DEVELOPMENT OF A PROPOSAL OF A METHODOLOGY OF INTERFACE DESIGN IN THE CONCEPTUAL DESIGN

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Abstract*. This paper presents an initial proposal of a methodology for the interface design in the conceptual design phase. This methodology was developed based on a bibliographical research that raised some requirements. The bibliographical research had try to consider different aspects of the product lifecycle. Some of these aspects are the way to design interfaces, the role of the definition of the product architecture in the product development and different aspects and techniques in the product lifecycle. The techniques considered were Failure Modes and Effects Analysis, Design for Assembly, Design for Manufacturing. However, costs, reciclability, disassembly and others were considered too. As result of the research was evidenced the gap in the interface development into product design methodology. So it was elaborated a list of requirements for the development of a methodology that supplied this gap. Some of the requirements found were the necessity to take care of different subjects and to make possible the evaluation of conceptions with different degrees of detailing. On the basis of these requirements a conceptual methodology for the improvement of the design process was then proposal. This methodology aims at to reduce the uncertainties, and consequently the time and the costs, during the phase of definition and selection of the conceptions for the product. This research is on development.*

Keywords*: interface design, conceptual design, Failure Modes and Effects Analysis, Design for Assembly, Design for Manufacturing*

1. INTRODUCTION

The Conceptual Design phase (Figure 1) is considered one of the critical points in the design process (Hölttä and Otto, 2005). It is important because at this point the design structure and concept are defined. We can to estimate that up to this point about 20% of the work involved in the design is completed, and that this percentage is responsible for defining 80% of its cost (Back and Forcellini, 2000). This occurs due to the conceptual design works with the abstract phase of design process. After that, it moves to the product concretization. As a result of its importance, this phase has some points requiring a better definition.

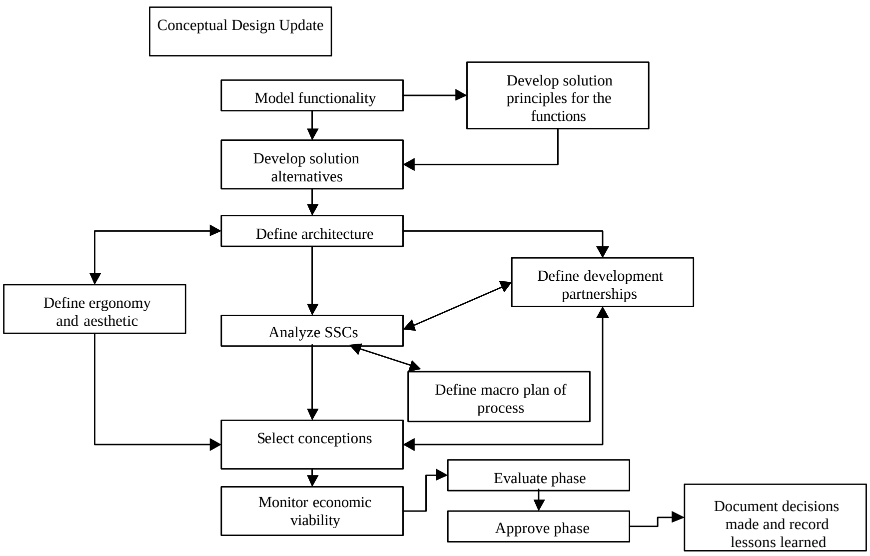

Figure 1. Conceptual Design phase (Rozenfeld *et al*, 2006)

Inside the conceptual design, we can note some areas that still are needing of a better detailing like the interface design. In this aspect, the existing methodologies attend the interface design just in the embodiment design. This lack of interface design method causes some troubles like the need of iterations due to connection fails among solution principles or the need of complex interfaces among two principles. These troubles can cause late and increase in the design costs.

Moreover, the role of interface design is showed by Ullman (1992) which points that "functions occur in the interfaces between components". This is based on the following interface definition: "the boundary area between adjacent regions that constitutes a point where independent systems of diverse groups interact" or "the interconnection between two equipment that possesss different functions and that could not connect directly themself" (Ferreira, 2003).

The great advantage of the earlier determination of the product interfaces is that the change of the abstraction level to the concrete level becomes less abrupt and uncertain, that is, instead of creating the solution principles directly from the structure of functions we can to reduce the possibility of problems in the latest phases by the product architecture definition. Thus, parameters for the product development as the involved variable, flows of material energy and signal as well as its proper interfaces, would become more apparent to designer.

Another advantage is that the interface design appears like a tool to effectivelly implement the concurrent engineering environment (CE). This advantage is due to its characteristic of connect different product components. So, the manufacture, assembly and reliability areas can be related to the interface design (Andrade and Forcellini, 2004). Thus we can affirm that the development of a methodology of interface design is a potential factor of implementation of a CE environment.

So, the objective of this paper is to present a proposal of a methodology of interface design in the conceptual design phase to increase the knowledge of the design team about the designed product and reduce the design uncertainities. However, its necessary to use methods and tools of support. So, we will analyse some of them, too.

2. BIBLIOGRAPHICAL REVIEW

To develop an interface design model in the conceptual design phase, we must to do a bibliographical review to look for information about the subject. This search helps us to collect requirements to the methodology. So, we will relate the information found in the bibliographical review.

2.1 Interface design

There are some works in the literature about the interface design.

Ulrich and Eppinger (2004) proposed a way to determine the product architecture by the mapping of interactions between functions and the possible product interfaces. However, the proposal of the authors is inserted in the embodiment design what indicates that for its application already exists a defined conception. Stone *et al* (2001) describe the possibility of use of the method of Ulrich and Eppinger (2004) still in the conceptual design phase and, moreover, presents another proposal of architecture generation and determination of the possible modules that are executed by heuristical means. This proposal presents the advantage to use the design specifications and the product constraints as parameters for the development of the product architecture.

Ullman (1992) considers a systematic of interface development in the embodiment design in which presents some steps that are executed since the establishment of energy, material and information flows in the functional level, passing to the most critical interfaces determination, the maintenance of the functional independence of subsystems and components and the care in separating the design in distinct components. Another proposal to interface development is made by Stone *et al* (2001). The authors point the need of initially to define the product architecture and, based on this, to define embodiment layouts. So, we can establish the product interfaces. However, the authors do not point how to do it.

Sousa (1998) evaluates the techniques to develop a product layout. He made an analysis of the use of methods of Design for Manufacture and Assembly (DFMA) in the conceptual design. In this study, the author points that the manufacture and assembly requirements, beyond the functional requirements, are important for the evaluation of the product structures. Also, he places that, for does not being made a correct evaluation of product assembly and manufacture in the conceptual design, there are unnecessary iterations when the design already meets in the embodiment and detailed phases returning to the conceptual design. These iterations cause increases of costs, delays and reworks that could be prevented.

Ullman (1992) and Linhares and Dias (1998) places that CE must consider four basic elements: function, geometry, material and manufacturing processes. Moreover, they place that design and manufacture (including the assembly) must simultaneously be developed. They point that the development of each part needs to be integrated to the funtions definition and refinement and its respective interfaces. Linhares and Dias (1998) emphasize that the design must take in account two tasks in the individual conception of a part: (1) to design it like it was a product and (2) to consider that it is part of a realizable module taking in account its interfaces. Siqueira and Forcellini (2001) make the consideration that the requirements of the unions are excellent factors in the selection of concepts.

Siqueira and Forcellini (2001) and Scalice (2003) developed a systematic for the interface development in specific products and based in sequential models of product development.

The first one presents a systematic for selection of injected plastic unions. This systematic is developed in the embodiment design and has as entered the chosen conception in the conceptual design. The author points that are necessary information as that: "related to the components manufacture process; related to existing geometry and materials of the components and unions; related to the product use conditions; recommendations of components and unions design; and related to the design and manufacture of molds".

Based on this list, we can detect the need of, for the determination of the product interfaces, to consider all the aspects of the product lifecycle. This occurs because we are working with elements that are joining different components. These elements affects directly the manufacture, assembly, use and recycling processes. So, it is necessary that there are information of all these phases in the interface development.

Scalice (2003) had develop an interface design tool called Interface Selection Process (PSI) for modular products. Accordingly to author, the interface development has a importance in a modular product design. Other authors who point such importance are Erixon *et al* (1996) which affirm that "the interfaces present a vital influence in the final product and in the variety flexibility".

The tool proposed by Scalice (2003) is part of the embodiment design of modular products and is based on procedures adopted in the conceptual design. Scalice *et al* (2001) say that "the previous knowledge about the modules to be designed and the functions that will compose them are the basic requirement for the start of the interface determination". Therefore, these information assist in the identification of the existing interdependences between the modules. It allows to define position and ways of linking between the modules.

Therefore, as Scalice (2003), the interface development process is carried through by follow three steps.

The survey of the necessary interfaces are made by the application of a matrix that relates the modules determined in the conceptual design with the interface functions presented by Hillströn (1994). These are: to provide support, to transmit force, to locate the component in assembly, to provide the localization for other components in assembly and to transmit movement.

The search for Principles of solution for the interfaces can similarly be made by the morphologic matrix.

The generation and selection of the interface alternatives can be carried through by comparative choices, Matrix of Pugh (1991), or for a technical analysis.

We can note that the procedure is very similar to the conceptual design. However, it is carried through in the embodiment design and it is related to an element of union of components. Another question is the need to design the interfaces after the definition of design modules. This implies that exist a dependence of the shape before the interface generation.

The method considered by Ulrich and Eppinger (2004) points the need of identifying the portability of the interfaces as well as the interactions between the developed blocks. For this, the authors place the possibility of use an interaction graph or an interaction matrix according to the product complexity. Also, we have to differentiate the types of interactions if they are fundamental or incidental. The fundamental interactions are those where the basic connections between the elements exist, that is, where the flows of material, energy and information occur. The incidental interactions are those that are originated from unknown relationships, or resultant of interactions exactly waited, but with unexpected consequences due to influence of external variable.

Fixson (2005) presents a method of evaluation of the product architecture. In this method the author points the existence of a linking between three distinct areas of design process: product, process and supply chain. Inside of this model, he develops an evaluation method of the interfaces that considers their characteristics.

The author points that, while the function component allocation (FCA) metric is related to the functional overlapping, the characteristic of the interfaces are related to the degree of coupling between these elements (component X function). The interface measure must be carried through in a disaggregated way so that it allows an inquiry of its individual effect. For this the author divided in three categories of information regarding the interfaces: type, reversibility and standardization.

- The interface type is the role that it plays for the product function;
- The reversibility is the capacity of execution of product changes;
- The standardization is the capacity of substitution and elaboration of product families.

For the definition of the type it is necessary to consider the interface intensity. Fixson (2005) points that the interface intensity reflects its force and desirability with respect to its functional role. This can be a measure of the coupling.

For the measurement of the reversibility the author uses a metric of the effort necessary to detach an interface. This effort depends basically on two factors: the physical difficulty of disconnection and the interface position in the product architecture. It calls these two factors as effort and depth and defines some criteria as the need of tools and time of disconnection of the interface (effort) and number of components to be removed to access the component (depth).

With respect to the measurement of the standardization, the author points a mapping in accordance with the type and the involved components in the interface. So, there are interfaces where change is very difficult and there are interfaces where is possible to do multiple alternatives of substitution. In this case, do not exist an explicit quantification of the standardization degree, there is only an evaluation by a map that also considers the possible types of modularity.

By this evaluation the author elaborates what he calls of product architecture map where we will verify the modularity degree and, consequently, the types of product interfaces indicated. This model presents as to measure the interfaces but not as determine them.

From these representations we can use different solution principles. With them we can to evaluate the product architecture. However, we must to emphasize that product components must be known. So, we can be able to evaluate them by the model proposed by Fixson (2005).

Another way to formulate the product architecture is presented by Stone *et al* (2001). The authors consider that the product architecture is based on grouping rules that combine the functions in modules according with pre-defined parameters. The authors point that the design process is essentially heuristical, that is, it do not possess only one solution. Therefore, they call the developed method of method of heuristical of design.

The method of heuristics is elaborated in order to search the definition of constructive modules for the product. It groups the functions considering the type of flow (if dominant or it is branched) or if exists the transformation and transmission of flows. Each one of these processes defines a possibility of grouping functions that can constitute a module. The selection of which modules will be implemented will be done by the design team accordingly with its perception about the most interesting solution to design problem.

Based on these groupings, the authors determine the possibility of definition of the product architecture in a functional level. A limitation of this method is its application without the consideration of the internal module interfaces. This occurs because the inter-modular interfaces are specified only after the modules definition. Thus, the grouping process do not consider the interfaces as selection element what means that the intra-modular interfaces are relegated to a secondary plane and they can be defined just after the modular architecture definition.

Using the heuristics method, Stone *et al* (2004) present a methodology of use of the Design for Assembly method (DFA) in the conceptual design phase. In this model they have a concern with the assembly of the product and with their interfaces. Although to consider the development of interfaces, we can perceive that the main focus of the model is the redesign. It is necessary the existence of a product that can be optimized to be applied this model and the DFA. However, the use of the method of DFA in the early phases of design already is important for the improvement of design quality and the definition of production process.

Greer *et al* (2004) point the possibility of decomposition of the designed product in effort flows. This implies that we can define the product architecture by the need of execution of an effort by a determined path. This path can be determinative for the definition of the product architecture.

Also based in the heuristic method, Otto and Dahmus (2001) say that the function structure serves to establish specifications, to generate solution principles and to specify interface requirements. Another aspect pointed by the authors is the concern with aspects as repair costs during the product lifecycle denoting the possibility of application of the FMEA in the decisions on the function structure of the product.

Pahl and Beitz (1995) establish the definition of product lay-out in the embodiment design. This started with the product concept generated in conceptual design and, from this, the generation of embodiment and detailed lay-outs. Thus, the product interface design is developed, for these authors, in the embodiment design. However, when we analyze their conceptual design proposal, we note the existence of a early lay-out development. This occurs due to the application of combination of solution principles tools like the Compatibility Matrix proposed by Dreibholz (1975) apud Pahl and Beitz (1995), which assists in the determination of the work structure. This work structure is a sketch of a product lay-out that consider the compatibility among the solution principles to evaluate the generated conceptions.

From these techniques a product work structure can be established. The authors point that “in the combination process of solution principles the main problem is to guarantee the physical and geometric compatibility of the work principles to be agreed what, in turn, guarantees an adequate flow of energy, material and information”. Moreover, they still point the concern with economic and technical factors to execute such combinations. However, they leave the interface design to be developed in the posterior phases. So, this stage is just a survey of needs for the interface design.

To Baxter (2000), “the product configuration phase is differentiated from the conceptual design by the introduction of diverse instruments of test and evaluation of the product”. The author defines product architecture as being “the study of the interactions between the blocks of physical elements and their physical arrangement, constituting the product configuration, called product architecture”. Thus, the author proposal is to work with function and style in a separate way, integrating them in a subsequent phase. Another question is that the author emphasizes the use of the integral architecture because he classifies it as a “simple and elegant” configuration.

Rozenfeld *et al* (2006) places that the functional structures must contain all the involved flows of energy, material and signal. Moreover, the compatibility between the entrances and the exits of the adjacent functions must be guaranteed. For the definition of product architecture the authors place that the unfolding of the solution alternatives in systems, subsystems and components (SSC’s) must be made that will have to take care of the functions of the product. Thus, each alternative of design or model of generated principle of total solution in the preceding activity will have a specific architecture.

The classification of the architecture type is based on the developed list made by Ulrich and Eppinger (2004). Moreover, they place that the elements that constitute the product as well as its inter-relationships, including its structure, are not represented in the accurate form. Also, the development of the architecture involves the division and identification of individual SSC' s, its localization and orientation.

Due to this aspects, the interactions between SSC' s are defined by their interfaces. These, in turn, can be mobile, fixed or to be a way of transmission. Therefore, they have a important role in the final item due to interchangeability between SSC' s and to be determinative for its assembly.

The definition of the Interfaces can be carried through by the Interface Matrix proposed by Erixon *et al* (1996) (Figure 2).

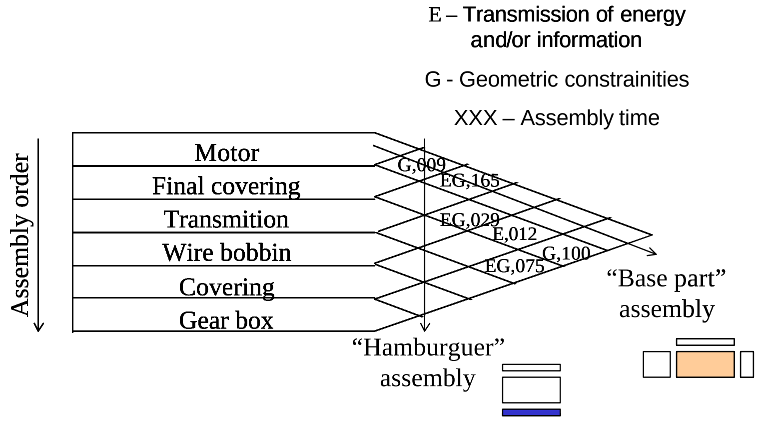

Figure 2 – Interface Matrix (Erixon *et al*,1996 and detailed by Rozenfeld *et al* 2006

Another aspect related to the development of product architecture is the product representation by physical and technical properties. However, these properties are not the only criteria to be evaluated. According to authors, use, appearance, production, costs, etc, also must be considered. Thus, the use of other techniques and tools that consider the lifecycle impacts in the product design must be developed to avoid poor decisions and unexpected design problems.

Ullman (1992) points that the transformation of the abstract to the concrete field follows 9 steps. Amongst these steps, we can to distinguish those which are involved with this work. Thus, the step 5 - to create and to refine interfaces for the functions – uses the functions developed during the conceptual design which, according to author, must present balance of forces and consistent flows of energy, material and signal. Moreover, an indication to the creation and refinement of the interfaces is the accomplishment of this task from the external interfaces to the interfaces that involve the most critical design functions. Another point detached for Ullman (1992) is the importance to remain the functional independence of assemblies and/or components.

In the step number 6 - to connect the functional interfaces with materials -, the author points that less than 20% of the dimensions in the majority of the components are critical for the component performance. This occurs because a lot of materials are placed to connect the functional interfaces and does not need critical sizing. Also, we must consider that the material in the interfaces serves generally to three intentions: to transmit forces or other kinds of energy, to guide other components and to provide appearance surfaces. Another rule that must be considered is that the interface connections must be made with robust structural shapes in order to transmit the minimum effort between them. We must consider that the rigidity frequently determines the adequate component sizet. So, we must use standardized shapes.

With respect to product interfaces development, the author points the need of establishing the interfaces with the application of the DFA. Thus, he places that to make an efficient assembly sequence the designer must:

- to list all the involved components and processes in the assembly operation;
- to list the interfaces between components and to generate an interface diagram;
- to determine, for each coupling, the principal interfaces;
- to determine, for each coupling, the interfaces that must be left to be carried through after its accomplishment;
- to generate sequences of interfaces submitted to restrictive relations;
- to eliminate the "disfigured" interfaces of the diagram of sequences and the ones that result in separate subassemblies.

Brunetti and Golob (2000) present a way to define product structure from its computational modeling. This is based on features of product semantics, in particular of its functions, in the conceptual design. The advantage of the considered model is that it has a detailing of the relation between function and form in order to get a way to model the function structure representing not only static information of the function, but also, loading the knowledge on its intention and its concrete form in terms of solution principles. Although this, they present a way to modeling the inter-relations between parts, features and assemblies but do not speak how to create these relationships inside the model.

Wilhelms (2003) considers a way of functional modeling that allows the reuse of solution principles elements and, at the same time, the addition of new elements without inhibiting the diversity during the design with the objective to the use of a semantic network to the function modeling in the conceptual design. His objective is to contribute with an information semantic model with bigger formalization of solution principles reused allowing the instantiation of the elements as well as supplying to a limited support to the synthesis and the detailing.

Gui and Mäntylä (1994) proposed a tool in the computational functional modeling field that makes possible the functional modeling of the product assembly. The authors search, by means of this model, to link the product function to its shape as a functional data base of solution principles and structures. Thus, they define a general model of assembly which allows to support the high levels of abstraction of conceptual design as the features modelling.

Rehman and Yan (2003) developed a methodology that is based on Product Design Elements (PDE). The proposal has as objective to support the functions in the conceptual design of mechanical devices using the knowledge of the consequences of the context that occur due to selection of a PDE.

Another technique used to analyze the functional structure of a technical system is the Systematic Technique of Functional Analysis (FAST) (Csillag, 2000). It allows the unfolding of the function structures from the level of global function until the level of elementary function. Also it allows the verification of the existent relationship between the functions of a determined system without necessarily define how are these interactions.

The FAST is a representation of service and technical functions of a product solution.

The functions identified by a logical and intuitive reflection are placed to constitute a kind of diagram that we can modify until getting the foreseen relations and a product functioning representative chain. Some imperfections in this logic suggest that some functions had been forgotten and that they must be searched.

Barraza (2003) points as advantages of the use of diagram FAST that: the analysis of the functions can clarify a design and to find only the functions that are related with the design costs. The functions propitiate a more creative team due to their degree of abstraction and they make the linking between the information and the shape definition phases.

However, the author also points some difficulties associates to the FAST: it is necessary time for complete and correct application of the FAST, it is necessary training to correct application of the technique, as it is a logic diagram as/because/when it requires patience, and as it can have many different interpretations in the application of the FAST the process can become excessively complex.

2.2 Model Requirements

Based on the bibliographical research, we can list the following model requirements:

- to be clearly – the method must be simple and logical in the organization of the information;
- to be easy to develop – we must consider the possibility of computational implementation, so the method must be developed considering that;
- easy manipulation – all kind of designers (researchers or industrial product designers) must use the method without difficulty;
- easy visualization – all the information must be easy to see inside the method;
- to contain information of all the stages of the product lifecycle – we must have to consider all the product lifecycle to develop and evaluate conceptions;
- to have consistency of information – the method must be logical;
- to restrict solutions – we must be able to see the illogical conceptions and eliminate them;
- to add functional, geometric and physic restrictions – consider all the product constraints;
- to analyze compatibility of solutions – to map the feasible conceptions;
- to provide information with cost – consider the product development costs (material, process, assembly);
- to be based on the functional structure – start with the functional analysis;
- to consider different architectures – the method must to consider both the integral, modular or an hybrid kind of product architecture;
- to verify the fundamental and incidental interactions – map and simulate to find all the effects (desirable or not) of the use of product;
- to make possible the evaluation of conceptions with different degrees of detailing – the designer must be able to see and evaluate all the conceptions in their different degrees of detailing. This is a difficult found by different authors that point the need of detail the conceptions to the same stage which is very restrictive or, at the same time, complex.

These requirements search to attend all the stages of a product development. So, we will have to look for a lot of skills that give From the presented list it will be proposed a model of interface design for the conceptual design. Before this we will analyze some methods and toos to support the model.

3. SUPPORT METHODS AND TOOLS TO THE INTERFACE DESIGN TO THE INITIAL PHASES OF THE PRODUCT DEVELOPMENT

In this topic the methods of DFA and DFM and the tool of FMEA will be boarded as auxiliary mechanisms in the product development process and, especifically, in the interface development in the early phases of the design process.

3.1 DFA e DFM

The methods of DFA and DFM aim to optimize the design in the phase of definition of processes and final shapes, searching lesser times and costs. These methods had been developed by Boothroyd *et al* (1994) and, initially, was used in set (DFMA). However, due to importance of each one of the processes and the possibility to be applied separately in agreement the case, them they had been branched in two methods: DFM and DFA. To have an idea of the relevance of such methods Boothroyd *et al* (1994) and Pereira and Manke (2001) esteem that 50% of the manufacture costs are related to the assembly process and both represent a great parcel in the final cost of the product.

Moreover, the two methods are based on the last experience and search to expose and systemize the knowledge Ferrari *et al* (2001). Thus, its role is observed as mechanisms not only of aid technician but, also, of support to the management of knowledge of the company.

However, for its application, it is necessary that there is an integrated product development environment, with processes and products engineers working in set in the early phases of design. This is another characteristic of the DFMA methods. It require the implementation of a CE environment with representants of different knowledge areas in the design team.

To Keys (1990) apud Valeri and Trabasso (2003) the DFX methods can be defined as being “a set of techniques generally applied in the early phases of the integrated products development, to guarantee that the hole lifecycle will be considered in the product design”. In this definition the authors point that the DFM method is one “technic applied in design, aiming at definition of alternatives which optimize the manufacture system as a whole, identifying concepts of easy manufacturing products, help the design of these kind of products, facilitates the integration between the development of manufacture processes and the design of the product”. Therefore, Stoll (1988) apud Valeri and Trabasso (2003) place a list of directives for the DFM:

- to minimize the number of parts;
- to develop modular designs;
- to minimize the variations of parts;
- to design multi-functional parts;
- to design parts for multipurpose;
- to facilitate the manufacture;
- to prevent the separate fixing use;
- to reduce the assembly directions;
- to maximize the elasticity of the assemblies;
- to minimize the handle;
- to evaluate the assembly methods;
- to eliminate or to simplify the adjustments.

Relative to DFA Lee and Hahn (1996) apud Valeri and Trabasso (2003) define it as “a group of design techniques used in the product development to improve the assembly”. The authors divide the DFA in three boardings:

- general rules used by the designers as directives;
- measurelines of assemblability of parts and the product as a whole;
- revisions of design to combine the measurelines of assemblability with times of assembly and its costs with assemblability rules in order to assist in the revision of the design.

Because of this, it can be defined some basic lines of direction for DFA: minimize the number of parts and easiness of assembly to reduce the cost of the product (Valeri and Trabasso, 2003).

Thus, Kuo *et al* (2001) apud Valeri and Trabasso (2003) cite the criteria of DFA as being:

- to minimize: number of parts and elements of setting, variations of design, movements of assembly, directions of assembly;
- to provide: chamfers, automatic alignment, easy access, symmetrical or to evidence anti-symmetrical parts, simple manipulation and transport;
- to prevent: visual blockages to parts, entangled or hidden parts, necessity of posterior adjustments in the assemblies.

So, we can note the capacity to integrate the product development process that the presented methods possess. From this, we can think about the best use of the same ones, suggesting to apply them in the interface design in the Conceptual phase.

3.2 FMEA

The tool of Failure Modes and Effect Analysis (FMEA) was developed with the intention of assisting in the diagnosis and forecast of military and aeronautical equipment imperfections. However, due to its predictive character, it passed to be used in product design.

The FMEA is a standardized analytical tool used to detect and to eliminate potential problems by a systematic and complete way (Ferrari *et al*, 2001). It uses the knowledge of the design team on quality, performance and process. Moreover, the FMEA allows the hierarquization of the causes of the problems and establishes parameters for the adoption of preventive or corrective actions (Ferrari *et al*, 2001).

Thus, when the FMEA is applied, we can to determine the design critical points. This will help the team to define the priorities of design. This tool, as well as the DFA and the DFM, is used in the Embodiment Design phase. However, like the FMEA implies in functioning preview it is useful in the Conceptual Design.

The application of FMEA in the Conceptual Design possesss the advantage to detect and correct problem earlier. However, it presents the disadvantage of, in this phase, to possess few available information. This lack of information can be a source of uncertainties, but this can be useful in the interface design to solve some of the uncertainities.

4. THE MODEL

The model of interface design in the conceptual phase must follow the requirements pointed in the previous topics. For this, it must verify the compatibility of energy, material and signal in the functional modeling, product lifecycle aspects and process design, to analyze the compatibility of involved physical principles, to make an analysis of the product modularity, and to assist in the concept generation and development.

From these considerations we can perceive that the first step of the model is the analysis of functional compatibility of the product. This start with the functional structure of the product and verify which are the material, energy and signal flows existing between his functions and allow the visualization of which are the possible functional groupings to be carried through. This analysis can be compared with the method of the heuristical proposed by Stone *et al* (2001).

In this step, the functional FMEA (Andrade and Forcellini, 2007) can be used to define the critical product functions. The functional FMEA can to establish a parameter of functional priority. This can be defined as being the metric of the function importance as well as its centrality in the design context. Such centrality can define the function as the product base. So, all the function interactions must be defined from it.

After that, it can be established the solution principles associated to the product elementary functions. For this it is used the Morphologic Matrix tool that allows to visualize all the principles associated in a simple way. In this matrix it can be inserted other aspects of the product lifecycle.

Such aspects are based on the developed solution principles. From these principles it is possible to carry through an analysis of assemblability, manufacturability and fails more concrete. These analyses not only work as a definition of product shape as well as supplies more effective information to evaluate their use in product and process design.

The assemblability analysis can be developed by the application of DFA methods as the developed for Stone *et al* (2004). These authors had develop a methodology for use of the DFA in the conceptual design phase based on the heuristical method (Stone *et al*, 2001). Another alternative is the DFA analysis proposed by Boothroyd *et al* (1994).

The manufacturability analysis can be made by the application of DFM (Boothroyd *et al*, 1994). This analysis can be made considering some main lines: to minimize the parts number; to develop modular design; to minimize the parts variation; to design multi-functional and multipurpose parts; to design parts for easy manufacture; to prevent the use of separate elements of setting; to eliminate/simplify the adjustments; to prevent the use of flexible components; to minimize the manipulation; to use easy processed materials; to use normalized materials and components; to use the special characteristics of the processes; to design the waited volume; to liberate the tolerances.

By the comparison with the directives above, a cost, time and complexity of manufacture of principles estimative can be made. This is determinant to get a evaluation parameter of solution principles, which can be qualitative.

Another aspect that can be evaluated from these comments is the modularization or integralization decision. This occurs because the different evaluated aspects, combined with the defined design specifications in the informational phase, provide a measure of the degree of product modularization. For this, we can use the Module Indication Matrix (MIM) (Erixon *et al*, 1996), modularity evaluation metrics (Fixson, 2005) or the heuristic design method (Stone *et al*, 2001). We can to evaluate the flow of effort (Greer *et al*, 2004), too. The choice of which modularization technique to use can be done based on the amount and quality of information gotten until this design step or on the company product development strategy.

We can also to associate a risk factor involved in the evaluation of the principles which is directly linked with the degree of innovation desired for the design. This risk factor can, in such a way, be measured by an analysis of FMEA (Andrade and Forcellini, 2007) of the solution principle as for manufacturability and assemblability analysis.

Thus, to concept generation, the different combinations are verified. However, all the raised information must be critically considered. In the practical this means that we will have a reduction in the number of possible combinations having, also, a reduction in the work of concept selection. In such a way, the existence of a metric is necessary to we associate with the solution principles and in a way that we can to evaluate its degree of usability. This degree of usability must contain the information mentioned above but it will not be the only one evaluation parameter.

This occurs because still it is need that we make a compatibility analysis among the generated solution principles. This analysis is important because we can verify potential problems of logical combination between the considered systems. For this, the matrix of compatibility presented by Dreibholz (1975) apud Pahl and Beitz (1995) can be used.

Finally, the interface matrix of Erixon *et al* (1996) can be applied for the definition of assembly strategies and consideration of the geometric restrictions for the product.

We must emphasize that this model became viable due to the current stage of development of the tools of product design. This development had propitiate new ways of more realistic visualization as the virtual models (CAD, for example) that assist in the definition of conceptual shapes and tests, mathematical models that allow that we do, with a conceptual model, a embodiment strenght analysis and the iconic models that allow the perception analysis of product aesthetic and assembly can be carried through.

4. CONCLUSIONS

From this model the followin conclusions can be drawn:

The interface design in the conceptual design has a kind of implementation difficulty. There are not interface design methodologies for the conceptual design. However, there are proposals that suggest its development in the embodiment design but, these keep the sequential status of the product development. Other differences between the proposed methodology and that proposed by Rozenfeld et al (2006) are the definition of the product configuration still in the conceptual design as well as the start of the production process design in this stage. Also, we can to work with fewer degree of uncertainties than that methodology.

There is a need to anticipate the DFA, DFM and FMEA. This anticipation tends to add information of different areas of the product lifecycle facilitating the implementation of the CE environment.

The DFx techniques can be considered as a knowledge base which objectives to design products maximizig characteristics as: quality, reliability, services, security, user, environment, time-to-market, at the same time that it minimizes costs of the product lifecycle and manufacture. Thus, the use of the DFx in the conceptual design can have a great role in the taking of abstract level decisions and in the product costs later phases of its development. In addition, they define the product performance in its lifecycle.

The use of DFA, DFM and FMEA in conceptual design is a new perspective in the field of integrated product development, therefore it can use all the advantages that those tools present in relation to the type of knowledge used in the generation and selection of product concepts. This because, being the same exposers of the tacit knowledge, they can contribute for the diffusion of the experts knowledge for the whole organization.

Although the initial state of the research, the proposed methodology contributes in the direction to establish concept evaluation parameters based on practical aspects of the product and process development. This becomes the selection of the concepts more concrete. Another important characteristic of the same one is the determination of compatibilities. This occurs in such a way of the functional point of view as of the point of view of the involved physical principles in the concept definition.

Finally, the proposal presented is viable for implementation inside of a product design methodology. We just need to execute some evaluations to verify its applicability. This evaluation can be carried through by means of case studies and evaluation of specialists.

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