Achieving Lean Design Process: Improvement Methodology

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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—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.

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Introduction

The design of architectural/engineering/construction facilities poses difficult management problems. While site construction can operate on a definition of quality as conformance to requirements, design must produce those requirements from a careful identification of customer needs and meticulous translation of those needs into engineering specifications (Ballard and Koskela 1998). The nature of the design process is complex; it involves thousands of decisions, sometimes over a period of years, with numerous interdependencies, and under a highly uncertain environment. A large number of participants are involved, such as architects, project managers, discipline engineers, service engineers, and market consultants. Each category of professionals has a different background, culture, and learning style (Formoso et al. 1998). Trade-offs between multiple, competing design criteria must be made throughout the design process, often with inadequate information and under intense budget and schedule pressure. Early design stages are notoriously hard to evaluate and control against progress milestones; lacking physical deliverables such as drawings, it is difficult to measure the amount of work completed and remaining on any given task, and consequently in the project as a whole. Moreover, feedback from the production and building operation stage takes a long time to be obtained, and tends to be ineffective. To make matters worse, projects are increasingly subject to uncertainty because of the pace of technological change, the rapid shifting of market opportunities, and the inability to keep pace with relentless pressure to reduce time and cost (Ballard and Koskela 1998).

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 when the customer's ideas and speculations are conceptualized into a physical model, defining his/her needs and requirements into procedures, drawings, and technical specifications. However, the administration and engineering of design have 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 methods 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; and (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.

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Table 1. Comparison of Conversion, Flow, and Value Generation Views (Ballard and Koskela 1998)

Item	Conversion	Flow	Value generation
Conceptualization of engineering	As a conversion of requirements into product design	As a flow of information, composed of conversion, inspection, moving and waiting	As a process where value for the customer is created through fulfillment of his/her requirements
Main principles	Hierarchical decomposition, control and optimization of decomposed activities	Elimination of waste (nonconversion activities), time reduction	Elimination of value loss (achieved value in relation to best possible value)
Methods and practices	Work breakdown structure, critical path method, organizational and responsibility chart	Rapid reduction of uncertainty, team approach, tool integration, partnering	Rigorous requirement analysis, systematized management of flowdown requirements, optimization
Practical contribution	Taking care of what has to be done	Taking care that what is unnecessary is done as little as possible	Taking care that customer requirements are met in the best possible manner
Suggested name for practical application of view	Task management	Flow management	Value management

This paper proposes an improvement methodology for the design process, based on concepts and principles of lean design. Following a brief description of the theoretical basis of the methodology, each one of its stages is thoroughly described, highlighting its most important aspects. Later, 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.

Lean Design

Lean design is the application of lean production principles, which promote the elimination of waste and non–value adding activities in processes, to engineering and design. It considers three perspectives to describe the design process as shown in Table 1—conversion, flow, and value generation. The difference in these visions is in the way that they conceptualize the process—in other words, the way in which they describe their aspects and properties. These symbolic representations make them vary from their essential principles to the methods and practices to carry out their practical contribution.

The conversion view is instrumental in discovering which tasks are needed in a design undertaking; thus, it is perfectly possible to realize design projects based on this view. However, the conversion view is not especially helpful in figuring out how not to use resources unnecessarily or how to ensure that customer requirements are met in the best manner (Koskela and Huovila 1997). In short, the conversion view is effective for management, but not for improvement. In fact, this view only addresses the first of three issues that, according to Turner (1993), make up the core of project management—(1) an adequate, or sufficient, amount of work is done; (2) unnecessary work is not done; and (3) the work that is done delivers the stated business purpose. In consequence, the single-minded use of this view has contributed directly and indirectly to many persisting problems in engineering projects—fragmentation (it is more important to carry out the task than to take care of interaction with other tasks); the needed iterations and the inevitable variability in task outcome lead to rework that is not visible in the functional consideration; and the requirements of the final customer tend to get blurred in the often long chains of activities.

Conceptualizing the design process as a flow of information lends itself to reducing waste by minimizing the amount of time before information gets used, the time spent inspecting information for conformance to requirements, the time spent reworking information to achieve conformance, and the time spent moving information from one design contributor to the next. Further, and even more important than reducing the cost and time of design, conceptualizing the design process as a flow of information allows coordination of interdependent flows and the integration of design with supply and site construction (Ballard and Koskela 1998).

In the value generation model, the emphasis is on obtaining the customer's requirements. The improvement of design lies in reducing the loss of value that arises when not all requisites are transmitted in the process. On the other hand, value consists of product performance and lack of defects. This value has to be evaluated from the perspective of the next customer(s) and the final customer. To prevent the loss of value, it is necessary to analyze the requirements and needs at the outset in close cooperation with the customer, use a systemized management of requirements [like the application of quality function deployment (QFD)], and organize rapid iterations between all of the participants who issue design and construction information (Huovila et al. 1997).

Lean design incorporates the views of both flow and value, in contrast to the traditional vision of the conversion model. Even though each perception is analyzed separately, the design process involves all three. In other words, in reality the three views exist as different aspects in design tasks. Each task in itself is a conversion. In addition, it is a stage in the total flow of design, where preceding tasks impact it through timelessness, quality of output, etc., and it impacts subsequent tasks. Also, some of the customer requirements are converted to solutions in each task (Koskela and Huovila 1997). However, conventionally, it has only been the conversion aspect that has been explicitly modeled, managed, and controlled. The two other aspects have been left for informal consideration by designers. The major contribution of concurrent engineering is extending modeling to the flow and value aspects, thus subjecting them to systematic management.

In this manner, lean design ''opens the doors'' to modeling toward the practical application of the three perspectives in the design process. The incorporation of new ways to ''visualize'' the

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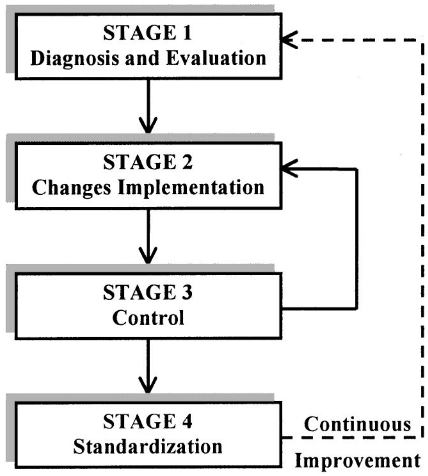

Fig. 1. Improvement methodology

process increases the understanding and comprehension of how it works. This approach motivates the implementation of tools to integrate these frequently neglected aspects in the process, thus improving it.

Improvement Methodology for Design Process in Construction Projects

Introduction

With the theoretical base of the concepts and principles of lean design, an improvement methodology for the design process in construction projects is proposed. 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 the detection and analysis of aspects that are commonly veiled. This methodology is schematically summarized in Fig. 1.

In general terms, the methodology includes four phases for the improvement of the design process in projects, as follows (Freire 2000):

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, the cycle time with its respective categories, and different performance indicators.
2. Changes implementation. This stage considers the results of the previous phase in order to implement different changes according to the categories of waste and the problems identified, with the improvement tools suggested. The methodology makes it possible for the implementation of changes 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: C=client; A=administration; P=project; R=resources; I=information (CAPRI).

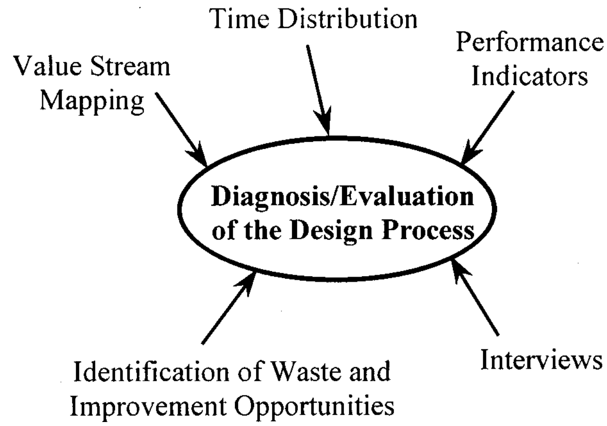

Fig. 2. Diagnosis and evaluation model of design process

3. Control. This phase consists of 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 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. Fig. 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 the 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 a complete understanding of the process.

Performance Indicators

To obtain an objective measurement of the quality of the products in the design process, the following two performance indicators were defined: (1) changes in design=number of changes/total number of drawings (or documents); and (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 deviations of the original specifications and bid documents of 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 nonconformance to requirements of the specifications and design criteria in the drawings or documents." It is necessary to emphasize the importance of 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 for several areas of construction, and call them "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

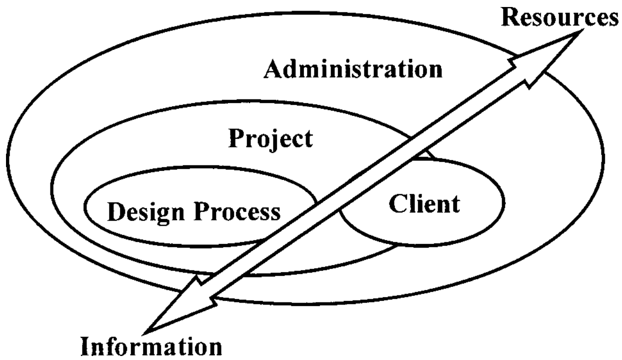

Fig. 3. CAPRI

Table 2. Focuses of Improvement Tools

Improvement tools	Area of improvement C	A	P	R	I
Interactive coordination	—	—	Yes	Yes	Yes
Intranet	—	—	—	—	Yes
Checklists before design	—	Yes	Yes	—	—
Checklists after design	—	Yes	Yes	—	—
Quality function deployment	Yes	—	—	—	—
Value stream mapping	—	—	—	Yes	Yes
Training	—	—	—	Yes	—

Note: C=client, A=administration, P=project, R=resources, and I=information.

documents in order to physically advance in the project. Special attention should be paid when measuring and comparing these performance indicators in different environments. Even though most drawings are produced in computers, the total number of drawings generated via computer varies greatly from the number of those that are handmade (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.

Time Distribution in 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 of the other activities are waste and should be reduced or eliminated. 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)."

Methodology to Identify Waste and Improvement Opportunities

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.

Value Stream Mapping

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

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 for the acknowledgment of the reality of the process.

Stage 2: Changes Implementation—Improvement Tools

The improvement tools are classified based on five areas (CAPRI) that interact, as shown in Fig. 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.

The following improvement tools are proposed: (1) interactive coordination; (2) intranet; (3) checklists before design; (4) checklists after design; (5) QFD; (6) value stream mapping; and (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).

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.

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.

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, a checklist before designing "shields production" [a lean strategy developed by Ballard and Howell (1998)], forcing the designers to obtain a minimum amount of necessary requirements and information in order to begin their work and avoid costly rework.

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 contribute 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 (proactive).

QFD is a very useful methodology to determine the requirements and needs of the client. Its basis is in the construction of matrices that are used to relate the necessary input information for the design process, being ideal for the conceptual design and basic design phases (Akao 1990).

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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.

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 on people's experience, 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 the knowledge of lean design principles, use of design programs, general computer skills, concepts of quality, and concepts of safety.

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

1. 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 the realization of activities, to consider constructability and quality issues, and so on.
2. 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 the exchange of information (with quick feedback).
3. Flexibility. The set and environments vary from project to project. Thus, a decision in one project could be inappropriate in another. This means that the system (of work) needs flexibility to be able to adapt to these changes/new conditions.
4. Importance of preliminary phases of design. It is necessary to emphasize the early design phases. Early participation of construction personnel in the engineering could promote 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 reworks in engineering.
5. Introduction of 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 (Ballard 1994)].

Stage 3: Control

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

Control consists of measuring the performance indicators and time distribution in the process, observing variations of these values, and acknowledging the effectiveness of the changes. 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: Standardization

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 its specific needs at a given time.

Thoughts on Nature of Design Process—General Considerations of Methodology

No engineering company is identical to another. They have different strategies, goals, organizations, procedures and work methods, resources, experience, size, and so on. They also have diverse market segments, like building design, civil or industrial works, mining and metallurgy, and so forth. 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 concept behind the methodology—lean design. For example, a company that has International Standards Organization (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 with the ISO norm. In the same nature, if a firm wants to completely fulfill all the requirements and needs of its 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), for the methodology of identifying waste and improvement opportunities, it is sufficient to begin with the elimination of activities that do not add value and implement improvement actions 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, and so on). Also, in stage 2 (implementation of changes), it is not imperious 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 writers recommend beginning the implementation with everything related to the elimination of waste (kaizen on processes). This area shows immediate results due to the great amount of activities that do not add value in the processes. Afterward, it is important to work on other areas, such as generating value in the processes. This is essential for achieving client satisfaction.

Application of Improvement Methodology in 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 of the projects were in the detailed engineering phase and used a

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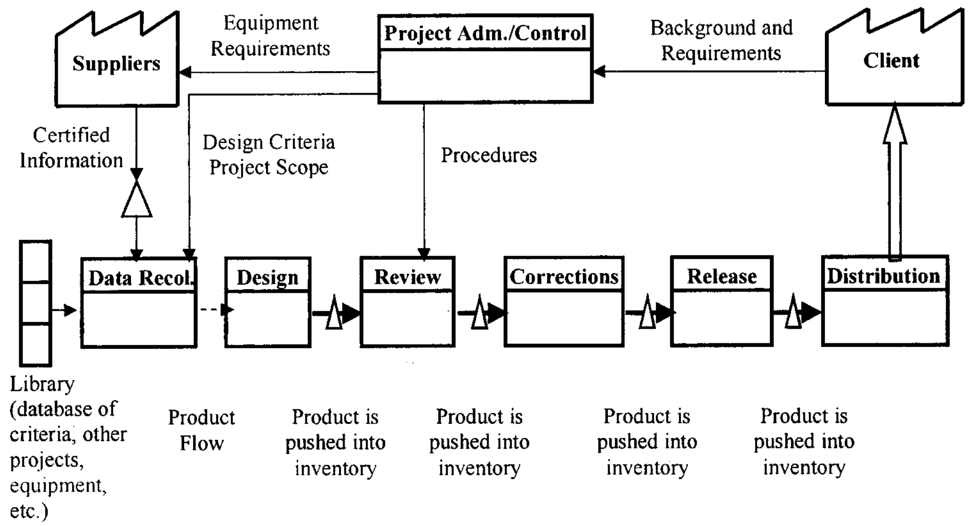

Fig. 4. Initial value stream map of design process

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 for the acknowledgment of the entire process. Value stream mapping was extremely useful for visualizing how the process worked, and for recognizing the different activities involved. It was possible to draw a map (Fig. 4) of the initial situation and categorize the time in each production stage—data recollection, design, review, corrections, release, and distribution.

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 spent most of the time in inventories, waiting to be worked on. As shown in Fig. 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.

The results from using the methodology to identify waste and improvement opportunities (Alarcón 1997) allowed the writers to develop a comprehension of the main problems in the process, with causes and categories of waste. An example of this analysis is depicted in Fig. 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).

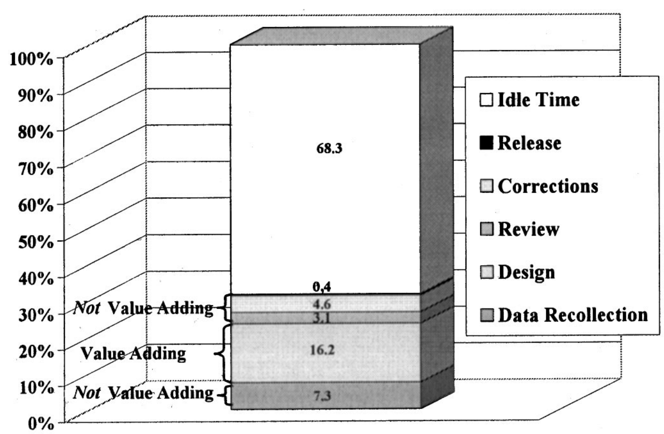

Fig. 5. Cycle time distribution in drawings

Improvement Actions

From the analysis of the diagnosis and evaluation stage, it was necessary to draw an ideal value stream map to visualize how the process could be changed (Fig. 7). The fundamental aims of this new map were to eliminate the inventories and allow 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, feedback between the client and the project administration is 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.

The improvement tools that were implemented were the intranet, interactive coordination, checklists before and after design, and training. The design firm was developing its intranet 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 database was organized in the intranet that was accessible to everyone. Also, the data recollection stage in the production presented the greatest amount of waiting times, i.e., time when work could not be done due to variables external to workers. Again, the

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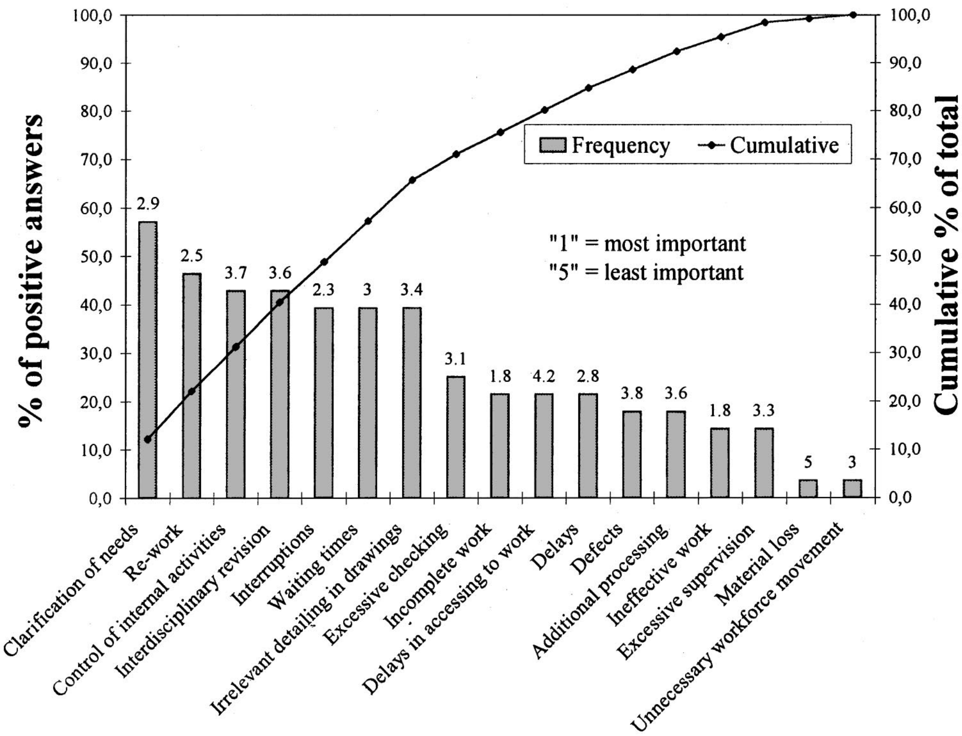


Fig. 6. Waste frequency

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 design. Checklists were already being used by the company to review the designs, but new ones were made to determine the minimum amount of 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 ensure a minimum amount of data before beginning, thereby paradoxically saving time by delaying decisions. The format used for this purpose was a matrix that contained all of the products from a certain discipline as rows and the necessary information from that discipline, other disciplines, the client, equipment supplier, etc. as columns.

The errors and changes in the products were constantly monitored throughout the entire investigation. There were two controls that covered a period of three months 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

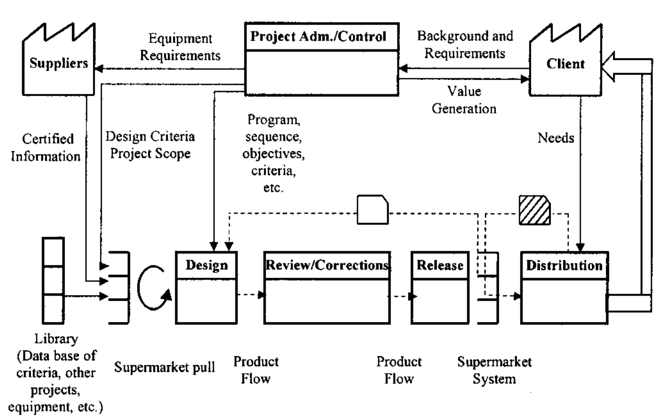
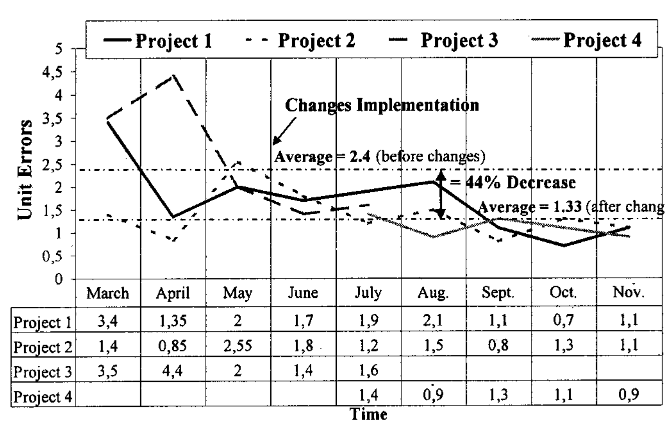


Fig. 7. Example of ideal value stream map for design process



	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.
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

Fig. 8. Evolution of unit product errors

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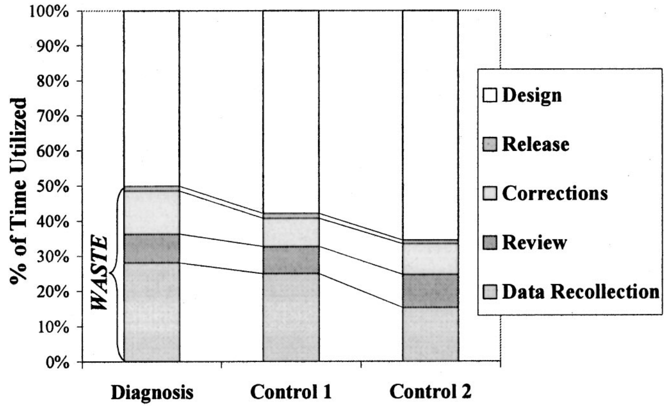

Fig. 9. Time distribution evolution

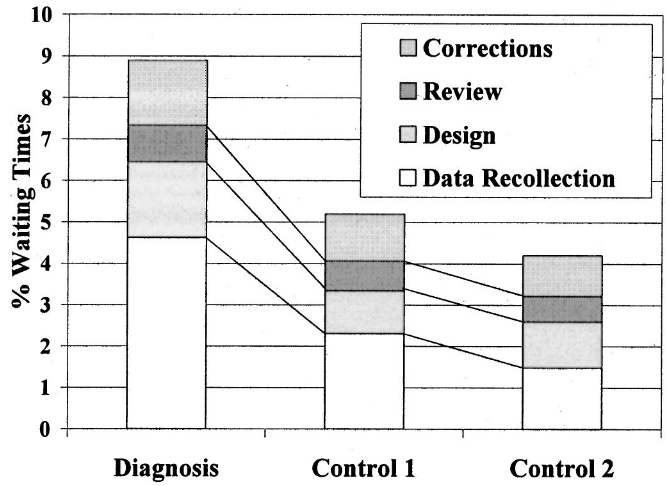

Fig. 10. Percentages of waiting times in process

before the implementation of the improvement tools was 2.4 errors per product and 0.15 changes per product. Fig. 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 work flow in the process.

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 of the others) was 31% (Fig. 9). If the assumption is made that the production rate is maintained, the increment of the proportion of time carrying out the 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 the intranet and checklists before designing).

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 Fig. 10, there was a 53% reduction, which 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 to information problems and changes that are substantially lowered with the intranet and checklists prior to design.

As a summary, Fig. 11 provides some of the results obtained from the application of the improvement methodology in a design firm.

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 writers, the potential of improvement is even greater when there is a joint effort from the entire organization.

Conclusions and Recommendations

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. In 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. Application of the methodology generated 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, having fewer variations, and taking 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.

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

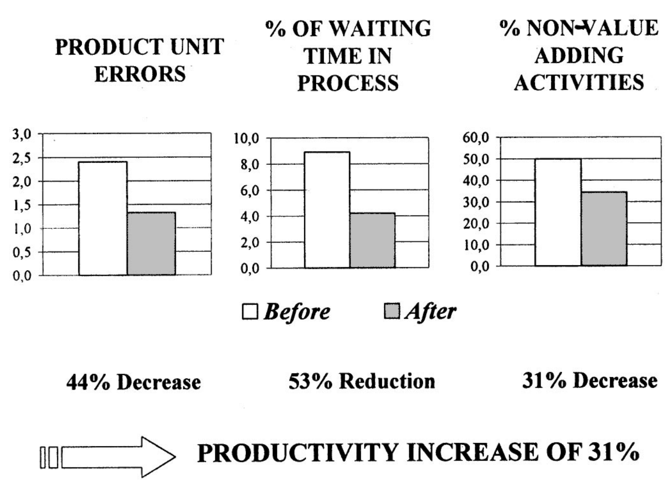

Fig. 11. Summary results of improvement methodology

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 value generation 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 to 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 by knowing them and determining their complete characteristics, including types, magnitudes, variability, and so forth. Nevertheless, these human-nature barriers tend to fall when improvements start to appear and the workers begin to benefit from the new work methods.

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