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Design For Materials: A new integrated approach in Computer Aided Design

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Abstract

Nowadays, the engineering designer defines the structural and the geometrical aspects of the product based on the functional requirements. In the detailed design step, the material corresponding to the product requirements is chosen. In this step, several loops are done in order to adapt the topology and the geometry according to new material specifications. In order to minimize these loops and using the integrated design paradigm, this research proposes a new approach. In this approach, the product geometry and structure are driven by the material specifications with the help of new CAD tools. The combination of insights from functional and material domains builds the theoretical background for this new proposed approach, called Design for Materials. The concept of CAD multi-views skeleton, customized according to the material specifications, is proposed as input of the detailed design. An implementation of this new approach in a CAD system is presented.

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1. Introduction

There have been many attempts to draw up models of the engineering design process in systematic steps [1-4].

Pahl and Beitz' systematic approach [2] to engineering design decomposes the process in the following four sequential steps: 1) Planning and task clarification step, 2) Conceptual design step, 3) Embodiment design step and 4) Detail design step. Design begins with identification of the customer needs and specification of the requirements. The conceptual design primary concern is the generation of physical solutions to meet the design specification. In the embodiment stage and the detail stage, an overall layout and then the definitive layout of the product are given. It includes the structure and the morphology of individual components, the prescriptions of final dimensions and materials. *In detail stage, several loops are done in order to readapt the topology and the geometry on the new material specification.*

Using this similar decomposition, Ashby [5] proposes to choose a family of materials in the second step, to refine the choice in the third step and to define it technically in the last one. *In this step, several loops are also done in order to adapt the topology and the geometry according to new material specification.* For example, if the designer chooses the plastic family in the second step, the PP in the third step, he will determine the mineral filler in the last step. If the product needs to integrate crash specification, the last choice will directly impact the geometry, like the number of ribs or its thickness.

Morphology and *materials* are thus considered to be two key variables of the engineering product design. In the new economic, social and technical environment, *the pressure for change on materials is increased*. New requirements have been emerged for the materials of the product. The material should often satisfy conflicting technical specifications. In addition, the efficiency of the use of material should be increased: it should not be allowed to not make full use of the material in the product. In addition, in an industrial context, companies are continuously setting new design and development strategies in order to reduce products costs and decrease development time [6]. Based on this assumption, a new approach that allows the

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product geometry and structure to be driven by the material specifications is proposed. This new approach is called Design for Materials and it is implemented in a CAD system.

Thereby, the second section of this paper presents the general methodology and a theoretical framework in order to answer the following research question: how to drive the product geometry and structure by the material specifications? The third section presents the methodology implementation into a CAD system which is being tested in the fourth section. Discussions and conclusions of the new approach and its first results are summarized in the last section.

2. General methodology

In order to finalize the conceptual design step, two major outputs can be pointed out. The first output is the architecture of the future product [7], and the second, the form of the future product, which it is itself based on the architecture [8]. These outputs will be also the input of the Embodiment design step.

To obtain this result, the initialization of the conceptual design process is based on the Functional Requirements [2]. Regarding these specific Requirements and in order to transform the customer requirements into an industrial product, Suh proposes a transformation mechanism [3], beginning from the customer requirements (CR), which are transformed in functional requirements (FR), which are transformed in design parameters (DP), which are transformed in process requirements (PR). This mechanism is illustrated on the Figure 1a.

As detailed in the previous section, we propose to integrate the materials specifications into the early phases of the design process. Therefore, based on the Suh approach, we switch the process requirements as input of the functional requirements, as illustrated on the Figure 1b. Then, the CR are transformed into FR and PR.

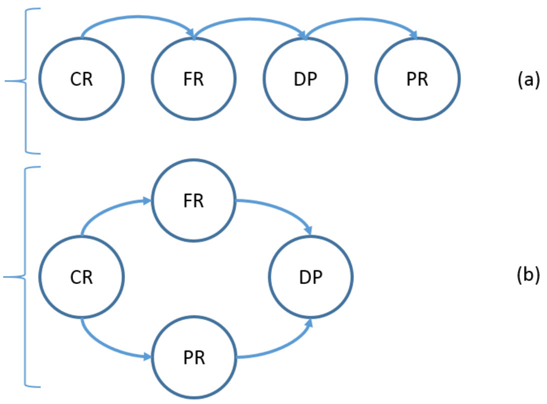

Fig. 1. (a) Suh's transformation mechanism; (b) Proposed transformation mechanism

Now the design problem can be defined as: Find DP to satisfy FR under the constraints of PR.

$$\left\| \begin{array}{l} FR = f(CR) \\ DP = f(FR, PR) \end{array} \right. \quad (1)$$

Regarding the morphology, we need to detail the concept of integrated design. This concept proposes to implement the downstream constraints in the early phases of the design process [9]. To obtain this result, this concept is based on the use of computer systems [10]. Therefore, a lot of research work has been performed since decades proposing new methodologies using specific computer tools as, for example, new CAD system integrating expert rules provided by downstream specifications [11].

One of these approaches consists to base the detailed CAD model on a CAD skeleton which is built with specific constraints [12]. Many researches have already been carried out using the skeleton based modelling [13-27]. Like the human body, the skeleton holds muscles: a CAD skeleton holds the morphology, which is the Topology-Geometry (TG) of the future product. The main objective of the skeleton is to validate in early phases of the CAD process the major specifications without wasting a lot of time to define a detailed CAD model which will be reworked afterwards. Skeleton can be considered as a basic concept in CAD modeling of machines and mechanisms.

Different types of skeletons and their roles in modeling are introduced in CAD modeling: part Skeleton, assembly skeleton and motion Skeleton. Depending on the level of conceptualization, these alternative solutions could be firstly represented as a simplified shape which is driven by material requirements and secondly embeds the working principles. A simplified model, or a material skeleton solution, represents thus the architecture of a product by defining the relationships between its simplified components in order to satisfy the material performances. This representation is thus incomplete.

The simplified model is enriched gradually in order to satisfy the whole set of *functional requirements, material requirements and constraints* imposed on the product. The final morphology of the product will emerge from a multi-views enrichment.

A skeleton should formally contain the following information:

1. Engineering requirements - design loads, performance requirements.
2. Materials
3. Simplified morphology: (a) attachment, which relates to the immediate proximity of the importing and exporting of design loads; (b) Functional structure which defines the simplified morphology to channel the loads; (c) Envelope which defines where the morphology of the part can be without interfering with others.

To illustrate this concept, the figure 1(a) illustrates the architecture of a rail, which can be called skeleton, composed of two vertex linked by an edge. The figure 1(b) illustrates the modeling of the topology, for example the solid revolution, and the figure 1(c) the geometry, meaning the definition of the driving parameters like the vertex coordinates, the edge equations or the L diameter.