A comparative study between lean design and eco design in product development

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Abstract

In a challenging environment characterized by strong competition, companies have to be able to identify costumers' needs and to offer some products that best fulfill their requirements while respecting the environment. For this purpose, every company, regardless its size or its activities' field, should properly master its workflow, as the majority of defects that occur during the production phase are mainly related to the design phase.
Lean design is as an approach that aims to optimize the design of products so that they are easier to make in a Lean production environment, so, this article propounds an analysis of the fundaments of Lean design, moreover, it analyzes also design methods in relation with the environmental aspect, in order to emphasize the link that might exist between the approach and the design methods within the context of new product development while taking into account the environmental constraints which nowdays have become a key success factor for some companies.

Keywords
Lean Design, design methods, development of new products, environment, environmental constraints

1. Introduction

Today, more than before, manufacturing companies are confronted to a high level of instability, where competition is becoming increasingly tough and fierce. This is reflected in the varying demands of customers, shorter and shorter lead times, high quality, customization of products, etc.
For these reasons, manufacturing companies have begun to set up the Lean Production System (LPS), the purpose of such a system is to eliminate any kind of waste in the production process and align all processes with the Value, which made it possible for these companies to achieve significant gains at different levels. The question that naturally came up later was whether or not this approach could be used for other processes in the manufacturing company and to transfer the knowledge acquired in lean manufacturing to other processes in the company such as product development or after-sales service [1].
Environmental consideration in product seeks to decrease and prevent environmental problems throughout a product's life cycle as well as to gain market advantages, cost savings and minimize business risk, aiming to improve environmental performance not only demonstrate responsible corporate behavior, it is critical to good business practice. Environmental protection is rapidly becoming an essential factor in business competitiveness.
Currently, a lot of research is being done on the integration of environmental constraints during the product design process and the design of processes related to these products. Thus, new design methods are developed based on taking into account the entire product life cycle, in order to reduce their environmental impact.
At the level of the design domain of new products, a significant reduction in costs and quality improvement can be achieved by an optimized design process; the basic conditions for potential improvements are generally defined in the first stage of the product cycle. Product life is the stage of development, according to Ehrlenspiel 75% of product life cycle costs are already set by product design [2].
Indeed, while Lean is widely applied in the fields of flow management, material supply, production, product delivery to customers, authors like Womack and Jones point out that lean can be applied to several fields other than manufacturing fields, knowledge-based activities such as design, introduction of new products, product development, domains or lean approach can generate considerable profits.

Originally it can be said that the Lean concept has been developed to some extent for Lean design in order to focus on customer value throughout the entire product lifecycle process, an adequate product design.
The objective of this article is to confront the Lean approach to the product design methods while integrating the environmental aspect. First, we present some features of the concept of Lean design. Then, we present some design methods such as QFD and Design for X, besides, we study the application of these methods from the Lean point of view and also from the environmental point of view.

2. Lean Manufacturing

The Lean system is a management approach aimed at improving performance based on the elimination of waste. This approach is defined by a variable number of principles, more or less neighbor, according to the authors.
The objective of Lean is to optimize quality, costs, lead times and productivity. To achieve such an objective, it is necessary to act on three sources of inefficiency of any operational system: waste, variability and lack of flexibility [3].
By implementing a Lean approach, practitioners often realize that the increase in performance and efficiency of operations thanks to Lean Manufacturing is quickly inhibited by the limits of initial choices. As during the early phases of design, choices have already been made, which subsequently conditioned the performance of the products themselves and also the processes and means used for their elaboration. These choices once fixed, can often no longer be changed and thus limit improvements once development is completed [4].
The Lean approach can be broken down into five principles according to James P. Womack and Daniel T. Jones [5]

- Define the value: we must adopt the customer's point of view and ask the question of what a customer is willing to pay. No customer (if he knew) would accept to pay the extra cost of the products and / or services he buys to offset the inefficiency,
- Identifying the value chain means identifying the sequences of value-added transactions used in the development of the product or service as expected by the client under its definition of value. On the other hand, identifying value-added transactions also means identifying transactions with no added value.
- Encourage the flow of flows: to ensure that value-creating transactions uninterrupted throughout the process, that the products carrying this value do not undergo expectations, backtracking or erratic circulation.
- Pull flows: produce goods or services only if the client has explicitly requested them.
- Aiming for perfection: Once the dynamics of transformation are launched, opportunities to eliminate new wastes emerge, and new ideas of improvement are emerging. It is the entry into the virtuous cycles of continuous progress, which must nonetheless be endeavored to perpetuate.

3. Lean Design

3.1 The objectives of lean design

Lean Design was developed from the basic idea of Lean Thinking, the idea behind this approach is to focus on value-added activities from the point of view of the end customer, hence all non-value activities should be eliminated or at least reduced during the life cycle of a product or service, such activities that do not contribute to the value of the customer are considered wasted [5], this definition shows that the point of lean thinking is based primarily on a direct process improvement in which non-value added activities occur.

Lean Design has the same goal, but takes a different approach. According to this approach, it is not the processes within the product life cycle that should be optimized, but rather the design itself should be optimized, this approach is based on the fact that 70% to 80% of the customer value and waste that occur downstream of the product lifecycle process depends mainly on decisions made during the design phase [6], so the Lean Design also aims to increase the efficiency of the processes from the design point of view.

According to Dombrowski et al three different definitions of a product can be derived depending on the difference between product design, value and waste.

- From a design point of view: the product is the sum of the parts, its properties and its relations.
- From a value point of view: the product is the sum of the functions it delivers or the properties it offers to create the customer’s value.
- From a waste point of view: the product is the sum of all life cycle processes.

3.2 Lean Design and the guidelines for product design

The Lean Design provides an integrated model, methods and qualitative guidelines for product design to reach the maximum value for the customer and minimize wastage [6, 7]. These guidelines provide recommendations to help designers make good decisions during the product design phase.
These qualitative design guidelines are suggestive in nature and focus primarily on preventing waste during the early stages of the product life cycle, but these guidelines should not be interpreted as strict rules, the applicant of these design guidelines must always be called into question in the context of the conditions of the undertaking [8].
The qualitative design guidelines offer general recommendations for design, however the transformation of these guidelines into the actual design remains difficult due to their low level of detail, especially in the advanced stages of product development or more specific guidelines become necessary [9]. Table 1 illustrates some qualitative guidelines for the product design from the point of view of the two authors Huthwaite [6] and Mascitelli [7].

Table 1 : Design guidelines according to the Lean Design literature

Qualitative guidelines of Lean Design		
Product Features	***Huthwaite***	***Mascitelli***
Simplify Product Architecture	*	
Minimize components	*	*
Avoid complexity	*	
Simplify assembly	*	
Reducing the danger when using a product	*	
Developing evolving requirements		*
……		

4. Eco Design, product life cycle and environmental impact reduction

In response to the United Nations initiative to support sustainable consumption, the World Business Council for Sustainable Development proposed, on the sidelines of the Earth Summit in 1992, eco-design as an approach to sustainable consumption. Development of sustainable products.
Eco-design aims to integrate environmental impacts throughout the life cycle of the product from the product design phase in order to reduce them (Brezet 1998).
The choice of the design phase to integrate the environmental problem that 80% of the future impacts of the product are defined by decisions made during the design of the product (Wenzel et al., 2000).
Eco-design differs from the classic design on two points:
- Design and evaluation with equivalent functional unit. This choice makes it possible to remain in conformity with the concept of economy of functionality by legitimizing the comparison of a design solution based on the sale of a physical product with a solution based on the realization of a service contract.
- Analysis of the life cycle of the product. The assessment of the pollution associated with the product or service is done on several environmental impact indicators, ie. Representing different types of pollution, and throughout the life of the product, from its "birth" to its "death". The next paragraph details what the life of the product includes.

4.1 Product life cycle

The definition of the life cycle of the physical products required to achieve the functional unit is the first step in an eco-design process. It consists of chronologically listing the stages that will make up the product's journey from birth to death.
The product life cycle is therefore often defined as going from the cradle to the grave. The meaning of the word cradle is relatively accepted by the life-cycle community, as regards virgin raw materials: it represents the steps of extraction of raw materials from mines, wells, natural reserves ... As regards the word tomb, the consensus is more difficult to obtain: for some, this is the only landfill of the product, for others it includes recycling processes and energy recovery...
The acquisition phase of the raw materials covers the processes necessary to obtain semi-processed materials for manufacturing. It can be mining, material recycling or forestry. This phase ends at the door of the material processing plant.

The manufacturing phase includes all stages of shaping the materials into finished products. It begins at the first materials processing plant and ends at the end of the last product packaging plant for its distribution.
The sales and delivery phase covers all the logistical steps to access the last factory to the sales sites, as well as all stages of promotion and marketing of the product. It starts at the exit of the packaging plant and ends at the exit of the store where the final customer acquires the product.
The use / maintenance phase begins at the exit of the magazine and ends when the product is considered as a waste, ie is no longer used or is thrown in a trash.
The reuse / recycling / energy recovery / disposal phase (hereinafter referred to as end-of-life) covers all waste treatment activities either to restore it to working order or to recover materials or energy, or to eliminate it by mechanical, chemical or biological processes. It starts with the collection of the discarded product and ends, either by entering into other phases (distribution for reuse, manufacturing for recycling and energy recovery), or by landfill.

4.2 Environmental performance of eco designed product

PEC & IDP (2009) and Plouffe et al. (2011) studied different eco-design approaches in companies, in Quebec and in France. Environmental benefits were assessed in relation to the phase of the improved life cycle. The greatest environmental gains were made in the raw material extraction and end-of-life phases. In the second place, there are the phases of "transport and storage", called sales and delivery by ISO 14062 and manufacturing. The phase where they record the least gains is the phase of use.
This study points out that some phases have succeeded in being integrated into eco-design but that an additional effort has to be made for the phases or the approach has not been effective. It shows, like the previous paragraph, that the use phase remains one of the most difficult phases to improve in eco-design since only 8 of the 24 companies have succeeded in reducing its impacts.

Table 2: Evaluations of improvements made through eco design (PEC & IDP 2009)

	Total	Quebec	France
Raw material	24	10	14
manufacturing	10	5	5
Use	8	4	4
Transportation and warehousing	11	2	9
End of life	24	11	13

5. Methods of design from the point of view of lean and environment

All product life cycle processes are strongly determined by product design. The Lean Design concept focuses on maximizing customer value and reducing waste at all stages of the product lifecycle through optimized product design.
[Morgan, 2002] identified eleven wastes related to product development activities:

- The transfer of products or processes from one head of service to another.
- Collection of unnecessary data.
- Expectations: data, responses, decisions, revisions, availability of a resource.
- Time and effort to organize the work to be done (Negotiation of contracts, meetings on quotations, tenders and selection of suppliers, etc.).
- Reinventing existing processes, solutions, methods and products.
- A poorly structured system: misunderstood roles and responsibilities, weak accountability, lack of planning and incompetence.
- Strong variations in the process.
- An overused system, or too accelerated.
- Inefficient communication, significant lot sizes (represented by the number of projects in progress).
- Non-synchronization of current processes.

5.1 QFD and Lean (The LQFD)

Several research projects have integrated the Lean approach with design methods (Design for X, QFD ...) in order to increase customer value of the first phase of product development.

Moreover, another design method proves to be very useful during the product design phase, namely the deployment of the quality function (QFD), the deployment of the quality function (QFD) is widely used as a technique in the Engineering field to analyze customers' needs and relate them to actions that satisfy them, particularly the characteristics of the product, it uses a matrix relating the needs (the what) and the specifications to satisfy them (the how), the purpose of this technique is to ensure that none of the expectations of customers are neglected in the design of a product and it allows to give an order of priority to the possible characteristics of the product.
D.Rajenthirakumar et al incorporated the principles of lean and QFD to bring out a new technique called the Lean Quality Function Deployment (LQFD) by integrating the fundamental principles of lean and QFD.
This new approach according to D. Rajenthirakumar aims at two aspects: quality and elimination of waste, the unique characteristics of the LQFD technique is that it provides quality solutions oriented to the problems of the industry through the " Elimination of waste", to this end, the combined home of quality and lean provides solutions from the guidance of quality and lean to face the competitive market scenario.

Deploying the quality function is considered an important method for product development that aims to translate customer requirements into a technical context for each stage of product development.
QFD uses four matrices which are called quality house (MQ) to associate the voice of the customer regarding a product has technical requirements. Thus the model used to integrate the Lean tools with the QFD technique is as follows:

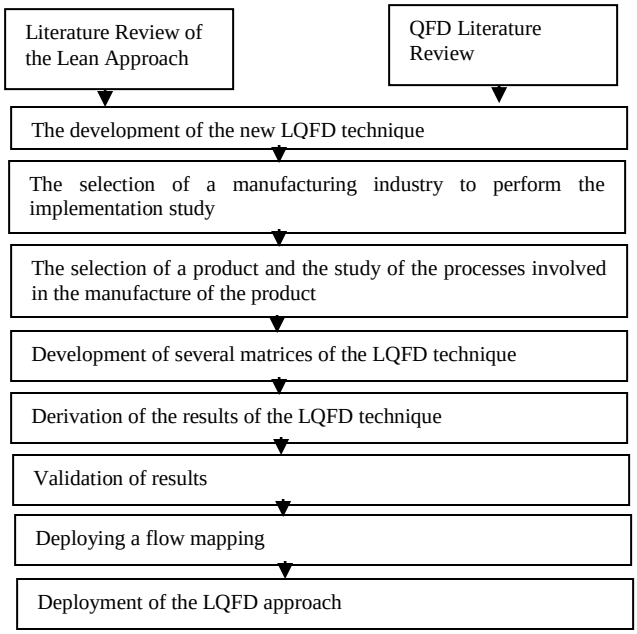

Figure 1: Methodology adopted for LQFD

The structure of LQFD can be considered as a house called the home of LQFD, as shown in the following figure

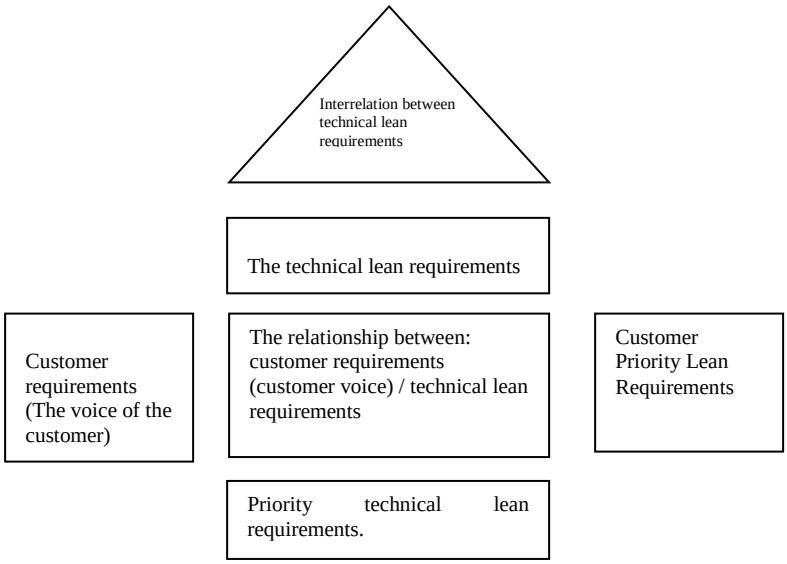

Figure 2: House of LQFD

5.2 QFDE (Quality Function Deployment for Environment)

To achieve sustainability, it is necessary to achieve improvements in economic, social and environmental areas. Quality Function Deployment for Environment (QFDE), as the extended version of the well-known method QFD has a large application area within the sustainability framework such as sustainable product development, improvement analysis and design process. In this study in order to design effectively a sustainable product, the QFDE approach is used as it is a commonly used tool for the environmentally conscious design process. QFD is "a method for developing a design quality aimed at satisfying the consumer and then translating the consumers' demands into design targets and major quality assurance points to be used throughout the production stage" (Akao, 1990). The complex relationships between customer requirements and technical attributes, and the correlation between different technical attributes, can be illustrated in a typical "House of Quality" (HoQ) matrix. HoQ serves to link the Voice of Customer (VoC) to engineering metrics (EM).

QFD for Environment (QFDE) is a method developed by Masui et al. (2003). It introduces environmental aspects (environmental VoC and environmental EM) into QFD to handle the environmental and traditional product quality requirements together, and it is intended to be used in the early stages of product design.

The major advantages of the QFDE framework are summarized as follows. Unlike traditional QFD, to improve the product design process, not only the end users but also business-to-business (B2B) customers, recyclers, the government and the environment itself are considered to be stakeholders in QFDE. In this multi aspect method, SR weights play an important role since they significantly affect the target values set for the engineering metrics; hence it's crucial to give a realistic approach. Various methods have been attempted to determine the importance weights. The simplest method to prioritize customer requirements is based on a point scoring scale, such as one to five or one to ten (Griffin and Hauser, 1993). However, this method cannot effectively capture human perception (Kwong and Bai, 2003). Furthermore, the judgments of the decision makers are more difficult to assess with the precise quantitative forms due to the vagueness and uncertainty existing in the early stage of new product development (Zhang and Chu, 2009). In early stages of product development, the decision makers have limited information about the relationship between different SR and EM. As being a convenient tool for integrating the fuzzy theory application, QFDE helps the product development/ design teamto overcome the vagueness and uncertainty faced in SR weighting. Finally, various technical attributes and environmental concerns can be prioritized such that the product development team can concentrate their limited resources on critical issues to develop customer-oriented environmentally friendly products (Kuo et al., 2009).

A typical QFD system usually has four interlinked phases, where four matrices that integrate the customer requirements, design specifications, product or part characteristics, manufacturing processes, and production requirements are used. The matrices explicitly relate the data produced in one phase of the process to the decisions that must be made at the next process phase (Griffin and Hauser, 1993). Product planning is the first matrix. Customers' desires, in customers' own words (VoC e WHATs), are determined and translated into technical description (EM e HOWs) or proposed performance characteristics of the product. The second QFD matrix relates potential product features to the delivery of performance characteristics. Process characteristics and production requirements are related to engineering and marketing characteristics with the third and fourth matrices (Temponi et al., 1999). Four-Phases of QFD are illustrated in Fig. 1 and summarized as follows (Chan and Wu, 1998):
QFDE is also carried out in four phases. Phases I and II allow the user to identify environmentally significant components (component parts and devices) of the product. Phases III and IV allow the user to choose the most environmentally friendly design from alternative design proposals.

5.3 Design for X

In the same context, the Design for X approach is nowadays considered as an essential element of Lean design insofar as it makes it possible to take the right design decisions with the help of the concrete qualitative design guidelines. However, the design for X approach focuses on a specific stage of the product lifecycle or a specific aspect of the products, which makes an overall optimization of the design of highly complex products. Therefore, [Dombrowski et al, 2014] propose an integration of the Design for X approach in the Lean Design concept, which is based on a wide range of qualitative design guidelines given in the Design for X have direct effects on the life cycle of the product and recommendations for optimized product design.
The design for X approach suggests a significant number of guidelines, more than 150 qualitative guidelines for better Lean product design, for example:
-minimize the number of components.
- Develop a modular design.
- Avoid separate fasteners.
- Corners that could cause injury should be avoided.
- Avoid hazardous materials that are harmful to the environment
These guidelines can help design engineers to develop Lean products, so Dombrowski et al suggests integrating the Design for X approach into the Lean Design methodology portfolio. The Design for X approach offers qualitative design guidelines, which are more detailed and linked to a specific objective.
Indeed, using the design guidelines provided by Design for X, the properties of the expected products (product from the point of view value according to the lean design approach) can be derived from the characteristics of the given product Design according to lean design).
This analytical approach can be used to evaluate a given design. On the other hand, the design guidelines also allow the translation of the required properties of the products into the concrete characteristics of the products in a lean perspective. This integration of axiomatic design with Lean design can be used to design new products. [12]

5.4 DFE (Design for Environment)

Design for Environment (DFE) is the systematic consideration during design of issues associated with environmental safety and health over the entire product life cycle [9]. DFE can be thought as the migration of traditional pollution prevention concepts upstream into the development phase of product before production and use. DFE is applied to the design of new and modification of existing products, processes and facilities.
As global markets is undergoing continuous and rapid change, every company's ability to innovate and be flexible will be critical to its profitability [10,11]. DFE strategy can stimulate product innovation in areas of choice of material, production techniques, finishing technologies and packaging methods. Also partnerships with suppliers, distributors, recyclers can open up new market areas and improve product quality. While most companies do not control the whole product life cycle, their design decisions do have an impact on upstream and downstream processes, from selection of materials to product service and end-of-life options.

5.4.1 DFE and Environmental Management Systems (EMS)

EMS such as 14001 is an organizational approach to facilitate environmental evaluation and management. The core requirement of EMS is that a firm should have a reasonable amount of information on environmental effects of its products and processes, and seeks continuous improvement. Pollution prevention is typically part of EMS.
DFE is complementary to EMS. It enhances the organizational approach by including product-oriented environmental evaluations and improvements. Manufacturers using DFE strategies take into account the

environmental aspects of a product's use end of life, and apply this information during its design, production and distribution [9]. Motivation for DFE program arises from the need to reduce Non Product Output (NPO). The cost of NPO includes costs of material, warehousing, manufacturing as well as internal collection, treatment and external disposal or recycling. Hence, DFE seeks to minimize NPO or create valuable by-products from them. Typically for Aluminium die casting processing, they add up to 30 to 50% of total output by weight [9, 11].

It is important to note that high level of environmental performance can only be improved by regular reviews of related scientific information and existing environmental legislation.

5.4.2 Benefits of DFE

DFE offers business opportunity to improve environmental performance, as well as improving profits. The companies would also reduce the environmental impact of products/processes; optimize material and energy consumptions; improve waste management/pollution prevention systems; encourage good design and drive innovation; reduce costs; exceed current customer expectation for price, performance and quality; increase product marketability. DFE provides means for establishing a long term strategic vision of an organization's future product and operations. It is an enabling force to shape more sustainable patterns of production and consumption [9].

It can be seen that the study carried out in this communication clearly shows that the integration of eco design with the Lean design approach offers several opportunities for a high-performance and optimized product design.

6. Conclusion

Manufacturing companies have implemented Lean Manufacturing on Production Systems to meet the requirements of these customers, and they have already transferred the idea of value and waste to other stages of product life cycle with the aim of optimizing product life and essentially the product design.

Lean Design states that the effects of product design are of great importance to customer value and product life cycle processes, unlike Lean Thinking, Lean design does not focus on reducing waste but rather on prevention of non-value added activities so as to convert them in a way that they can perform more effectively.

Over the past few years, many environmental professionals have watched the rapid expansion of Lean activities sweeping across diverse commercial and manufacturing sectors. A growing number of environmental professionals see an exciting opportunity to leverage this trend to achieve better environmental results more quickly.

For this reason the integration of eco design methods with lean design can generate significant gains to the extent that they allow designing products and optimizing the product life cycle in a Lean / Green vision.

Indeed, if lean manufacturing has reached maturity, the application of lean design to the process of product development is still in the evolutionary phase, hence the need to work on the link between the design profession and the Lean design approach for the development of new products that respect the environment, integrate other design methods with the lean design approach and propose new tools that are adapted to the design activity to prevent waste and reduce environmental issues.

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