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AXIOMATIC APPROACH APPLICATION DURING THE PRODUCT CONCEPTUAL DESIGN PHASE

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Summary

The field of design, be it dedicated to products, processes or organizations, has undergone and is still undergoing an intellectual renaissance - from the still prevailing notion that design can be learned only from experience, to the idea that it may be amenable to a systematic and scientific treatment. Although these design activities in different fields seem to be distinct, cognitive processes and design principles are used in all fields, thus existing many ways to approach it. The axiomatic approach is one of them, and it gives a general theoretical structure, common to all fields. In the product development process adopted, the design activity is defined as having four phases: informational, conceptual, embodiment and detailed design. Among them, the two earliest phases are detached, where the decision taken has a broaden effect on the product’s success or failure. In this sense, as an aid to the development of these two design phases, is been developed at the Group of Integrated Product Development at the Federal University of Santa Catarina (Brazil), researches aiming to determine methods and tools to aid the product development. The overall goal of this work is to study the axiomatic approach to design with emphasis on the decision-making process and to contribute to the product conceptual design informatization, registering the relations between functions and solutions. Through the identification of these relations it is intended to reduce the function-solution dependence. The greater the independence, the better the project, according to the axiomatic approach. Therefore, the research to be performed aims to determine how the axiomatic approach and its computational implementation may contribute to the product conceptual design phase.

1. Introduction

The overall goal of this work is to study and develop the axiomatic design approach during the product conceptual design phase, keeping in mind the three

great goals on developing a product: to develop it as fast as possible, provide real satisfaction of customers needs and to reduce the product cost on its life cycle, topping the competing products.

The choice for the axiomatic approach is justified by many ways. One of them is the fact that the creative process during conceptual design has not been properly aided by traditional methods. The axiomatic approach aids the creative process, because it gives means to evaluate projects by means of design axioms. Selecting “god” and “bad” projects the project team can spend more time searching and developing new solutions. Also, through the mapping of relations between functions and solutions, foreseen by the axiomatic approach, stimulus occurs to get creative solutions, because the challenge of searching for uncoupled or decoupled solutions * is to be met.

Other great advantage of the axiomatic approach is the use of design axioms as decision criterions for design, still in conceptual phase, where the decisions reflect broad consequences in the whole product life cycle.

Also, through the mapping of relations between functions and solutions, it is possible to estimate the effects of changing the project, where the propagation of these alterations is indicated by the design matrix.* [Harutunian, Nordlund, Tate, Suh, 1996].

Therefore, aiming to provide such advantages to the product conceptual design phase it is intended to develop and implement the axiomatic approach into a software tool, to be used for solving design problems.

2. Research goals

For getting the advantages that the axiomatic approach may render, firstly it is necessary a proper definition for the product functions. Suh uses the “functional requirement” (FR) term to characterize the customer needs for the functions which the product must perform.

Function, in this sense, is to be understood as “something desirable”, the project goal. These definitions are a little vague and thus one may note a lack on the axiomatic approach on stating the functional requirements.

Furthermore, as this approach has only some decades of existence, in literature still there is no agreement among the authors about the real contribution of the axiomatic approach. The validity of the axioms and the application of the axiomatic approach for the whole design fields are contested by some authors. [Dimarogonas, 1993], [Ringstad, 1997].

Based on theses axiomatic approach concepts it is objective of this work to develop studies aiming to demonstrate when such approach may yield benefit for the product conceptual design phase and as well as identify possible situations where its application may not yield satisfactory results, determining if there are limits on its application and which they are, if they really exist,

* Explained in detail at item 4.

because even though different opinions have been found in literature, counter-examples have not been shown to invalidate the axioms.

Also, it is intended to implement methods aiding the formulation of product functions, because by using the axiomatic approach the solutions are analysed and evaluated based on the axioms, but completely dependent on the functional decomposition and on function formulations.

3. State of the art of the axiomatic approach

The researches on axiomatic design began in 1977, by professor Nam P. Suh, from MIT (Massachusetts Institute of Technology). In one of his first works Suh, 1978 analysed the axiomatic approach application into manufacturing systems. After, the following works, Suh, 1979 and Suh, 1984, also proceeded the axiomatic approach analysis on manufacture field.

Suh, describes the design activities as an interplay between “what” is to be achieved and “how” it will be done, depicted by Equation (1).

The “functional requirements” and “design parameters” terms are introduced to deal with this interplay. The function is defined as something to be achieved, the project goal.

Functional requirements (FRs) are defined as a minimum set of independent requirements that completely characterizes the functional needs for the product in the functional domain.

Design parameters (DPs): are the key variables that characterize the physical entity created by the design process to fulfil the FRs.

To guide on determining the domains relations, the axiomatic approach provides guidelines for designers. These guidelines are the design axioms. The axioms are self-evident truths that are always observed to be true and there are no counter-examples or exceptions.

$$\begin{Bmatrix} (FR)_1 \\ (FR)_2 \\ (FR)_3 \end{Bmatrix} = \begin{bmatrix} A_{11} & 0 & 0 \\ 0 & A_{22} & 0 \\ 0 & 0 & A_{33} \end{bmatrix} \begin{Bmatrix} (DP)_1 \\ (DP)_2 \\ (DP)_3 \end{Bmatrix} \quad (1)$$

The first axiom is the independence axiom: “ Maintain the independence of FRs”. In an acceptable design, DPs and FRs are related in such a way that a specific DP may be changed to satisfy its correspondent FR without affecting the others. It establishes that during design process, coming from DPs to FRs, the mapping must be such that a perturbation in a specific DP will affect only its respective FR.

The second axiom is the information axiom: “Minimize the information content of design”. Among all designs that satisfy the first axiom, the one with

less information content is the best. Therefore, designs which minimize the number of functional requirements and constraints, present integrated parts maintaining its functional independence, use standard and interchangeable parts and, render symmetry as much as possible, will yield projects that have a reduced information content, expressing a better probability of success.

Designs that do not satisfy the independence axiom are called coupled designs. In these designs, it is impossible to adjust a specific DP without affecting at least two FRs. Designs which satisfy the first axiom are called uncoupled or decoupled. The difference is that in an uncoupled design the DPs are totally independent, whereas in decoupled designs, at least one DP affects two or more FRs. Thus, the adjustment order of DPs in a decoupled design it is very important.

From Suh, many authors have performed studies and applications using the axiomatic approach.

Harutunian, Nordlund, Tate e Suh, 1996, propose the use of the axiomatic approach on controlling the affects of a product change. By means of the design matrix, which contains the relations between functions and solutions for each hierarchy level, it is possible to verify the extension of a change on other hierarchic levels, and thus, in the project.

Magrab, 1997, also uses the axiomatic approach for solving design problems. In his book, he combines the QFD method with the axiomatic approach by means of some examples and states that when appropriated, the design requirements may be classified based on the functional requirements, that is, the requirements must be firstly established and used for organizing the design requirements (named engineering characteristic by the author) on QFD.

Yang and Zhang, 2000, perform studies aiming to determine the compatibility between the axiomatic approach and the Theory for inventive problem solving (TIPS), developed by Altshuller (1988) and co-authors.

Dimarogonas, 1993, performs a historical review of design field and has pointed out the importance of having design principles during the decision making process. According to Dimarogonas, a set of general principles were firstly established by Redtenbacher in 1852 e 1862, but they were contradictory and overlapping at mostly of their applications to become a formal system of design axioms. Another abstract set of design principles was introduced by Reuleaux in 1854, dealing separately shape and function.

Dimarogonas, states that the quality of the design expressed by Suh’s equations is not related with the way coefficient matrices are populated and the mathematical basis for the first axiom is not valid. Also contests if the axioms may be treated as so, or only as rules, though he accepts the fact that in some cases such axioms yield satisfactory results. Dimarogonas also states that there are myriads of designs that violate the design axioms, but does not mention concrete examples that would invalidate these axioms. Therefore, the author

has proposed the unification of Reuleaux rules and Taguchi principles, suggesting new principles of designs.

Ringstad, 1997 performs a comparison between the axiomatic approach and the functional/means tree [Andreasen, 1992] on product functional decomposition. The author’s objective was not the definition of the function term, but gives emphasis on using design methods that are function based. Also emphasis how important is the synthesis and analysis process on design.

By his analysis, the author states the advantages of the axiomatic approach, but points out some lacks on defining the function requirements. The author also says that the axioms should be treated as two design principles, among many others, applicable to many cases.

By this brief literature review, it was verified that the axiomatic approach aids the product development, though has some lacks and still does not present an uniform opinion of the authors related to its applications and axioms validity.

4. Final considerations

By this brief literature review it was identified many axiomatic approach contributions for the design process. Such approach makes use of axioms as criterions for decision making process. Many authors have used and investigated the axiomatic approach, showing examples and its integration with other theories aiding the product development process. However, there are authors who contest the axiomatic approach for whole design fields, stating that the design axioms should be treated as two design principles, among many others, to be used in many cases.

It was also verified how important is to define the functional requirements, because the solutions – named design parameters, are evaluated basically on the first axiom related to functional requirements. Thus, such evaluation process is totally dependent on the selected functional requirements and that the axiomatic approach presents some lacks on defining the functional requirements.

Therefore, it is objective of this work to verify the axioms applicability to different domains. If the axioms may not be understood as so, there may be some design cases where the axiomatic approach does not yield satisfactory results. The objective is to find them out, making possible the determination of consent that still no exists among many researchers on this field.

It is also intended to implement methods aiding the product function formulation aiming to improve the axiomatic approach.

To reach theses objectives, firstly a complete and detailed research may be performed, yielding to a broad understanding of the axiomatic approach, allowing a theoretic basis to perform critical analysis, identifications of limits and contributions.

Subsequently methods will be identified to aid on functional requirements specification, because of its great importance previously mentioned and the lack of theses methods on axiomatic approach. Such methods will be implemented in software to be developed.

Cases studies will be performed at different fields of design, to use the axiomatic approach for solving existing design problems and to create new products. By theses studies, it is intended to show possible new contributions that this approach may yield to the product conceptual design phase and to verify possible cases where its application may not yield satisfactory results, specifying some limits for its application.

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