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UNIVERSAL FUNCTION-STRUCTURES IN EARLY DESIGN STAGES

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Abstract

This paper describes a possible way to bridge the gap between two-dimensional function-structures according to Pahl and Beitz and the three-dimensional world of modern CAD-systems. Functions are equipped with information about design spaces and connections. Therefore two tools are introduced, which support the designer in using the design-methodology and give him the possibility to build up different variants of a product in a short spell.

Keywords: product modelling, digital mock-up, product data management.

1 Introduction

The state of the art in the early design stages presents itself as an area inside the design process where no computer-supported software-tools for the designer's work are available. The problems resulting from this lack are on the one hand a deficient use of design theories and on the other hand a bad traceability of decisions, made by the designer during the development process. To solve these problems and to make early design stages' decisions more comprehensible for co-working designers, our engineering workbench "KS*mfk*" was enhanced by a further software-tool integrating the early stages of design into the entire design process. This tool called "FunctionStructureModeller" and the appropriate background-strategies (e.g. the step towards three-dimensional design spaces) and methods will be elucidated in detail in the following.

2 State of the art and motivation

During the last years the entire, continuous design-process from the first idea for a product over conceptual, embodiment and detail design has been accounted being very important for an efficient product development. In doing so, the range of the early design stages, where no geometry is available yet, came to the fore. It was detected that there are made very many important decisions in the early stages having a bearing on subsequent realization and design of a product. At the same time the state of the art in the later, geometry-oriented stages of the design process are modern three-dimensional CAD-systems, which offer a very high degree in geometry's administration, handling and representation. Through this situation two major problems occur in the early stages: On the one hand there is missing a consequent and pursuable designer's use of the known design methodology. On the other hand there are nearly no software-tools available in the early stages of design, which support the user on his way towards the final geometry creation in known CAD-systems.

The link between the quite badly supported (mostly two-dimensional) early stages of the design process and fully developed software-tools for the later three-dimensional stages has to be found.

3 Demands on the new approach

The allegation, that new software-tools for the early design stages are necessary, does not answer the question, with which tools the lack described above can be filled. Trying this, there are different theories in research and industry. Several approaches have been realized in software products (CadSys [1], HNI [2] and TechOptimizer™ [3]). Due to the missing interconnection to preceding and primarily subsequent steps in the design process, these stand-alone solutions could not succeed in a satisfying manner.

In this paper an approach will be introduced, which guides the designer through the design methodology and gives him a thread for a straight, efficient, pursuable and last but not least successful way. To be able to handle all data, which is generated throughout the design process, an appropriate data model for storing and managing the accumulated information has to be realized. In the conceptual stage lots of data is created which stands in direct interrelation with the later existing geometrical information. This makes it necessary to store at least all information in one central and common product model, beginning in the conceptual design. Using such a product model, we can rely on the engineering workbench *mfk* (KS*mfk*) (see figure 1).

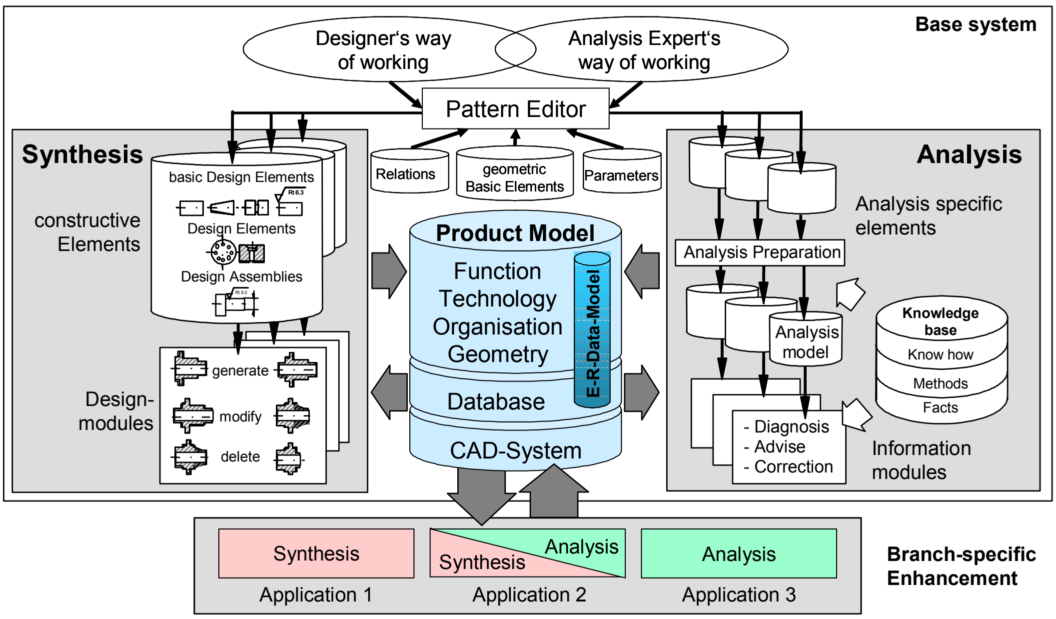

Figure 1. Engineering Workbench *mfk* (KS*mfk*)

The engineering workbench *mfk*, which has been developed and enlarged at the Institute of Engineering Design (University of Erlangen-Nuremberg, Germany) [4], is an approach to offer a tool for continuous support of the design process including the early stages of design. The hybrid product model (based on relational structures) [5] offers this much potential for the early stages, because using a powerful commercial database (Oracle™) any arbitrary semantic information can be used in addition to the geometric data at every point of time during the design process. By accessing the database using standard interfaces (SQL), it is furthermore possible to contact and modify the product model's information from different software-tools. At the moment only CAD-systems take advantage of this possibility. But for an efficient support of the overall process of design this feature will be exceedingly important.

Two ways to build up three-dimensional structures emerged during the comparison of different theoretical approaches [6]: Both of them are abutted to the approaches of Pahl and Beitz. The first one uses a requirement list to compose and structure the favoured attributes. From this list a three-dimensional structure can be deduced using known physical coherences (e.g. the distance between two shafts determined by the gear transmission ratio). The structure itself is built up by simple elements like datum axes and datum planes. These elements should be a help for the designer to get clues for modelling a project. The second approach starts with an exact list of requirements and uses these in the following to define functions. These different functions can be connected to a function-structure, which is able to describe the future product in the early stages. Thereby the second approach realizes a more flexible way handling the design. It will be prosecuted below.

4 Function Modelling

4.1 Function-structures according to Pahl and Beitz

Pahl and Beitz [7] wrote up a procedure to come to functions by abstraction. As soon as the crux of the problem has been formulated in general, an 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. Due to that the overall function can be subdivided into sub-functions of slighter complexity. Matching the different sub-functions yields the function-structure which itself 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. Using a variable level of detailing inside a function-structure, the designer is able to use this method over all non-geometrical stages during the entire course of design. This includes the possibility to build up very abstract functions which can be sophisticated during the further development.

4.2 Demands

Early tests with "conventional" aids (e.g. paper and pencil) [8] showed a fundamental change of the function's demands during the design process. The amount of information inside a single sub-function is growing constantly. While in the very early stages only semantic information inside a function is necessary to arrange one's ideas, over the intervening design process more and more details are added (e.g. data about complexity or further additional information). The universal type of functions to cover the whole range of the design process will never be available.

From the above-mentioned determinations follows on the one hand, that the function's appearance changes with the proceeding level of detail within the design process. The contents are both modified and extended. On the other hand it is improbable that all sub-functions exist in the same level of detail. However, these functions should be able to be joined to each other without problems. The connections are built up here – just like mentioned above – by predefined interfaces. These interfaces are constant in all stages of design. By using the abstract interconnections "energy", "material" and "signal" the desired compatibility can be reached. Creating a function the designer only has to define which and how many entries and exits of the possible kinds (energy, materiel and signal) are necessary. These gates are the only existing restrictions for a function's contents.

4.3 Design spaces

In this approach to support the early stages by using a unique product model, it is especially important to ensure a transfer to the CAD-system as immediate as possible. Without an uninterruptible implementation the advantages, reached by containing the early stages, were lost again. To come to this interconnection, the two-dimensional function-structure has to be transferred into a three-dimensional arrangement. Therefore two kinds of concrete information can be used: on the one hand data about the required volume of every single function is stored inside the database and can be used to build up the design space in the three-dimensional space. On the other hand there is information about the connections between the functions available, which can be used to create an overall design space of the entire product.

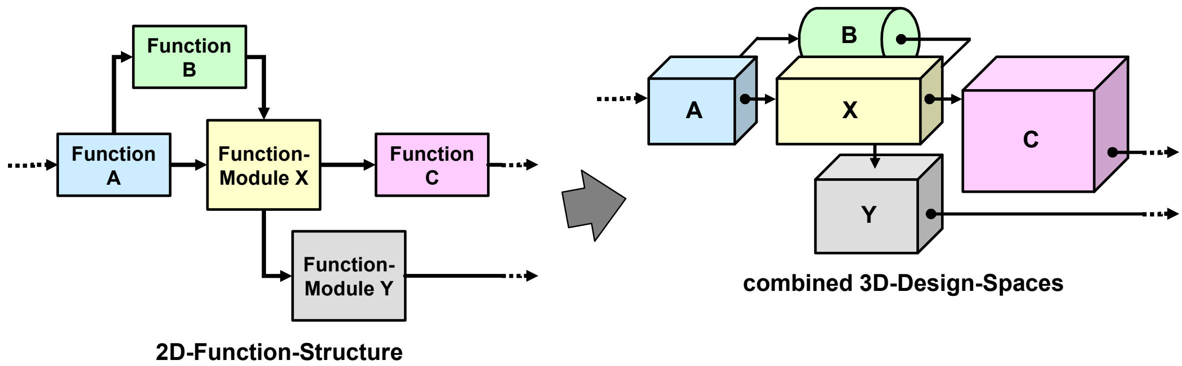

Figure 2. Transition from two-dimensional function-structures to three-dimensional design spaces

5 Expanding the approach "function-structure"

This step of passing from simple functions to three-dimensional geometry is quite critical on the level of functions, because only little information about the product is available. Therefore appropriate enlargements have to be realized in the classic approach concerning function-structures. It is of an especial importance, which information and parameters are accessible in the conceptual design after an accurate clarification of the concept and a classification of the complete system in sub-functions and their connections.

5.1 From a "function-structure" to a "wirkstruktur"

Enlarging the classical function-structures according to Pahl and Beitz into the three-dimensional world of geometry modelling, it has to be paid attention to the change, which the information acquired during stepping through the design process makes through. While we talk about "function-structures" in the beginning, the functions loose their abstract nature by storing more and more information. Step by step they are changing from a function-structure to a "wirkstruktur" [7]. Using this transformation is the only way to get from abstract approaches to concrete solutions.

5.2 Dimensions of the used connections

As described above, functions are connected with flows of material, energy and signal. Whereas it is of deciding importance for the later implementation – especially for sizing components – which quantity these connections have. For example a designer developing a coffee maker has to know exactly, whether 1, 5, 10 or 100 litres of water should be processed in one cycle. And how much is the force needed to grind the coffee beans? It has to be possible to answer questions like these directly from the requirement lists or from considering fundamental physical interrelations. To bring these links between the functions to an accessible state, the kind of connection, the quantity and the dimension-types are stored.

5.3 Converting the design spaces

As aforementioned, the kind and dimension of an interface between the function-structure and the geometry is a fundamental step. One of the most critical points in doing these transformations is of course the handling of dimensions. In many cases it is impossible for the user to define the design space of a single function as exact as it is needed to build up three-dimensional function-structures. Because of that, the exact dimensions of the design spaces which are used can be determined in the following three ways: the designer himself sets fitting sizes for the design spaces, the known physical correlations can be used to estimate the dimensions (using the linking information) or already used functions can be imported from former projects. For all that it must not be failed to notice that this is an approach for the very early stages in design, which is tended to give a coarse overview over the product being designed.

To keep the design spaces manageable, only two different kinds of volumes should be differentiated in this approach: cuboids and cylinders. Cylindrical design spaces (figure 3, left) we use for functions which include rotative movements (e.g. to transfer torque or a shaft) or for functions, which are realized by dynamically balanced elements in general (e.g. storing compressed fluids).

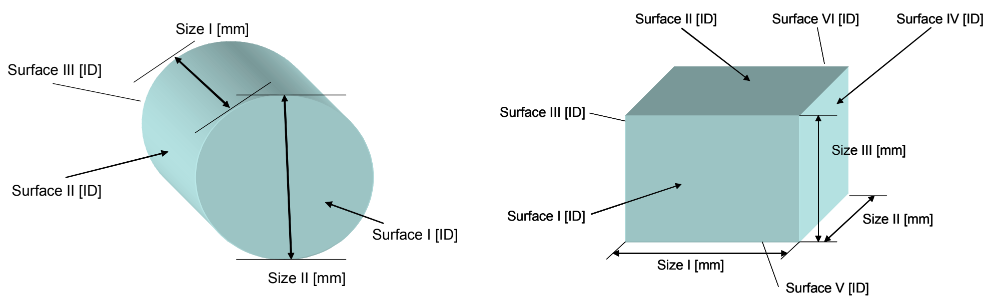

Figure 3. Cylindrical and cuboid design spaces used to map function-structures in three dimensions

Cuboid elements (figure 3, right) are available as bricks characterising a general design space. They can be used on the one hand to sterically separate complex sub-systems and on the other hand for building up basic cases.

5.4 Building up design spaces and linking surfaces

The linking information is generated in a two-dimensional tool called "FunctionStructureModeller". It is a Java-application, which was developed as an application-module for the Engineering Workbench *mfk* (see figure 1). This means a full access to the product-model, which was designed to store all product information and which is implemented in a relational database. To be able to describe the function-structure we use two different tables (according to the entity-relationship data-model). The first one contains the single functions; the second one stores the different joints, which were set between the functions. Inside the product model a few additional tables exist, which are at most used to pick up additional semantic information. These tables are not necessary to build up the function-structure and will be ignored for this reason in the following. The software-tool "FunctionStructureModeller" transfers the information about the two-dimensional configuration and additional data about the design spaces to the product model (see figure 4). A soon as the structural data is available in the product model, any enhancement-module of the Engineering Workbench is able to access these information (e.g. for analysing or optimising purposes).

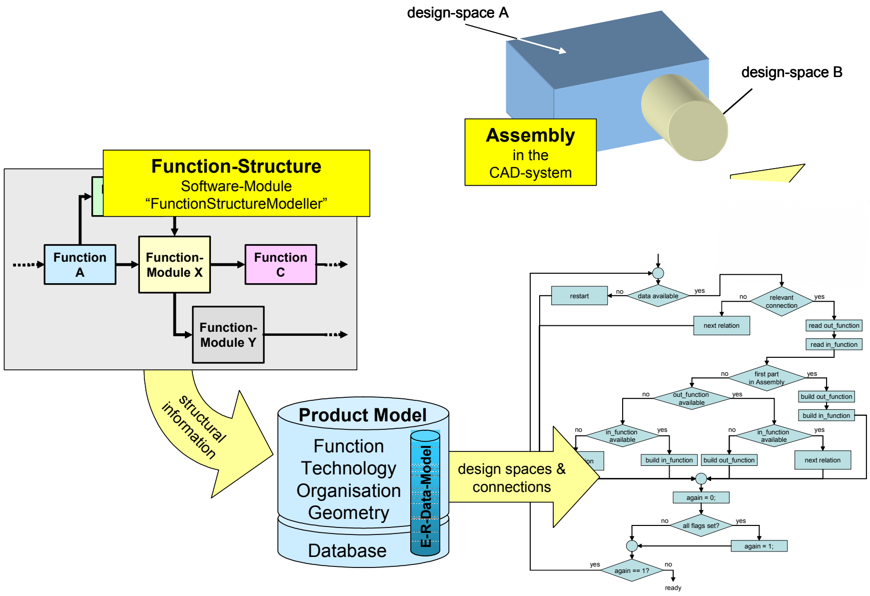

Figure 4. "FunctionStructureModeller" as an input device for the two-dimensional function-structure as well as the information about design spaces

Managing the step from two-dimensional function-structures to combined three-dimensional design spaces we implemented a further module for the Engineering Workbench *mfk*. By using appropriate algorithms the transferred structure is first analysed and then built up directly inside the CAD-system. Therefore different algorithms are used, which can reach a high complexity very fast. An example of the simplest conceivable algorithm to build up design spaces from the structural information inside the product model shows figure 4 (on the right). Here the database-entries for the connections between functions are analysed and the design spaces are generated if required. The demonstrated algorithm to build up function-structures is formulated so simple, because the different possibilities of arranging the design spaces were not considered. The different configurations which can be reached by changing couplings of surfaces are manifold. To explain the variety of the possible configurations, figure 5 (on the left) shows four possibilities to assemble two blocks. These configurations are only a small cut-out of the immense number of variants, which are possible using two bricks. Coming from these two entities to a higher number of design spaces the level of complexity increases enormously. To limit the variety in assembling, a number of boundary conditions is necessary. Therefore the individual surfaces are clearly identified (see figure 3). Using these identifiers makes a clear placement possible when assigning the building blocks. The additional information about the referenced surfaces is stored inside the product model: The database entries for the joints are expanded by three placement-conditions: firstly a contact-condition which places two surfaces onto each other and secondly two arrangement-conditions, which place the specified edges in respect to each other (see figure 5 on the right).

This arrangement of the arising product into linked simple geometrical bodies accomplishes boundary conditions for a reasonable cooperative design at a very early stage of the process. This is an essential condition to make a design task manageable inside a working group of designers. The single design spaces are implemented as parts into the CAD-system and can therefore be separated very easily to support the concurrent design.

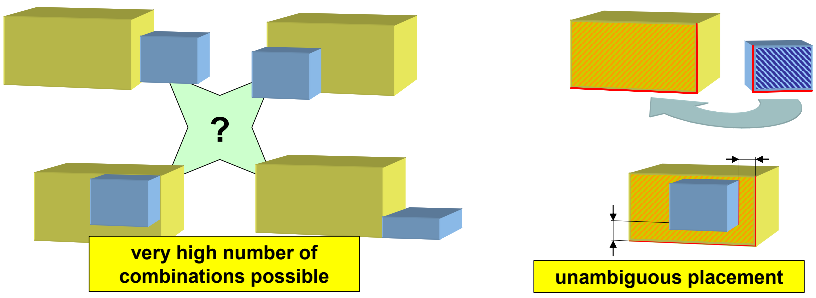

Figure 5. Using surface identifiers and exact references allows a clear positioning of the different design spaces

6 Example: Coffee maker

The example of a coffee maker is able to demonstrate the shown circumstances in a very clear way. Figure 6 shows the operating sequence during the early stages of design using the above described tools. The tool "FunctionStructureModeller" is used to define the function-structure. Figure 6 (right upper) shows the two tables, which contain all relevant information inside the product model. The third step is done in the CAD-system Pro/ENGINEER, where the data is retrieved from the product model and then the design spaces for the different sub-functions are built up using internal algorithms. This procedure enables the designer to build up and modify function-structures with deposited design spaces in an easy way.

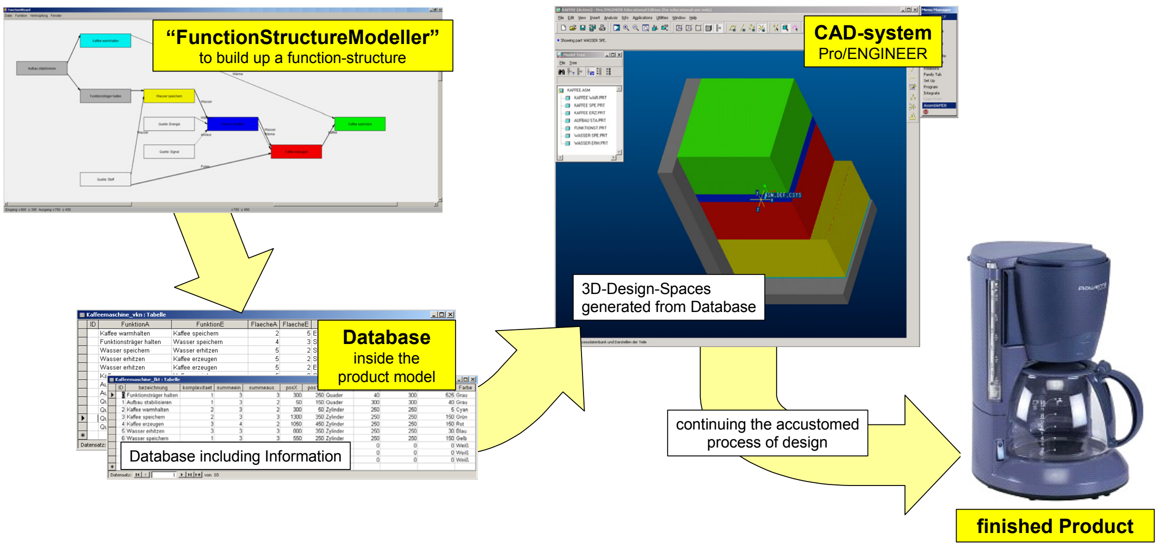

Figure 6. Example "Coffee Maker": from a "wirkstruktur" to a design-space-model

7 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 are automatically generated in a commercial CAD-system (Pro/ENGINEER™) and 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* [9]. 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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