AESTHETIC, FUNCTIONAL AND MANUFACTURING ISSUES IN THE DESIGN OF MODULAR PRODUCTS

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Abstract

In this paper, the design principles and methods for the development and production of modular products and systems are identified. Modular conception is mainly used in the production of complex products that can be divided in individually small subsystems and function as a group of interconnected components. Three main aspects can be addressed within modular design: product architecture, which specifies the modules and functions of the system; modules (components, subsystems or mechanisms) that interact and execute the functions; and interfaces that define the connections and communications between modules. Modular products perform the functions through the combination of different modules. A variety of products can be achieved through a modular conception design, essentially by combining standardized components. The basic principles of modular product show that these types of products play an important key role in the competitiveness of companies. In fact, companies can offer more customized products and customers/users can purchase products more adaptable to their needs and desires, since they can easily be updated, replaced or expandable through the use of modular components. Finally, the easiness of updating modular products can postpone its life cycle, avoiding its total replacement due to, for example, technological or aesthetic changes. It also contributes for the reduction of material and energy wastes that increase, directly or indirectly, when total replacing of the product takes place or when producing new products.

Keywords: Design, modularization, personalization, sustainability, rapid prototyping

Our living reality, in a globalisation world were the only constant seems to be the continuous changing, leads us to question the traditional forms of development and manufacturing of products, based on methods and processes that have as main goal the increment of life quality of their users and the competitiveness of the enterprises. The generalisation and massification of information and communication technologies brought more emphasis to the globalisation concept. The phenomena, issue of some social agitation, is characterised by enormous amounts of money movement by computer since anybody can buy the same product in any part of the world, which has pushed for standardized products, services and behaviours. Criticised by some and defeated by other, the effects of globalisation in economics, society and culture is recognised by all. As referred by Alves et al. (2001): "One of the world's characteristics is speed of communications with globalization of the economy and social dynamics, with trends and commercial solicitations more and more mutable".

Attitudes and behaviours of consumers are also shaped by rapid modifications and interchanges that occur at economical, technological, social, cultural and environmental levels. They are rapid because the actual information technologies are used and are of extreme importance because they go beyond the global level. In fact, speediness of communications and information divulgation are factors that influence these changes and with more visible effects in the societies, in the markets, in the consumers and in the competitiveness of the enterprises. No all seem to play the same influence, by all seem to play some effect.

It is in this scenario that industrial design needs to give reliable and capable answers to consumers that demand innovation, quality, diversity and speed, and to enterprises that have to compete in this context of change, where the quality of the “answers” are always subjected to evaluation. The success of the enterprises is now based on its capacity/ability to answer rapidly to the consumer’s demands and in the use of technological innovations (Kamrani and Salhieh, 2000).

On of the factors that seem to contribute to the competitiveness of the enterprises is related to its capacity to manufacture products that can be quickly configured to offer distinct features relatively to same concurrent products. By developing new methods and techniques to react/reply quickly to changes demanded by the products (read consumers), based on market trends, it is possible to lower significantly the development time of the product, allowing the enterprise to obtain more economic competitiveness.

The versatility and adaptability of objects seems to be one of the alternative ways to answer with efficacious to these changes. Giving these characteristics, companies can rapidly launch new products, change parts of existing products, build new versions, etc. These characteristics can be given by products of modular conception. Modular products or systems allow transformations, adaptations, substitution, or reutilization of its components and development time can be significantly less, postpone the life cycle and more possibilities of personalisation of the product. In fact, modular products are associated to the manufacturing of personalised products, which can also be followed by mass production (e.g. computers).

The era of mass production, which initiated in the 19th century, gained more relevance in the 20th century. This expression only entered on current use in the decade of 1920, mainly through the influence of the industrial and car manufacturer Henry Ford. The production model implemented by Ford moulded its era, characterised by a strong expansion of industry and massive good consummation. The Ford strategy was based on the massive manufacturing of automobiles at low cost and by the utilization of standardised parts of inter-changeability characteristics and with defined interfaces that allowed easy assembly and disassembly. By the separation of the product in a small number of parts allowed more reliable management of the manufacturing process; by giving each worker specific functions and by the creation of an assembly line.

The actual tendency for personalised manufacturing (mass customisation) appears as one more initiative of industrial management to face technological and market changes. This type of initiative has as main objective the optimization of productive systems, the improvement of processes, having in mind the minimisation of costs, products with better quality patterns or with a more efficacious adaptation of these to potential users. The market and industrial changes occurred in these last decades have had necessarily reflections in consummation and production of products and services. This new scenario seems to question the exclusivity of mass production used by most industries. Following Pine II (1993, p. 34), a new paradigm of management is emerging, where variety and personalisation is overcoming standardized products; fragmented and heterogeneous markets are appearing in opposition to homogeneous markets and life cycle and development of products are reduced drastically. Mass customisation is the synthesis of two competitive management systems: mass production of goods and services individually adapted. This new model appears as an answer to consumer’s demands for differentiated products. As referred by Pine II, Gradey (2000, p. 42): “…from the industrial side, dismassification, more variety, innovations that reduce life cycles of the products and, in certain cases, the individualization of solutions or custom made.”.

The pioneers of this new frontier of business competitiveness are now seeing that more variability – even in the individualized manufacturing – can be obtained at prices that are similar or even lower than the ones of mass production. New ways are opened for the production of products that seemed to be impossible to be materialised in higher quantities by industry. This pseudo impossibility relied on the fact that the execution of this type of fabrication was more costly. One can easily see that changes of a standardized and optimised product, based on a profitably perspective and optimization of production means and human resources, where different versions of the same product are perfectly studied, demand higher costs at all levels.

The basis that supports the fabrication of a personalised product relies on the equipment used, that can produce economically small series of products. This manufacturing flexibility is only possible due to the evolution of technology and the generalised use of informatics systems, especially to CAD/CAM, High Speed Machining (HSP), Rapid Prototyping (RP) and Rapid Tooling (RT) that allow rapid manufacturing of a product. RP is an example of a technology that based on the information of a virtual part sent to a RP machine can be quickly manufactured.

The change to the manufacturing of personalised products is considered as a first signal that the markets are more and more fragmented and that companies need to invent new strategies to answer and adapt to these changes. Manufacturing of personalised products is therefore a strategy to answer to the rapid changes that are operating every day and also to clients' demands. "… one of the most important factors of industrial and commercial competitiveness is speediness of the replies to market solicitations and on the time of launching new innovative products" (Alves e Braga, 2001). Due to these demands, the product assumes a even more relevance in the enterprise. "The product is the heart of the enterprise" (Ericsson and Erixon, 1999, p. 7).

Each client is observed by organizations as a unique client; with specific characteristics and companies need to be alerted to provide adequate answers to their desires. The generalisation of communication and information technologies is generally providing companies and society (individuals) of tools that until today were exclusively belongings to big economical groups that could influence and drive the market. However, the accessibility of information through communication means is actually changing the way clients establish their connections with products and how enterprises configure their relations with the markets.

Today we buy on a global shop, were novelty is asked by consumers, sometimes is the price. The client has less, or no possibility to negotiate, for example the price, by has more options to select and buy. Internet allows any client, localise in any part of the world, to buy products in any part of the world, in the same minute of the desire to buy. This new mercantile structure supplies the client with necessary tools to satisfy the desire of buying new products with new functional, aesthetic and adapted qualities. Consumers are demanding a new variety of products at low prices and with immediate disposability (Graddy, 1999, p. 1).

Products, the result of constant developments and implementation of new technologies, are becoming more and more complex, but not necessarily complicated. Moreover, this increment of complexity is a consequence of the need to facilitate and simplify the executed tasks by their users to obtain the product's functions. For example, in the automobile industry, the "informatization" of the car is a reality that hides a bigger complexity, providing higher differences relatively to passed generation of cars. Its is notorious the improvements for all users, as for example the use of active and passive security systems, the use of navigation through satellite, analyses of electric, electronic and mechanical systems, etc.

One of the first industries that adapted to this scenario was the personal computer (PC) industry, partly due to the modular constitution of the product. Each computer is composed by distinct modular parts that execute several functions and that can be grouped in several combinations. This type of structure provides the necessary instruments for the management of the complexity of the product, and at the same time allows the assembly of adapted products to the necessities of a certain client. We can say that modular design appeared as a competitive advantage in the computer industry in the decade of the sixties. However, the advantage of manufacturing products through their modular parts was early recognised by other industries, like the automobile, due to the complexity of their products. As examples of modular parts for the automotive industry we can refer the engine, transmission, audio equipment, etc. As for electronics, modular parts are the processors, batteries, motherboards or CD readers. Software can be grouped in modular ways that can be organised in several combinations. The International Space Station is an example of a modular construction. These modules are developed and manufactured separately in several countries and then transported by special vehicles. Associated to modular design, we find concepts of module, interface and product architecture. Interface allows the adaptation between two or more independent systems. In this way, the interface of a body is a set of identical characteristics that are placed between two or more modules, allowing its connection and relationship, and therefore its connectivity. The architecture of the product is defined by Baxter (1998, p. 234) as the study of the interactions and physical arrangement between modules, allowing the final product configuration.

Modular design can be a strategy for the construction of complex systems and products based on small subsystems that can be developed individually, but function as an integrated set. This set is a division of the system in functional modules that connected between them by interfaces define a structure defined as architecture. Each module represents a functional unity, more or less complex, that together with the rest of the modules contribute for the functioning of a bigger structure. The interfaces specify in detail the interactions between modules, its connection and communication. In this way, we can say that a modular system is composed by unities or modules that are designed independently to execute one or a number of reduced functions that when connected execute the principal functions.

The quality of modular design is independent of an efficient division of the information in visible design features such as interfaces and invisible ones like internal mechanisms. Modular design can benefit the product if division is precisely, complete and not ambiguous. Following Anderson (1997, p. 265) it is important that in modular product the division in modules is optimised. Due to the independency that components obtain in a modular system, modular conception and development can be made in parallel since they do not depend from each.

In a modular design, the division of information in modules has in consideration the division of the modules for several structures, and is made in a way that these modules can be combined and assembled in different products or systems with optimised objectives. In this sense, standardization of the modules assumes great importance in shaping the module and their interfaces as well as measuring the performance of one module relatively to other. The intervention on a product of modular conception for maintenance, substitution or actualization is also facilitated since the own system facilitates naturally actions of intervention in the different modules.

The definition or determination of these types of aspects appears in product planning and goes through the initial phases of the project and divulgated by all involved in the development of modular components. These types of design rules are catalogued in the three categories that define modular product: product architecture, interfaces and modules (Valeri et al., 2001).

For Ulrich and Eppinger (2000, p. 184) the most important characteristic of a modular product is the power it has being modular. Architecture is considered modular when each functional element of the product is made by a unique physical module and by the interactions that are defined between different modules. This type of architecture allows that one of the modules can be changed without changing others for the product to function correctly. With this type of architecture, modules can be developed and built independently. Pine II (1993, p. 136) refers that modular design, through the use of modular components that can be configured in a variety of products and services, is the best method for personalised fabrication, minimising costs, while maximising the personalisation of the products to reach specific needs of the users. For Ericsson and Erixon (1999, p. 17), modular conception allows the management of the architecture of the product. In other words, if we are able to divide a complex structure in small malleable units, we can control better the processes of development and its production. The complexity of a system can be easily manipulated if the system is divided in smaller parts and for each special attention is given.

Products, enterprises and markets have behaved differently through out the centuries using differentiated production systems. In massive industrial production, products are standardized, less flexible and maintain the same patterns throughout time. On the other extreme, there is the artesian production which offers higher degree of flexibility and non-limited variability, but also has other types of limitations. In the middle there is the manufacturing of personalised products. This type of production makes use of the flexibility characteristics of modular design, which has the capacity of change and actualization, obtained through differentiated combinations of the modules, and allows the product to be flexible and of ease personalization. In a company, a line of products is considered more or less flexible according to the number of options that product allows.

The modular conception of products and systems allows manufactures a variety set of products that allow them to quickly response to changes and consumers desires and necessities. Modular design allows designers, engineers and others to design the functions, the functionalities, or the form of the objects in independent modules. This can allow higher number of innovations, create and test different solutions without the necessity of changing a structure, and only respect the systems interfaces. Due to the independency of the parts of the modular product, enterprises which supply modular parts have the development of products more facilitated, and can specialise in certain functional modules.

Following several authors (Kamrani e Salhieh, 2000, p. 47-48; Ericsson e Erixon, 1999, p. 17-18; Anderson, 1997, p. 267), the development of products using modular architectures generates positive effects in the range of products and presents the following advantages:

- Reduction of the product development time - different modules can be developed and built simultaneously, if the interfaces are defined previously;
- Actualization of the product - a modular design strategy can be oriented for easy actualization, minimizing the impact of obsolete modules. The possibility of renovation of the product through the change of some modules can be given by the user, salesman or

manufacturer, allow the management and control of the real actualization. The set of modules that compose the product gives to the same the functionalities and expected capacities at the acquisition moment by the consumer. Meanwhile, with the evolution of the technologies or desires, some parts can become non actualised and are quickly replaced by others;

- Cost amortization - modular components can be used in different product lines, which mean that the volume of production is high. This will allow that amortization of development costs is made through a big number of products;
- Quality of the final product - the functional interdependency of each module allows that its efficiency can be testes separately before being connected to build the product. The quality control can in this way be divided by various components and guarantee a final product with better quality;
- Standardization of components - modular design promotes the standardization of components and interfaces. Therefore, it is possible to reduce risks of bad functioning, that can come from the interaction of the components with the rest of the product or other products;
- Reduction of time delivery - the time between buying and deliver is reduced. The use of modular conception of products facilitates the construction of various other product hypotheses. The modular product can be composed by combination of standardized components and/or personalised components (made by order). This combination can exist in a database of standardization components which personalised components can be added.

The design of a modular product can be made using conventional techniques for product development, but it is much more advantageous the use of a methodology than can use, in its maximum force, the concept of modular architecture of products. The use of modular conception means the decomposition of the principal design problem in sub-problems, functionally independent, in which the interaction or interdependency between them is minimised. The design modular concept tries to establish a decomposition technique that reduces the interaction between modules and the complexity and at the same time creates interface mechanisms that facilitate its connection and interaction. Modular design is seen as a process that in a first stage produces units that execute minor functions, and when connected and grouped execute a variety of major functions.

The advantages for the users seem to be evident due to the possibilities of actualization of the modular product. Even though, it seems that in the design of generalised products, not only the technical component is advantageous if modular, but also the aesthetical features can be valorised. For example, it is possible to personalise objects by putting own personal references on products at low cost. For this objective, technologies like RP and RT play an important key role. Modular conception permits products with this type of elements (personal), longer life and with actualizations on one side and versatility on the other which contribute to reduce the quantity of waste that are generated by total replacements and also energetic resources and raw materials that are used in the conception of new products.

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