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# CONCEPTUAL DESIGN OF PLASTIC INJECTION MOLDED COMPONENTS

A Ogliari and N Back

## Abstract

The conceptual design of molded components has, partly, a different nature from the technical systems design. Some activities of design, such as the functional synthesis, do not become evident in plastic component design, as in a machine or mechanism. Still, due the nature of plastic components, the design is carried out directly, from the design specifications, to the proposition of concrete solutions in features form. The exploration and generalization of the component design problem have been avoided. The study of the previous subjects resulted on a systematic for the conceptual design of molded components. In this systematic were proposed elements of transition among the design specifications and the product functions. Those elements were called "design icons". They are constituted of knowledge parts of objects, processes, agents, phenomena, among other entities of the application domain. To study the previous problems and the application of the systematic was carried out a case study in which the following aspects were evaluated: i) application of proposed tools by a multidisciplinary team and ii) improvements in the design process of components. This case study will be described and at the end, the propositions will be analyzed indicating the positive and negative aspects in conceptual design of plastic components.

*Keywords: injection molded components, conceptual design, simultaneous engineering, project –management*

## 1 Introduction

The conceptual design of molded components, considering the classic methodologies (Pahl & Beitz [1]), presents a different nature from the technical systems design, as mechanisms and machines, for instance. The plastic components design consists of the individual component design, that can be a product in itself, or the design of a component as part of a larger technical system. The nature of the molded components design can be variant, adaptive or original.

As example, in a design of housing for general applications, the housing is constituted in the main object of design. In this case, the solutions can be applied to different technical systems. The design solutions are influenced by elements as batteries, exhibition devices, keyboards, connections, among others, whose specifications can be several. In this case, the generality in the solutions can be obtained based on principles of variant design, including size ranges and modular products design.

In the case of dedicated design of components, there are two situations: component design to be used in an existent technical system and component design for a new technical system. In the first case, typically of adaptive design (materials substitution, resize, etc.), the component must be optimized. The other parts of the technical system are constituted as restrictions or requirements to the design. In this case, the main interests in the design are solutions with better performance, economical, of faster delivery, among others.

In the design of a new technical system, the component is considered as a partial function of the technical system for which several solutions can be developed. The restrictions or design requirements, considering the other parts of the technical system, can vary depending on the particular interests. In many cases, these requirements must be established. The interests in the design solutions, such as performance, economy and time of delivery, also are very important. However, in the original design we have opportunity to the product innovation that can be in functions, appearance, ergonomics, production methods, materials, among other aspects of the product life cycle.

One of the difficulties in the molded components design is in the synthesis of functions. It is verified that the establishment of the functions of a component, based on the flow of material, energy and signal does not happen with the same clarity as in mechanisms or machines, in general. The definition of the functions is naturally associated to the necessary form elements to the components to satisfy the design requirements. Those difficulties were explored in this research and ways were proposed of facilitating the definition process of molded components functions. The proposed method was used in a case study for to evaluate its potentialities. In this case study, the aspects of the teamwork were also analyzed, as well as the management of the design activities.

## 2 Literature review

The researches in design of molded components are proposed on several scopes. They are based on simultaneous engineering principles, use of expert systems tools and, with less intensity, on functional aspects. The proposals based on simultaneous engineering models systematize the design activities, considering: works in a multifunctional team, the use of software tools and parallel programming of the design activities. Some propositions in this direction are presented by Malloy [2], Defosse [3], Ishi [4] and Daré [5].

Malloy [2], for example, present a model for the simultaneous development of plastic components and highlight the need of the effective communication between the team members during the design decisions. It is necessary that each knowledge area, related to the plastic component design be present in the design decisions. This interaction presupposes the information diffusion, considering each specialist's point of view. Defosse [3], Ishi [4] and Daré [5] has also been showing this approach.

Particularly, in the proposal of Daré [5], the development process of molded products must be integrated, considering the requirements of the product life cycle, mainly in initial phases of the design. The Figure 1 represents the main process under this approach. That model was detailed in several phases and activities, indicating what it must be done, as well as the use of tools in each design activity.

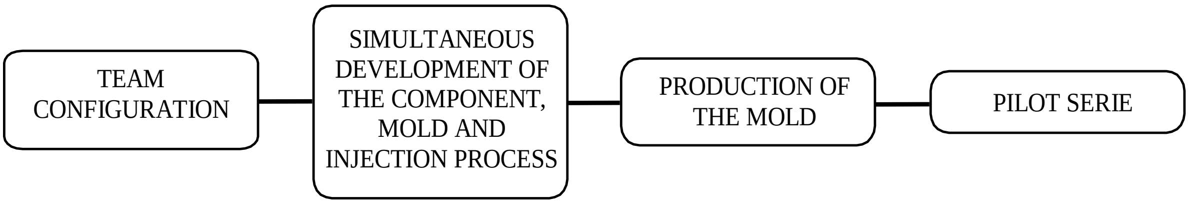



Figure 1. Integrated development model of molded components by injection [5]

The software propositions are focused on dedicated expert systems and intelligent CAD systems, mainly based on features. Hanada & Leifer [6] proposed a knowledge base of components solutions. These solutions are based in the functions of the injection process. As example, to remove the component of the mold several solutions can be used, such as the addition of extraction angles, superficial finish of the mold, material with better properties, among others. Expert knowledge is necessary to decide among those solutions.

Among the approaches that specifically treat on the functional design of molded components, it can be mentioned the proposals of Sebastian [7] and Wood [8]. Sebastian [7] proposes a system to the product design that, in the initial phases of design, considers the functional requirements to select the form elements to the component design. In a similar way, Wood [8] has shown a study that relates features and functions of the molded components. The features are considered as "primary blocks of construction", or specific geometric forms, that satisfy the functional needs to the component. The function is defined as the behavior or action that the feature must satisfy to assist the global purpose of the component. Under that focus, the author [8] has collected, based on knowledge and experience of area professionals, information about the typical features used and its functionalities. This knowledge can be used as an initial base to characterize conceptual solutions of molded components.

In spite of those approaches, it was verified that systematic procedures, based on classic methodology, to the conceptual design of injection molded component do not exist. This lack is more evident in the functional synthesis of components and creative generation of solution principles. Still, it was verified that the conceptual design of molded components seems not to be considered. The general practice is to develop the design specifications and from them, to configure the component geometry, without to explore the functional aspects of the components. After, the resultant geometry is optimized based in considerations about production process. Other observations on the conceptual design of molded components are detailed in the next sections.

## 2.1 Conceptual design of the injection molded components

Partly, the difficulties that are related to the conceptual design of molded components can be justified for the following reasons: (i) the activities of conceptual design are not known by the designers of injection molded components. There is lack on formation of design methodology, (ii) there is great emphasis in the geometric design, form and manufacturability of the components and little considerations about its functional aspects, (iii) there is need of additional abstractions in the functional design of components, because it is not evident the flow of energy, material and signal among the functions of a component and (iv) the solution principles of molded components, instead of effects for instance, are considered in the form of geometric elements, as holes, slots, projections, ribs, among other.

The nature of the conceptual design of products is quite flexible in its information and usually qualitative in its results. Many alternatives can be generated, and the evaluation criteria not always are evident. Still, the decisions, in general, are based on qualitative data and, many times, insufficient data. Like this, the practice of the conceptual design of products does not happen in the industry with the same intensity as is recommended in the literature and in the academy.

It is still observed, that the design specifications are appropriately established, however the subsequent activities, as functions structure and solution principles generation are neglectful, being looked for concrete solutions soon. The justifications "to avoid" the conceptual design of products are several and many of them are based in the lack of knowledge of what is the conceptual design and which one are its purposes and benefits. Other justification is due to the lack of practical tools, with which can be applied conceptual design principles and methods and the benefits observed through the obtained results.

The practice of design of injection molded components involves, in general, the geometric design of the component, based on features, and the correction of that geometry, under the restrictions of the production process. It is common that the design solicitation be presented to the companies that produce the molds, being looked to improve the appearance, to optimize the geometry and to guarantee the mold filling of an existent component.

In the functional synthesis of technical systems, as prescribed by the classic methodologies of design, it should begin by the elaboration of the overall function of the product and breaking down it in functions of smaller complexity to facilitate the solution principles generation. In the breaking down process, it is recommended, for instance, to use the flow of energy, material and signal to guide it. Still, it is recommended to begin by the main flow and to observe the auxiliary flows in the system.

In the case of molded components, does not become evident the flow of energy, material and signal among the elements that compose the component. Consider, for instance, the design of a molded cabinet that have walls, slots, ribs, projections, among other geometric elements. These elements have functions in the cabinet. Like this, can be asked, for instance, which is flow of energy, material or signal among the cabinet walls (housing) with the ribs (reinforcing)?

Still, a product solution principle in case of technical systems is considered, in general, in the form of effects associated to effects carriers. The effects represent the physical laws that govern the quantities involved at the solution principle, such as the effect of the friction, described by the law of Coulomb. In the case of molded components, the application of these definitions does not become evident. For instance, we can ask which effects are associated with a rib in a plastic component. Forces? Adhesion? Cohesion?

Due to those difficulties and considering, particularly, the functions synthesis of molded components, we have proposed a concept of "transition elements" between the design specifications and the product functions. The "transition elements" will be defined in the next section and they were denominated of design icons. The design icons are constituted, in essence, of knowledge parts of objects, processes, agents, phenomena, among other entities of the application domain (in our case, injection molded components), be in the form of facts, episodes, procedures, rules, among others elements which, when are systematized, promote means or knowledge to aid the recognition of the product functions.

# 3 Design icons

When the designer think in a design specification declaration, your perception will happens through a net of relationships with other conceptual entities. This is based, considering the model proposed by Sowa [9]. This net is denominated of semantic net. A partial example of that perception is being shown in the Figure 2.

According the Figure 2, a given knowledge part is configured in the form of a graph. The graph is constituted by concepts (rectangles) and relationships (circles) based on designer's previous knowledge. That knowledge part will be related also with other knowledge elements, such as procedures, episodes, others definitions types or rules, which can be used to infer other perceptions or to solve given problem.

Considering that perception model, design icon is defined as knowledge parts of the application domain entities, such as objects, processes, agents, phenomena, etc, established in the form of facts, episodes, procedures or rules, that activate the recognition of relationships between the needs and requirements of the design with the functions of the product.

Under that definition, the recognition of product functions can be aided through a database of design icons. Through of that concept it is obtained transition elements between the design specifications and the functions of product, as shown in the Figure 3.

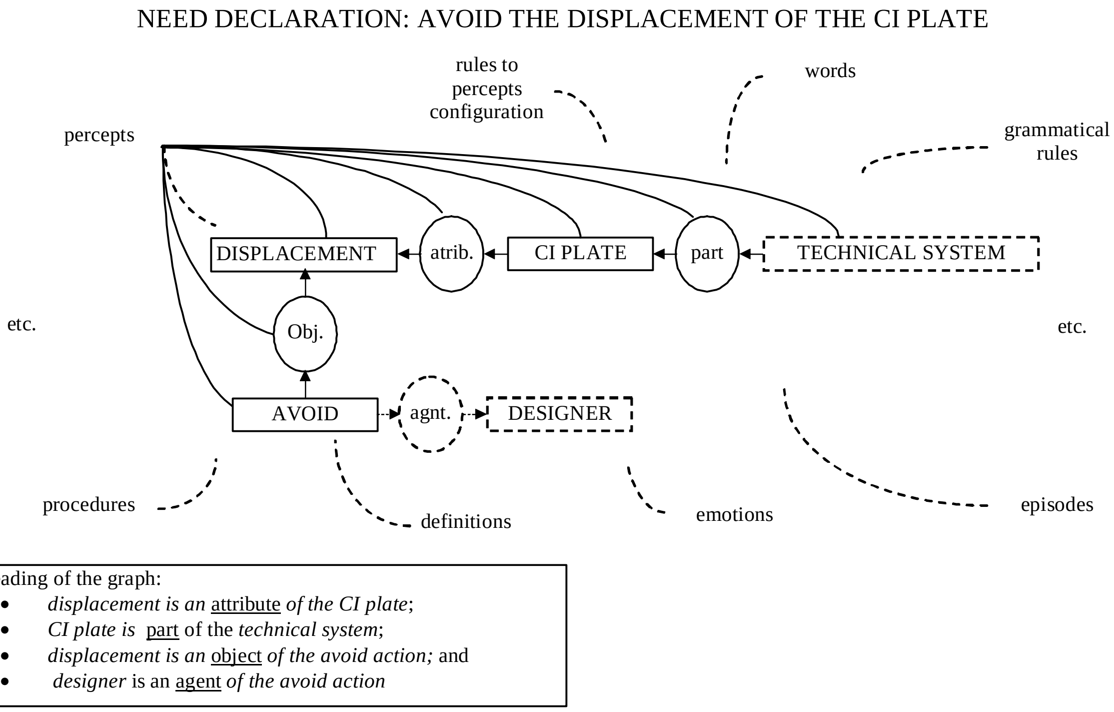



Figure 2. Partial model of the design need declaration perception, [10]

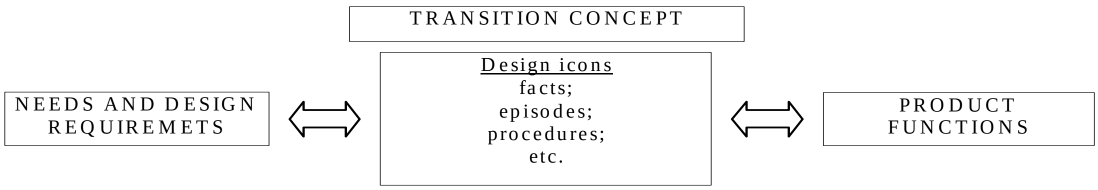



Figure 3. Transition concept to aid in the identification of product functions, [10]

The practical implementation of this proposal presupposes the systematization of design icons databases related to the application domain. This is not a simple and immediate task because the amount and the variety of facts, procedures, episodes or rules, on given domain, can be quite extensive. Like this, in a first moment, we proposed that this database be developed with base on phases of product life cycle, as organization criteria, together with principal elements that are linked with the product. Like this, for instance, in the case of molded cabinets and for the product use phase, typical examples of design icons are shown in the Table 1.

# 4 Case study

To study the problems described and to apply the proposed method, we carried out a case study of molded components design in the Mechanical Engineering Department in the Federal University of Santa Catarina. A design team was set up with the involvement of 10 members of the design, production and materials areas. In that case was tried to evaluate the aspects of the tools application for the conceptual design of molded components and to verify the performance of the design process with base on the team members integration. Will be discussed in the section 4.3, after description of the design problem and methodological approach, some aspects related to the use of tools and project management, with emphasis in the conceptual design phase.

Table 1. Partial examples of design icons to the use phase of the product, [10]

| Knowledge types | Domain elements | Design icons | Typical functions |
|---|---|---|---|
| episodes | Product users | "... during the use of the product the user dropped it in the ground…" … | **To protect** the elements<br>**To regulate** the mechanisms<br>... |
| procedures | Product environment | "... before leaving the work to verify the computers are turned off…" ... | **To inform** operations of the system<br>... |
| rules | Product components | "... the CI of the calculator must not lean in the box's walls…" ... | **To support** CI plates<br>... |
| facts | Product components | " ... the technical system has a sensitive plate to the heat...” ... | **To ventilate** the plate<br>... |

## 4.1 Design problem

The design problem was the design of plastic guides for a mechanism to monetary bills conduction to a bank automation equipment. The existent parts presented several problems, as warpage, misalignment, and high cost of the molds, among others. Conceptually in the Figure 4, we have the parts that were object of the case study.

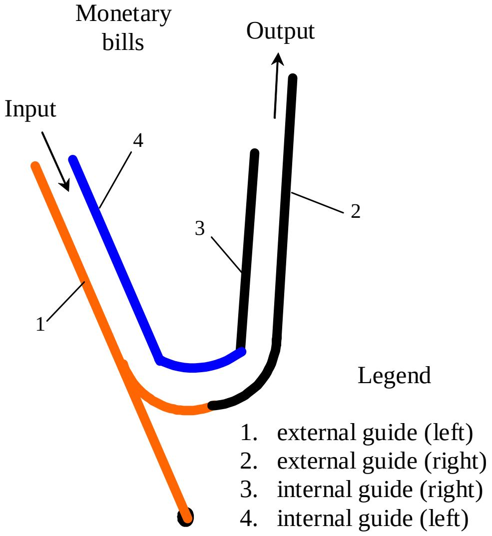



Figure 4. Guides of the automation mechanism

Considering that design problem the design team was set up and the planning activities began. The base to planning the activities was the guidelines of PMI [11] and the design methodology used was based on models of Ogliari [10] and Daré [5]. The next section describes the principal procedures and the tools used in the case study.

## 4.2 Methodological approach and results of the case study

The design of the guides was carried out considering the methodological approach, according to the Figure 5.

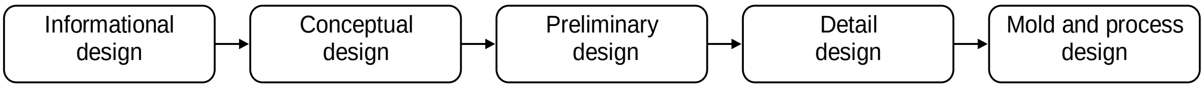
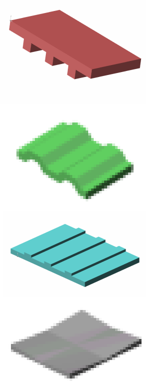
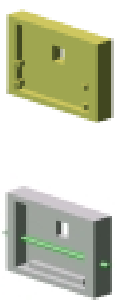
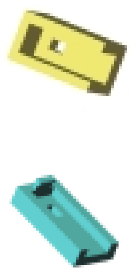
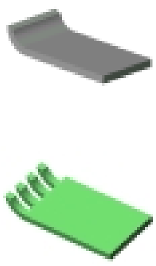
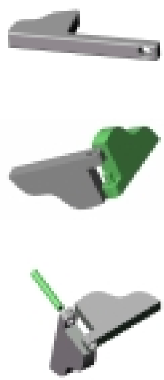
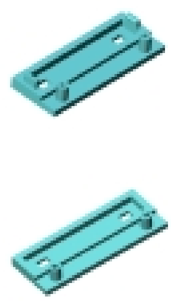



Figure 5. Methodological approach, [12]

In the informational design phase were obtained, through questionnaires, the customers' needs and were established the problem requirements. The main tool used in that phase was the House of Quality. In the conceptual design, based on design specifications, were established the components functions based on the design icons method. After were carried out the generation and evaluation of the guides solution principles based on use of brainstorming and morphological method. Besides the geometric modeling, prototypes construction and tests of the guides, in the preliminary and detail design, were carried out activities of structural analysis and mold filling simulation based on the softwares ANSYS and MoldFlow. The mold and process design are out of the scope of this article

Particularly, in the conceptual design, based on the design specifications, was used, in the form of data documents, a typical base of functions and of design icons. That information was used to aid the design team in the identification of the components functions. That information was presented to the members of the team and after a discussion, was proposed the necessary functions for the guides in a list form. It was verified in this activity the difficulty to establish the product functions in the form of quantities flow. It was natural to establish the components functions based on the situations of the product life cycle and on geometrical elements. Starting from the identified functions was generated through brainstorming, alternative solution principles for each function. The morphological matrix partial is shown in the Table 2.

Table 2. Partial representation of morphological matrix

| Functions of the components and solution principles | | | | | |
|---|---|---|---|---|---|
| Resist forces | Fasten springs | Fasten sensor 1 | Guide bills | Promote Access | Fasten sensor 2 |
|  |  |  |  |  |  |

The conception for one of the components and a view of the prototypes and of the guide's subset is shown in the Figure 6. The results of the preliminary and detail design and of the prototype construction and tests are described in Daré et al. [12].

## 4.3 Case discussion

With relationship to the management of the design activities, it was verified that large teams inhibit the creativity. The discussions are prolix and without focus, favoring the dispersion. In the development of molded components, it was verified that a basic team could be formed with three integral members, representing the principal areas involved: component design, mold fabrication and injection process. As the project develops, can be added experts to the team involving areas as cost estimation, material selection, geometric modeling, numeric simulation, prototyping construction, among others. In larger projects, it is appropriate the formation of structured teams.

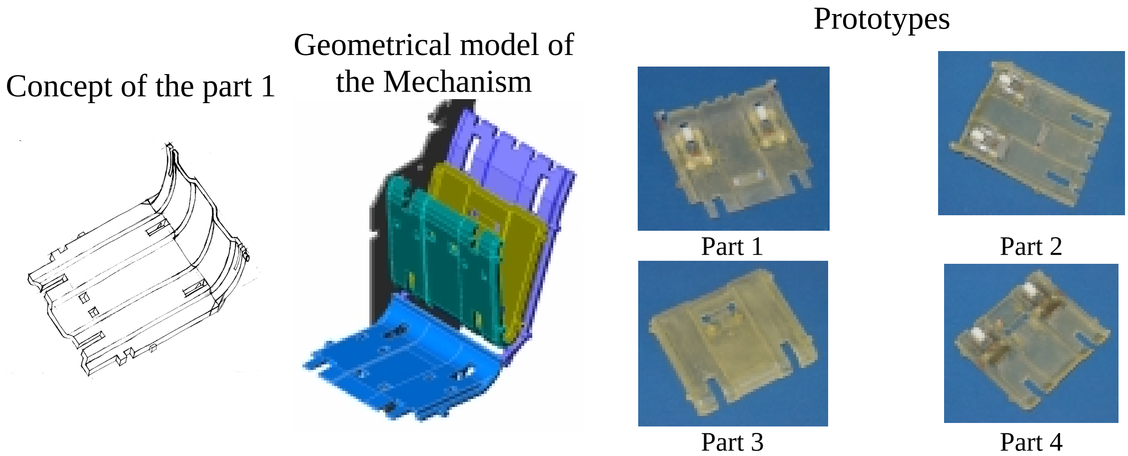



Figure 6. Partial results of the design

One of the important aspects for the design performance is to maintain a core team since the project planning to the end of the design. To avoid the "kidnap" of the team members during the design activities is of highest importance to the project success.

To maintain the best performance in design activities, to obtain team members integration and have focus in the design objectives are necessary that the meetings be regular, if possible daily. Besides, it is necessary that design objectives be very well defined. Meetings with great periodicity make the inefficient process. There is need of new reports on each meeting to uniform the understanding of the project team.

Among the employed tools in the initial phases of the design, the House of Quality promoted a great integration among the team members. It was observed that all team members had a wide understanding of the design problem. However, it is necessary to explain the principles of House of Quality to the team members that do not have knowledge of the method. This observation reinforces the need to train the team members before the design works to begin.

In the use of the design icons method, with documents that indicated typical situations for use of molded components, as well as typical functions of those products, it was verified that the flow of ideas was intense and it facilitated the elimination of certain barriers promoted by the classic methods of the functions synthesis.

With relationship to the preliminary and detail phases, it was verified that happens an effective integration of the component design knowledge with mold design knowledge and injection process knowledge. It was characterized in those phases the need of an intense communication among the team members. Like this, it was observed that those phases are potentially appropriate to promote integrations among design activities and to reduce the development time.

# 5 Final considerations

The use of the design icons method was appropriate as tool to aid the designer's creativity to the functions identification. Based on the application of this method was possible to observe that, even the designers without experience and practice in functional design, can contribute in the solutions of the problem. It is recommended for the use of that method the extension of the design icons database and the preparation of panels representing different situations of life cycle of molded components. Another recommendation is to implement software tools to apply that method and to develop an expert system to infer functions to the product.

With relationship the practice of the conceptual design, accomplished by a multidisciplinar team, is necessary, before beginning a project of this nature, a basic training in the methods and design tools. Some members of the team had a passive behavior during the project activities. This type of behavior made the process management most difficult, because there is need to intensify the motivation and participation of those members during the solution process.

As great part of the methods and tools for the initial phases of design already are well developed, one of the main conclusions of this work is the need of project management, mainly related with the team motivation. The members commitment and the planning of the activities are others important factors for the project success, mainly with the time of the project and the quality of the results. Like this, the knowledge of the design management and the integration of it with knowledge of design process are fundamentally to the molded component design success.

# 6 Acknowledgements

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André Ogliari
Federal University of Santa Catarina
Mechanical Engineering Department
C.P. 476, CEP: 88040-900
Florianópolis, Sc, Brazil
Fax: ++55 0xx (048) 234 1519
E-mail: ogliari@emc.ufsc.br
URL: http://www.nedip.ufsc.br