvement Actions

From the analysis of the diagnosis and evaluation stage it was necessary to draw an ideal value stream map to try to visualize how the process could be changed (Figure 7). The fundamental aspects of this new map was to eliminate the inventories and allow for a flow of products in the process, for example excluding the data recollection stage with a supermarket pull and merging the review and corrections phases. Also, the feedback between the client and the project administration are essential for value generation and a system that would deliver the products based on the client's needs. A closer look at the new map allows one to realize that using different tools from the methodology leads the design process into the ideal value stream map. For example, interactive coordination can represent the activities of review/corrections, while the intranet can be the library system with the supermarket. The idea behind the library-supermarket is to only "store" the required information for a specific project, allowing the designers to "pull" their data when needed. After the release of drawings and documents, the supermarket system paces the production with the needs of the client, thus distributing construction with the products needed to physically advance in the project.

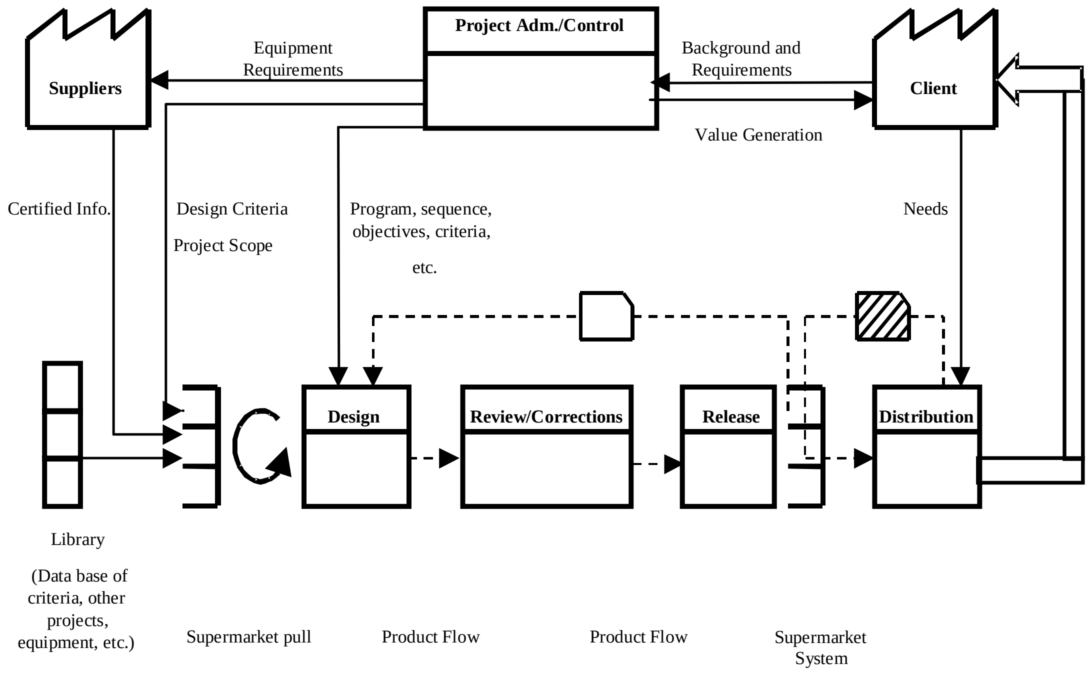


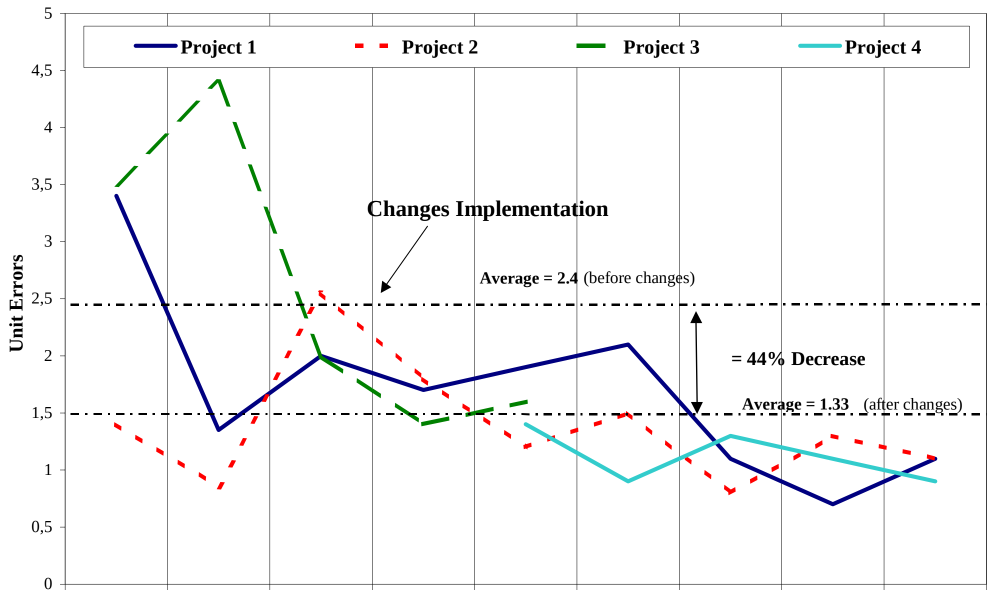
Figure 7: Example of Ideal Value Stream Map for Design Process

The improvement tools that were implemented were Intranet, interactive coordination, checklists before and after design, and training. The design firm was developing its internet at the time of the investigation which facilitated its construction to be specifically designed for the problems and categories identified in the diagnosis and evaluation stage. For example, one of the biggest causes of waste was information not being available, so a data base was organized in the intranet that was accessible to everyone. Also, the data recollection stage in the production presented the most waiting times, i.e., time that work could not be done due to variables external to workers. Again, the intranet was set up to reduce this type of wait. Interactive coordination was determined to reduce the time in-between the different disciplines when producing common drawings or documents; in some cases drawings took more than a week to pass through every discipline before coming back to the original designer. The idea was to simultaneously design and review the drawings and substantially reduce the number of corrections, avoiding interference in the designs. Checklists were already being used by the company to review the designs, but new ones were made to determine the minimum information needed to begin a drawing or document. Even though the engineering and design phase is iterative in generating optimal solutions, one of the most frequent waste categories was the costly rework due to designs that began without the necessary information. In most cases, designers are obligated to begin work with only partial knowledge of the information (for example final weights for designing foundations). At least in some areas or engineering phases like detail design it is necessary to assure a minimum amount of data before beginning, and thereby paradoxically saving time by delaying decisions. The format used for this purpose was a matrix which contained all of the products from a certain discipline as rows and the necessary information from its own discipline, other disciplines, client, equipment supplier, etc. as columns.

The errors and changes in the products were constantly monitored throughout the entire investigation. There were two controls which covered three months periods each for analyzing the cycle times, time distributions, and waiting times in the process.

RESULTS

Initially, the errors and changes in the different products were variable and irregular: depending on the project, engineering phase, or even the progress within a certain phase. This shows the great uncertainty and variability in the design stage. The average before the implementation of the improvement tools was 2.4 errors per product and 0.15 changes per product. Figure 8 summarizes the evolution of unit errors in four projects. As can be seen, not only did the average diminish by 44%, but also the variability was reduced: from a 1.1 to a 0.4 standard deviation in the unit errors per product. This reveals the accomplishment of stabilizing the workflow in the process. The changes led to a decrease of 13%, but maintained their variability.



	March	April	May	June	July	August	September	October	November
Project 1	3,4	1,35	2	1,7	1,9	2,1	1,1	0,7	1,1
Project 2	1,4	0,85	2,55	1,8	1,2	1,5	0,8	1,3	1,1
Project 3	3,5	4,4	2	1,4	1,6				
Project 4					1,4	0,9	1,3	1,1	0,9

Figure 8: Evolution of Unit Product Errors

The time distribution of the activities within the design process was based on the utilization time, i.e. the amount of time spent working in any of the following five categories: data recollection, design, review, correction, and release. Initially, the design category represented 50.2% of the time distribution, but increased to 65.6% of the total time in the process. This increase in the share of the value adding activity and decrease of the non value adding activities (all the others) was 31% (see Figure 9). If the assumption is made that the production rate is maintained, the increment of the proportion of time carrying out design is a direct increase in the productivity of the engineering stage of 31%. Also, the important reduction of the time used in data recollection (46% improvement) exhibits the effect of the specific changes carried out for this activity (such as Intranet and checklists before designing).

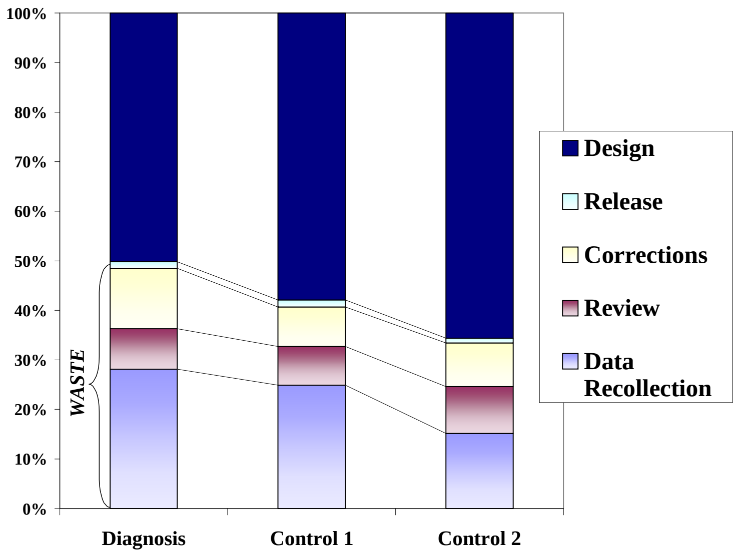


Figure 9: Time Distribution Evolution

As far as the cycle times were concerned, it was necessary to use the concept of utilization to compare values between different projects. After the changes and tools were implemented in the process, the utilization rose approximately 14% for drawings and 10% for documents.

An important decrease in the waiting times of the process was observed throughout the controls. As pointed out in Figure 10, there was a 53% reduction that demonstrates the importance of the tools in order to attack this type of time category. This means that there were more than 50% fewer interruptions and waiting times that prevented the designers from continuing their work. In general, the most frequent types of waiting times were those related with information problems and changes that are substantially lowered with the Intranet and checklists prior to design.

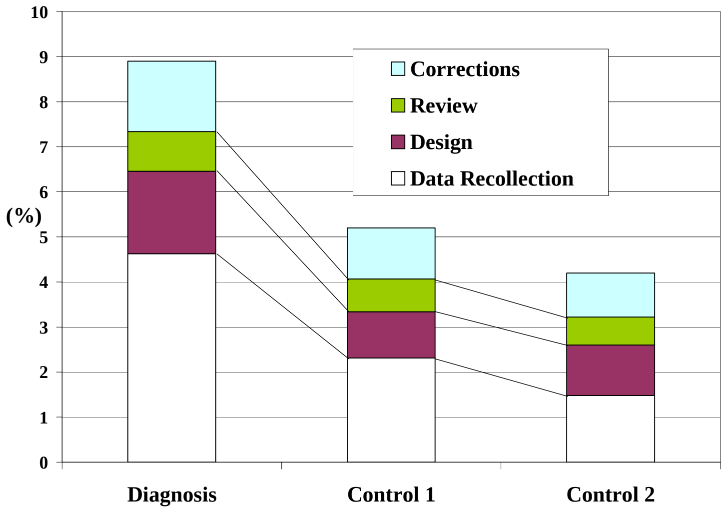


Figure 10: Percentages of Waiting Times in Process

As a summary, Figure 11 provides the essential results obtained in the application of the improvement methodology in a design firm.

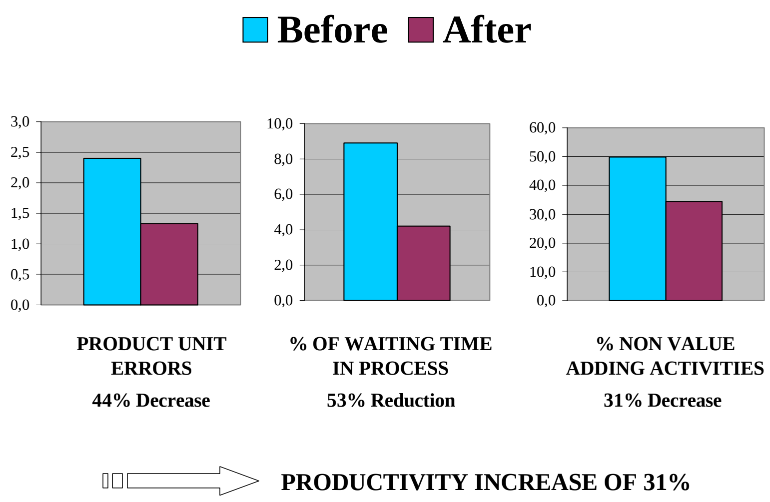


Figure 11: Essential Results of Improvement Methodology

The results obtained came from an investigation initiative to incorporate lean principles in design management without a formal commitment from the organization. In other words, the methodology was applied with only a partial involvement of the workers and the administration in the process. Therefore, in the opinion of the authors, the potential of improvement is even greater when there is a joint effort from the entire organization.

CONCLUSIONS

Lean Design promotes different views to model, analyze and understand the design process. Specifically, it considers the process as a group of three distinct models: conversion, flow, and value generation. This way, an improvement methodology based on these principles and concepts was proposed and applied in a design firm. The successful results from the application validate the use of the methodology, generating improvements in the engineering process by reducing product errors, cycle times, and the share of non-value adding activities; thus increasing productivity by 31%. At the same time, the performance of projects improved by supplying construction with better quality products, fewer variations, and in less time. Furthermore, the results are only a fraction of the potential of improvements that may be possible with the strategic endorsement of the corporation and the commitment of the entire organization.

RECOMMENDATIONS

A fundamental aspect that is necessary to emphasize is the necessity of creating awareness about the concepts of Lean Design. People generally do not know the principles involved in Lean Design and tend to work according to their habits, fundamentally based in the traditional conversion model. Furthermore, they have not questioned how this archetype works nor if alternative methods are available to manage the design process. In this manner, the focus on flow and generation of value provides an important complement to support the understanding of the process. In fact, it is the basis for analysis and later improvement. This means that tools and methods that support Lean Design concepts and principles must be introduced and applied.

It is not easy implement changes in companies. In fact, many people felt controlled when the diagnosis and evaluation stage of the process was carried out. In general, they did not like to specify what they did and how they distributed their time. This is a natural reaction, but it cannot be avoided in order to produce improvements. In fact, the only way of really understanding the flows is knowing them; determining their complete characteristics including types, magnitudes, variability, etc. Nevertheless, these cultural barriers tend to fall when improvements start to appear and the own workers benefit from new work methods.

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