DESIGN 2002

SUPPORTING THE EARLY STAGES OF PRODUCT DESIGN BY FUNCTION-BASED TOOLS

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Keywords: Early stages of design, Engineering Workbench

1. Introduction

Especially in the last few years the overall process of design from the first idea of a product over the concept and embodiment design up to the detailed design has been recognised as one of the most important tasks for an efficient product development.

At the same time the area of the early development phases, in which geometry does not yet exist, moves more and more in the foreground. It was recognized, that in these early stages many very important decisions are already encountered, which have strong effects on the later realisation and arrangement of a product.

In parallel state-of-the-art CAD-systems place the geometry administration, -handling and -representation on a very high level. Modern CAD-systems as Pro/ENGINEER™ or CATIA™ demonstrate this capability in late – and geometry-rich – phases of the design process. In contrast to that designers are missing a consistent and comprehensible use of the methodics in the early development phases on the one hand. On the other hand the phases without geometry are practically not supported by any software-tools which maintain the designer "on his way to geometry".
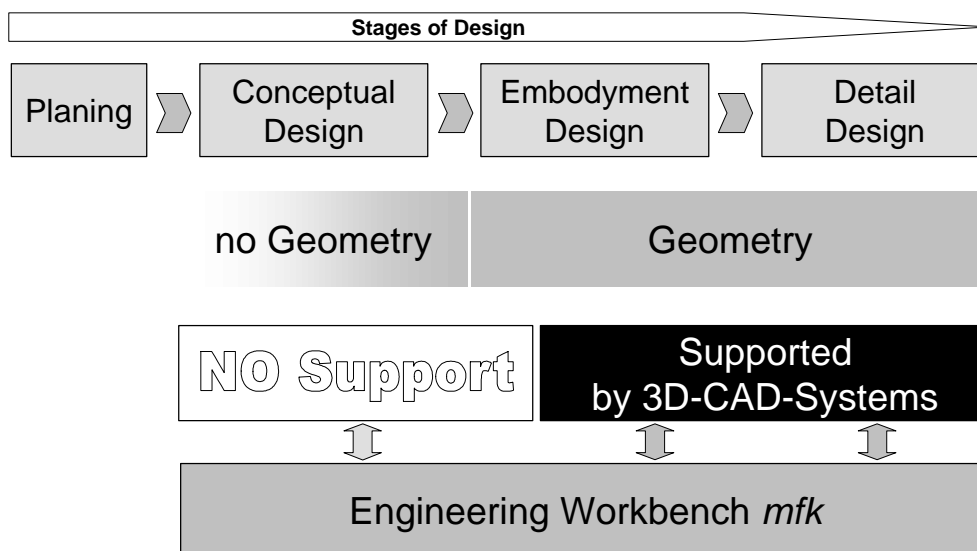

Figure 1. Stages of design and the lack of appropriate software

A tool which supports and supervises the methodical action of the designer is one of the most important implementation on the way to a complete computer-assisted design process. For this reason a tool is required, which leads the designer through the methodics and purports him the red thread for a straight, efficient and last of all successful way. In addition to this, suited data models for storing and administrating the occurring information have to be realized, too.

Especially important hereby, the conceptual design stage proves itself, because here important vertexes of the future product are fixed for the first time.

To the planning-stage, located even earlier in the design-flow, will be given less attention in the following, because data with more business-economic orientation occurs here. In this stage for example questions of the selling-potential of a specific product or the customers' requests for this product are discussed. These data do not intercommunicate directly with the actual engineering of the product. Due to this aspect these information has not to be managed side-by-side with the data from the conceptual stage and other following stages.

In the conceptual stage a huge amount of information is generated, which is or better: should be directly connected to future geometrical data. For this reason it is necessary to store at least all design-information regarding a product in an joint data model beginning in the conceptual design. Therefore we can revert to the Engineering Workbench *mfk* (KS*mfk*).

2. Engineering Workbench *mfk* and product model

The Engineering Workbench *mfk*, which is being developed at the Institute of Engineering Design (University of Erlangen-Nuremberg, Germany), is an approach to offer a tool for continuous support of the design process including the early stages of design. Inside the semantic and relation-based product model design-elements are provided for covering all the design knowledge. Although the KS*mfk* is set on efficient CAD-systems, their functionality is used only for dialog control and visualisation. In several research activities couplings to different CAD-systems have been implemented, whereby the current developments base on Pro/ENGINEER™ (Parametric Technology Corporation, MA, USA). For fulfilling the specific requirements of variable product families and design stages, the Engineering Workbench is subdivided in distinct modules, e.g. for sheet metal design or design of casted parts [Koch 1999].
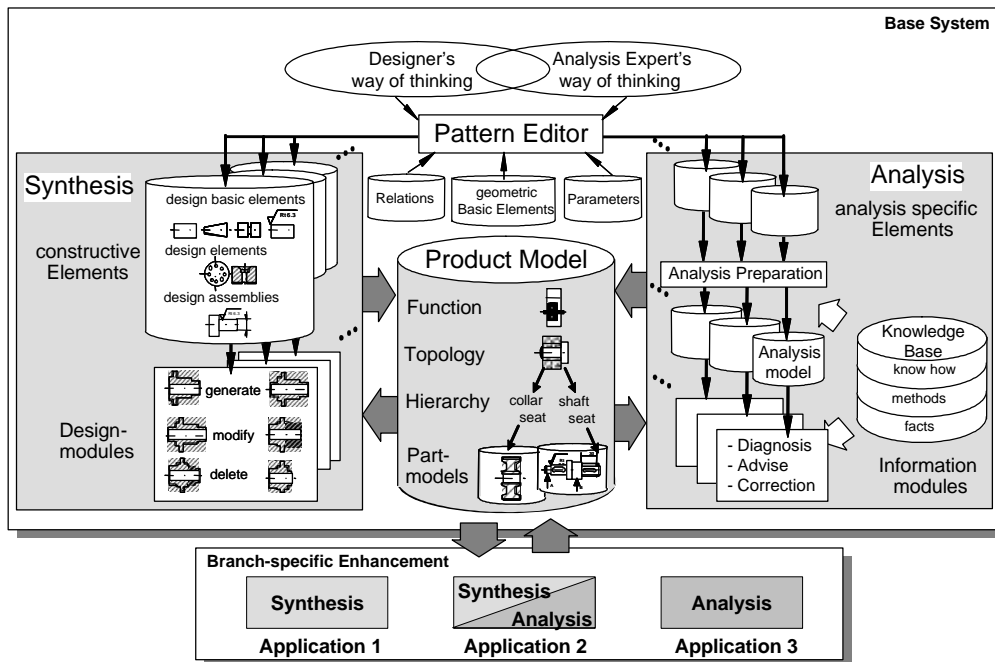

Figure 2. Overview over the Engineering Workbench *mfk* (KS*mfk*)

The concept of the Engineering Workbench consists of a synthesis part for the description of the product and an analysis part for evaluating different DfX (design for X) criteria [Meerkamm 1994]. A connection between these parts is guaranteed by the product model and the pattern editor.

The hybrid product model (which is based on relational structures) of the KS*mfk* offers much potential for the support of the early design stages because accurate geometric data and any desired semantic information can be stored inside the product model at the same time. By using a commercial database (Oracle™) it is possible to save and retrieve all the accruing or required information at every point of the design process. Accessing the database over standard interfaces (SQL) makes it moreover possible to supply the product model with data from different software-tools. Topically this possibility is only used by CAD-systems. For an efficient support for the widespread process of design the importance of accessing the product model this way is increasing very much.

2.1 Which (software-) tools are necessary?

The determination that efficient software-tools are necessary in the early stages of design leaves the question: Which tools are necessary to patch the space with missing support described above?

Many theories are dealing with this problem. Several of these approaches already were transferred in software products (CadSys, HNI, TechOptimizer). By missing the connection at preceding and above all following steps in the design process these isolated applications could not prevail. However all procedures is common that finally the result is a structuring of the future product. After a comparison of the different theoretical drafts [Koch 2000] for this conversion was chosen the method of Pahl and Beitz. It connects different functions of the product to function structures and in this way makes a flexible structuring of the design work possible.

3. Function Structures

3.1 Structures

According to Pahl and Beitz [Pahl/Beitz 1997] functions are formulated, using abstraction of the design-task. As soon as the crux of the overall problem has been formulated, a overall function is being defined. According to the complexity of the task necessary to solve the overall function, this function is more or less complex dependant on the task. Due to that the overall function can be subdivided into sub-functions of slighter complexity. Matching the different sub-functions yields the function structure that again represents the overall function in its entirety. The connections between the single sub-functions are realized by user-defined joints. For this feature three different kinds of connections come into operation: an energy-joint, a signal-joint and a material-joint. Each of these joints represents a stream of the particular entity.
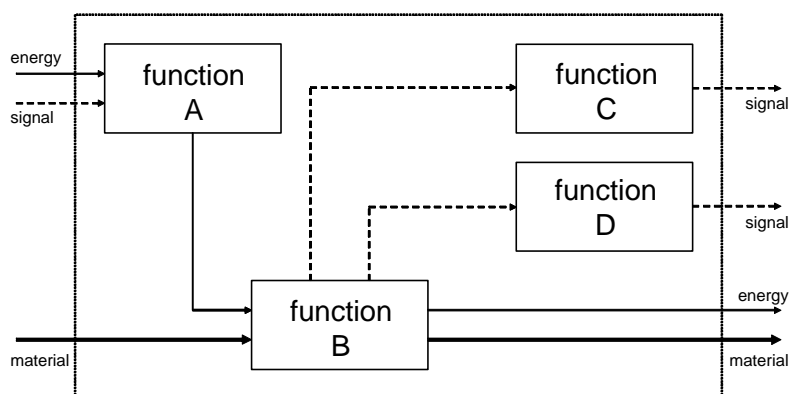

Figure 3. Overall function and depending sub-functions [Pahl/Beitz 1997]

Being free while choosing the degree of detail in the single sub-functions and thereby the detail of the overall function, the designer is enabled to use this approach during the complete process of the non-geometrical conceptual design. Exemplary, in this way at the beginning of design very general

functions can be set up. Further on this functions can be refined and prepared in the course of the development. Initial attempts with „conventional" tools (here: paper and pencil) already showed that the demands on the used functions change fundamentally during the progress of the design process.

The quantity of contents per sub-function to be administered increases steadily. While mere a semantic information is sufficient in early function structures, in the course of time for example indexes regarding the complexity of the function or other additional information come into consideration.

"The" type of function, which one can uncover the total width of the development process, is not available and never will be.

3.2 Functions and Function modules

From the above-mentioned determination on the one hand it gets clear that "appearance" of a sub-function changes with progressive detailing stage. The contents are both expanded and modified as well. On the other hand it is unlikely that all used sub-functions are available in the same level of detail. Nevertheless they are supposed to be interconnected without problems.

In the present approach these "always available connections" are reached by firmly given interfaces. These interfaces remain fix over all development stages of the function. So the desired compatibility is reached by the given abstract possibilities connected to the functions (by energy, material and signal). Generating a function the designer solely has to determine how many in- and output-streams of energy, material and signal are needed to supply the specific function. From this point on these gates should be basic and fixed conditions for this function during all stages of design.

Above all, within a certain topic or within a firm functions of a certain type will certainly be used again and again. Therefore it is suggestive to discard the function definitions that proved already to be functional in a catalogue. This catalogue includes different stages of detail of each function-module. This means, that fundamental information for the early stages are stored as well as physical effects, which are more important for later calculations in subsequent phases.

The catalogue's administration can be integrated into the product model using existing interfaces to the database. Then the designer himself can select the building blocks coming into focus for a specific product and arrange, vary and group these functions to a function structure. The additional information, necessary for building up this structures, can also be represented in the product model.
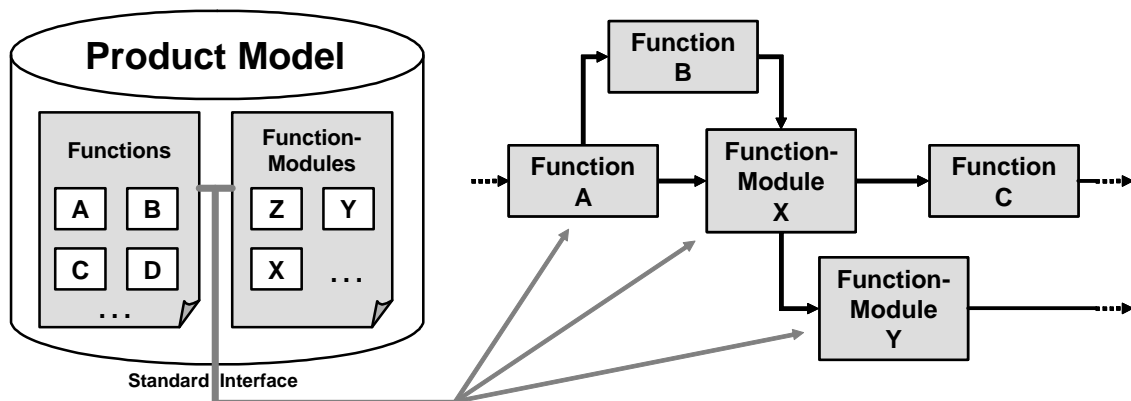

Figure 4. Functions and function-modules

The base for a designer are function data, stored in the product model. To keep the managed knowledge coinsistant and up-to-date regarding the state-of-the-art, the product model has to be able to take up new considerations and approaches. Similarly it is conceivable to create a learning system indicating the designer prior proposals, that already turned out to be suitable as well in related configurations. The possibility to couple several functions to more complex contexts and to dispose these modules into existing functions as a black-box, is recommended especially for more often re-used modules. Of course the designer himself has to be able to define and modify these function-modules. The described user intervention into the database as well as adding, modifying and

connecting of functions can be realized by the database's standard interface both from outside and inside the engineering workbench *mfk*.

3.3 Analyis of function structures

Once a function structure has been generated digitally, it is obvious to review this structure with respect to different criteria.

The possibilities for analysing such a structure are manifold. For example an inspection of the mutual influence of single sub-functions in a function-module is conceivable. In this case the software-tool could optimally arrange the sub-functions after finishing the analysis. This idea is illustrated in figure 5: A heat-dispensing resistor and a chiller are arranged next to each other. The adverse heat-situation is recognised by the analysis-routine and the concerning elements can be rearranged by the optimisation-part of the program.
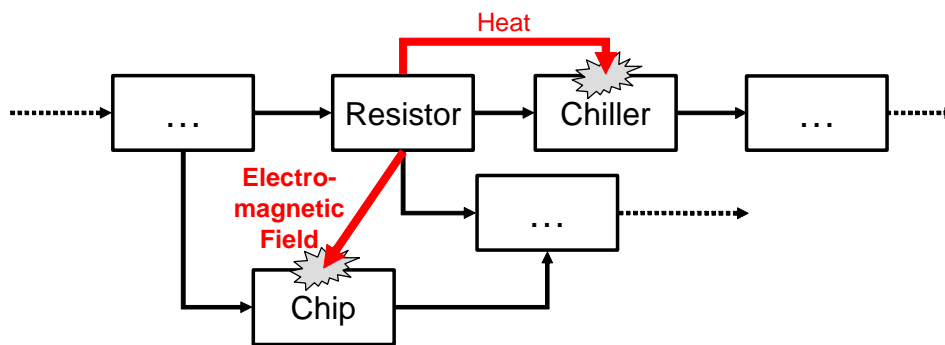
Figure 5. Functions are influencing each other

3.4 Coupling to the CAD-System

In the approach to support the early stages of design in the product model, a most direct transition into the CAD-system is of specific importance. Without a conversion free from interrupts the advantages reached by linking the early stages to the known way of design were lost again. In order to produce such a transition the two-dimensional function structure has to be transported into a three-dimensional arrangement.
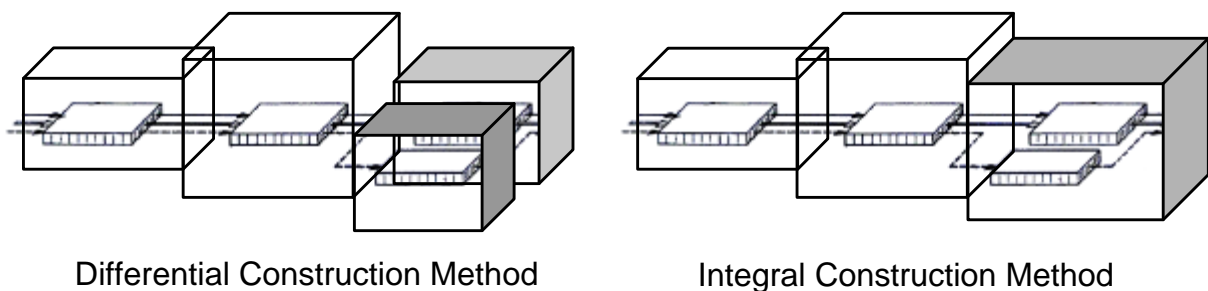
Differential Construction Method   Integral Construction Method

Figure 6. Different design-spaces depending on the construction method

Two concrete information can be used to realise this translation: on the one hand data about the necessary volume of each single function in the product model is available and can be used to build up design-spaces inside the three-dimensional CAD-system. On the other hand these individually generated design-spaces are combined with the connections known from the pre-geometrical function-structure. Using these connections a overall-design-space of the product can be built up quite easily. This design spaces offer a further kind of support to the designer, who is able to stoke up the single spaces "with life" step by step. Figure 6 shows the example of two different possibilities designing a part. On the left side there is a differential construction method represented in the early stages. The right part of the figure shows the same function structure in integral construction method. Due to that

the designer can handle different kinds of realising products already in this stage. This feature in no way represents a restriction of the designer's creativity. It just makes the design task more concise and provides best requirements, e.g. for concurrent engineering.

3.5 Tool "FunctionStructureModeller"

In the process of modelling functions, the designer can be supported on manifold manner by the computer. Due to that a new software-tool has been created at the institute to provide the support postulated in this paper. Based on Java this tool can access the product model as a module of the engineering workbench.

The selection of the necessary functions is done simply by "drag and drop" on the modelling desktop. The functions themselves are represented as a black-box at this stage of methodical design because the contained data are not yet relevant. After that the connections between the functions are established by the designer. Simultaneous the analysis part of the engineering workbench checks the chosen linkages and – if necessary – immediately advises the user to correct his structure.

After completing the function structures the overall allocation of all prescribed gates has to be reviewed. Are these requirements fulfilled, the function structure is released by the engineering workbench.

Now for example the designer can refine the used functions and split them into different sub-functions. From this point on every function-module can be handled independently.

4. Conclusion and perspective

In this paper the author shows a way how to vanquish the rupture between well known CAD-systems for later – geometrical – stages and the methodical approaches for the early – non-geometrical – stages of design. The core idea is to realise a continuous computer-supported workflow for the designer by generating function structures linked to design spaces. These spaces can be used to build up rudimentary geometrical structures, which give important support while entering the later stages of design. In a further step these functions can be analysed and optimized by a comprehensive engineering workbench like the KS*mfk*. Nevertheless this approach is a step towards concurrent engineering in the early stages by splitting overall functions in sub-functions with specific connections.

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