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A STUDY REGARDING THE USE OF METHODOLOGY DURING A DESIGN PROCESS

M. Koch and H. Meerkamm

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1. Introduction

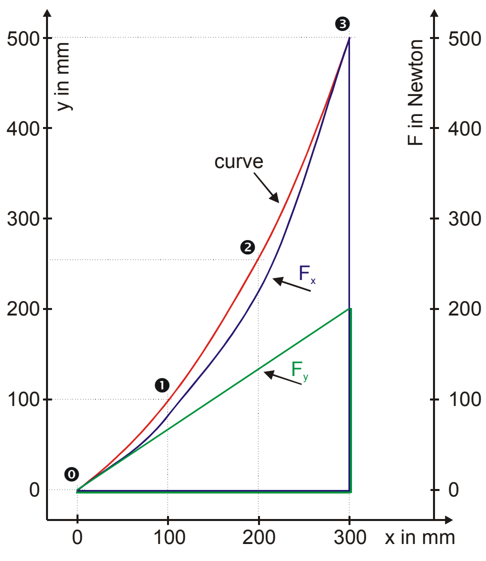
During latest enhancements of the Engineering Workbench *mfk* (KS*mfk*)* the goal has been aimed for to offer best support to the product developer in all stages of the design process.

* The Engineering Workbench *mfk* is a software tool based on a modern CAD-System on the one hand and on a hybrid product model on the other. It has been developed at the Institute for Engineering Design, Erlangen (Germany). An important approach of the KS*mfk* is to support the early (methodological) stages of design as well as the geometrical stages [Koch and Meerkamm 2001].

Because the focus of the support is moving from the later stages of the design process to the earlier stages, in this paper the designer's steps, decisions and utilities are to be examined comprehensively based on a practical development task. Further on future tools are supposed to be formulated out of the recognized problem fields for the KS*mfk*.
As a product for this development, a positioning fixture was chosen. Therewith any objects are able to be moved along a predefined path; four defined positions are attainable.
The demands on the realisation are represented in the following list of requirements:

Table 1. List of requirements for the positioning fixture

Kinematics	Predefined movement on a curve in x-y-direction with 4 fixed positions (⓿ to ❸). No movement in z-direction. Flange surface parallel to the y-z-direction. Locking in position ⓿ to ❸.
Forces	X-direction (F_x): increasing from ⓿=0 N to ❸=500 N. Y-direction (F_y): increasing from ⓿=0 N to ❸=200 N. Z-direction: without forces.
Actuation	Shaft, steps of 35 degrees from ⓿ to ❸.
Number of Pieces	2
Duration	4 months



2. Design and development of the positioning fixture

The design of the positioning fixture was done according to the approaches of Pahl and Beitz. These recommendations provide an arrangement of the design process into four stages: planning, conceptual design, embodiment design and detailed design [Pahl, Beitz et al. 1999]. The stage of planning was skipped because the list of requirements, which represents the result of planning, was already available.

During the conceptual stage, the list of requirements is decomposed into different functions. Here the designer tries to divide the main function of the product in single – and individually resolvable – part functions. For this example 14 different functions arose. Solutions for these functions where searched and where assembled in a morphological matrix. The solutions where gathered by hand from literature or evolved from designers considerations. Furthermore the software-tool "TechOptimizer™" (InventionMachine Corporation) was used for investigating continuative principle-solutions. This attempt of computer support did not produce a satisfying result and was stopped due to this. The problems using this software occurred by using principles, which where doubtless very interesting (e.g. the idea to generate force with the piezo-electric effect), but could not be transferred to the design task at all.

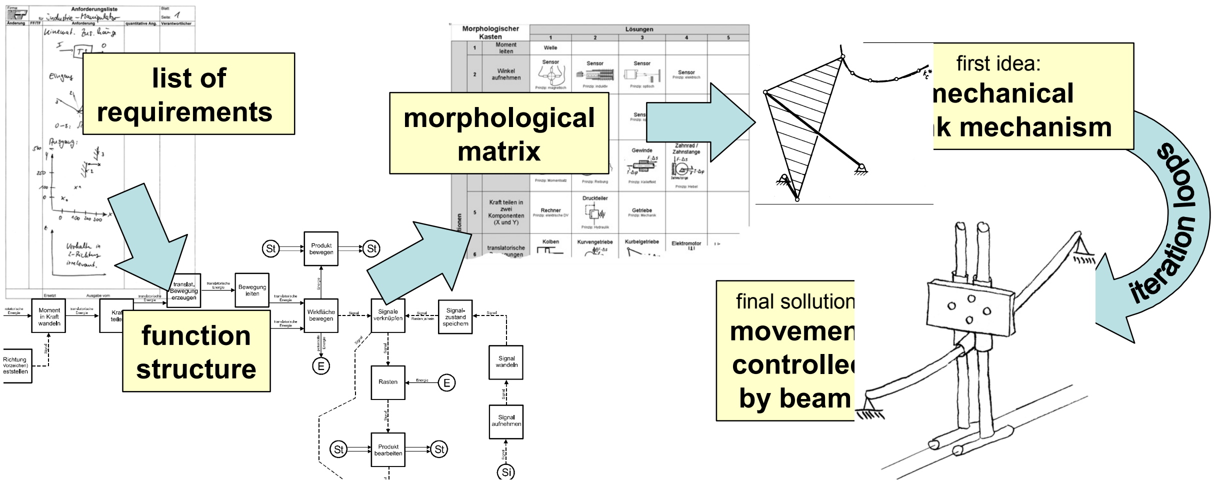


Figure 1. Steps during the early stages of design

By using the morphological matrix it was possible to eliminate several solutions, which where less interesting for this task. From the residual solutions there where formulated six different combinations. Each of these combinations represents one possible overall-solution for the product "positioning fixture". To reduce the amount of solutions to one, an evaluation was carried out to identify the most promising combination. So the monitored designer chose the set "mechanical crank mechanism, locking in position 1 to 4 by bolt", which he attended as most suitable.

Going on in the process of design there followed several rough calculations and feasibility-studies for the crank mechanism in a commercial multi-body-system (Pro/MECHANCA™). Different tests with the crank mechanism showed the feasibility of the postulated curve. The second requirement regarding the actuation (using rotation-steps of 35 degrees to come from one position to another) was more complicated to realise. In combination with the crank mechanism it was not possible to the designer to find a way integrating the claimed actuation. Due to this, soon the fact emerged that the crank mechanism could not be implemented as planned before.

After six weeks of designing the product, the process of design was aborted at this point. The designer stepped back into the very early methodical stage of design and tried to find a solution to realise the postulated movement combined with an adequate actuation.

To avoid this infeasible mechanism, a fixed, bended beam was used in the next step. The movement was accomplished by a slide, which was intended to move along the beam. Actuating the slide was realised by a thread rod. Choosing the adequate flank lead made possible a 35 degree stepping.

The bending needed to realise the curve (claimed in the list of requirements) was generated using the multi-body-system as well and was adapted to the machine's main function "control movement". Finally, the conceptual design work was done with paper, a pair of compasses and a pencil.

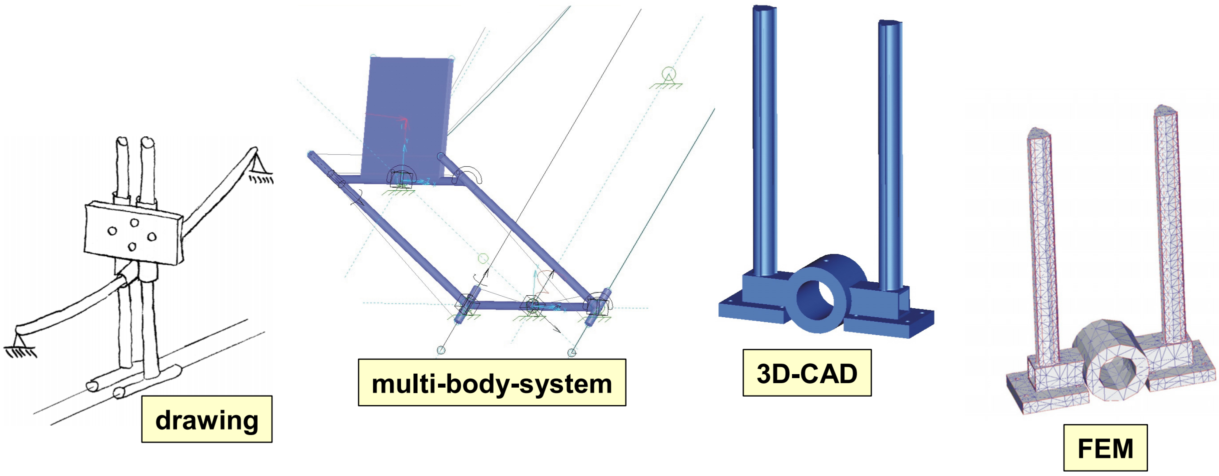


Figure 2. Dimensioning, modelling, recalculation

After the concept was finally decided, a rough estimation of the measurement was done. Then the modelling in the multi-body-system followed. This system was chosen first, because the kinematics where seen as the major problem in this product. As a result of the multi-body-simulation the software delivered the forces on the individual parts. These results where used as a base for the creation of the parts in the 3D-CAD-system (Pro/ENGINEER™). At this time the decision was made, which parts to produce and which parts to buy. Because the number of pieces planned to produce (2 pieces where planned), it was abstained from an in-house production as far as possible. Because only very few manufacturers of acquisition-parts offer three-dimensional data to their customers, all parts of the product had to be built up in the CAD-system oneself.

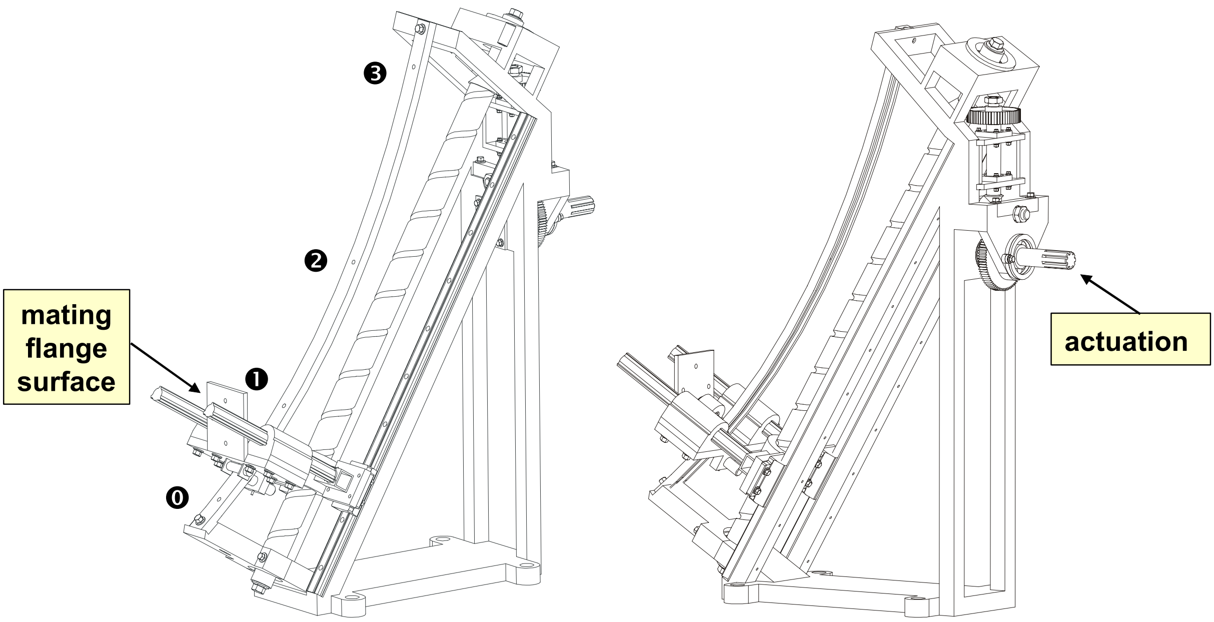


Figure 3. The finished positioning fixture

The next step in the design process was a successional stress- and displacement-computation of the finished parts. Therefor the forces analysed by the multi-body-system where applied to the geometry. Then all relevant parts where analysed using the Method of Finite Elements (FEM). The results regarding stress and displacement where incorporated in the parts shape and design. Thereby an important fact was accomplishing the best accuracy in combination with lowest deformation (e.g. for the thread rod, which needs a certain accuracy to work). Finally a rough tolerance-estimation gathered the decisive information about realising the function “lock position”. The finished product – after altogether four months of work for concepts, embodiment design and detailing – is show in figure 3.

3. Analysing the process of design

Reviewing the process of design of this concrete example makes clear, that unfortunately there has not changed very much with the problems and snares regarding the process of design. While the support for the designer in the later stages – this means in the stages, where geometry exists – has been increased distinctly by the further development of modern 3D-CAD-systems, to date there is all but real “support” in the earlier stages of the design process.

3.1 Problems occurring during this exemplary design task

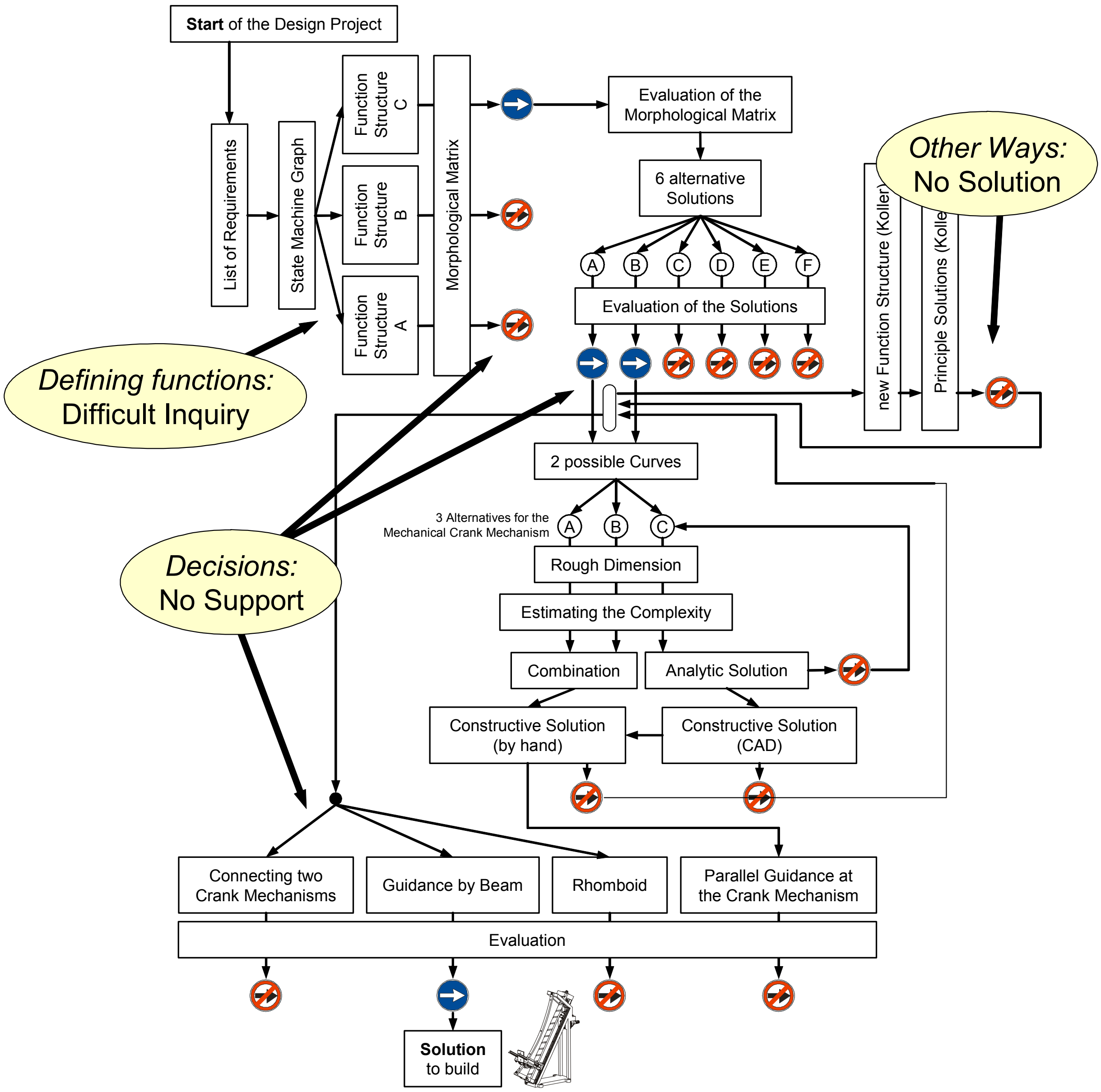


Figure 4. The course of action of the design project and appearing problems

Figure 4 shows the areas of the problems using a methodological way in this design task.
Using especial software such as “TechOptimizer™” for defining and arranging functions did not yield the desired results: While there are needed more constructive proposals and implementations to cope with a design task, the highly praised “Innovation software” described physical principles. Other solution catalogues based on principles resulted similar proposals [Roth 1982]. This kind of information did not support the designer in this stage of design and many problems in this early stage can be ascribed to this insufficient support.
When finishing the process of design according to the guidelines of Pahl and Beitz [Pahl, Beitz et al. 1999] the author reworked the whole process a second time according to the guidelines of Koller [Koller and Kastrup 1998]. All this was done due to the fear to overlook an important aspect. Because Koller considers and classifies technical activities on a more theoretical level of energy- and material-flows, this second approach to manage the design-task methodically did not provide any new conclusions.
The early stages of design are not yet supported by software products in a continuous way. This meant for the designer, to rely on his own subjective appraisal, which caused doubts, unnecessary long ways round and avoidable dead ends. All these things did cost time and thereby did extend the duration of the entire project.
During the stages of embodiment design and detailed design of the positioning fixture there did not appear the amount of problems as in the early stages by far. Modelling the tree-dimensional geometry worked fine using a state-of-the-art CAD-system (Pro/ENGINEER™). The only circumstance, the designer was offended at, was the missing link between the early stages and the geometry-oriented stages of the design process.

3.2 General demands on the design work’s computer support

Due to the attained experiences from this exemplary design task it becomes apparent, that there have to be solved the following problems in the context of the computer supported way of designing:
The use of the adequate methodology has to be increased on the one hand and has to be supported on the other hand by adequate software tools beginning from the start of the design work. This is necessary, to guide the designer through the methodological proceeding and to prevent him from meanders.
Several approaches have been realized in software products (CadSys [Krause, Tang et al. 2002], HNI [Möhringer and Gausemeier 2002] and TechOptimizer™ [Lindemann, Amft et al.]). Due to the missing interconnection to preceding and primarily subsequent steps we identified in the design process, these stand-alone solutions could not succeed in a satisfying manner.
As the first result of the above mentioned study, the design-theory of Pahl and Beitz [Pahl, Beitz et al. 1999] – which reached the best results in this study – has been chosen as the most promising theory for implementation into a software product. The software has to prescribe the proceeding and has to present the achieved results clearly arranged. Furthermore it has to be considered, how far the designer can be supported in evaluating (e.g. evaluating possible solutions in a morphological matrix).
An especial problem at this is the fact, that all evaluations are based on absolute subjective variables: On the one hand the designer chooses the criteria to evaluate by his own; on the other hand he decides in which way this criterion should be benchmarked to the others. Because of the missing candour inside the conceptual stage it is easily possible, that the designer’s favoured solution (which has not to be the impartial best solution) is being overestimated. The main point of the design-methodology, to bring up new, emerging solutions, is thereby missed.
When entering the embodiment stage coming from the concept, an elementary step is done in the design process: The information, collected and generated in the conceptual stage, has to be transformed from a two-dimensional (functional) into a tree-dimensional (constructive realisable) description. Nowadays this step is done exclusively by the designer, using his experience and knowledge. Here has to be cleared, how far this procedure can be automated and how far this depends on the designer. The integrated step from the two-dimensional to the three-dimensional computer-support is indispensable, because otherwise there always will be a gap between conceptual approaches

and the realisation in the CAD-system. All information, gathered during a design process, will be lost earlier or later, if it is not possible to transfer them into the later stages of design.

3.3 Approaches for implementing new software tools

A first important step for a computer-supported methodology is the supply of functions. The designer can use these functions generating a function-structure or a morphological matrix. The functions can be implemented in a database, which also should offer several coherent information (e.g. the physical basis). These additional data can be used for continuative tasks during the following stages in the process of design (e.g. dimensioning and calculation).
In this approach 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 (see figure 5).

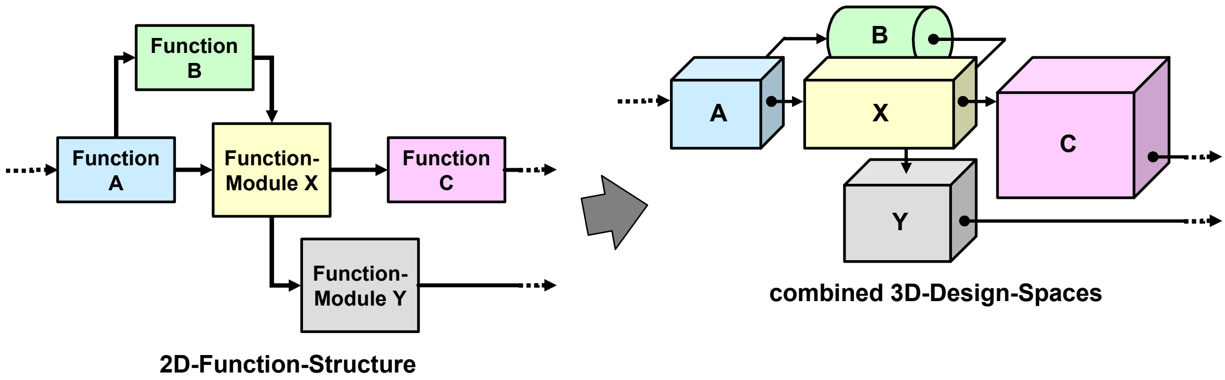


Figure 5. Transition from two-dimensional function-structures to three-dimensional design spaces

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.
Thereby, 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.
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 chapter 1, [Koch and Meerkamm 2001]). 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 6).
As 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).

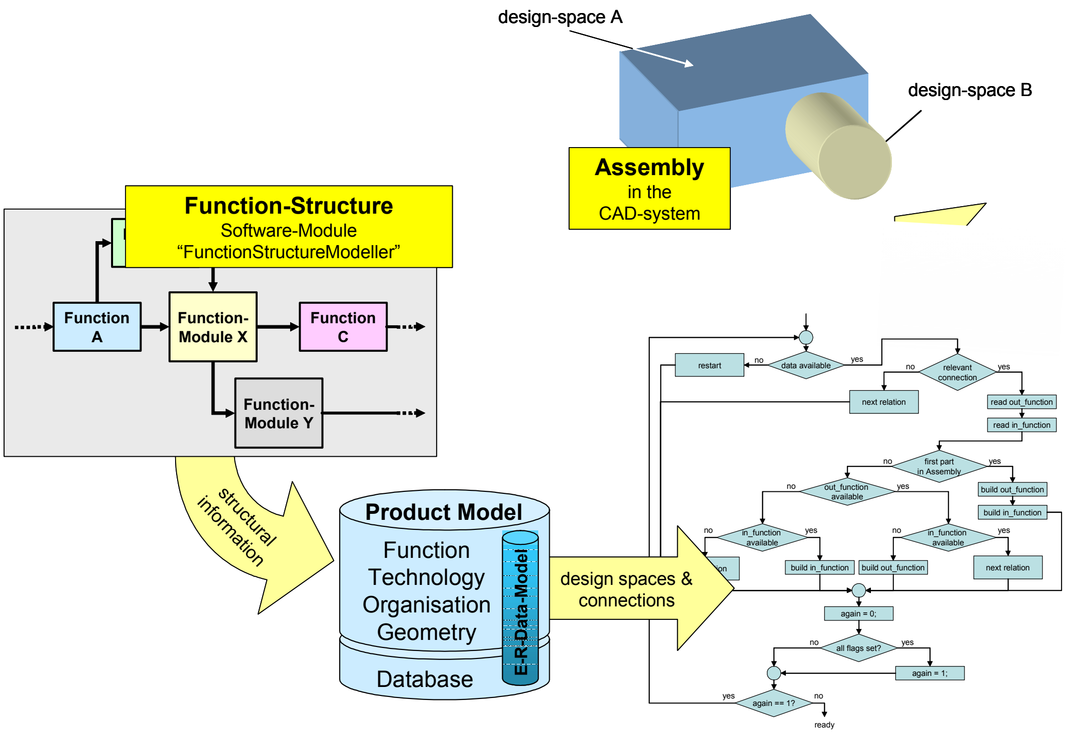


Figure 6. "FunctionStructureModeller" as an input device for the two-dimensional function-structure as well as the information about design spaces

The advanced approach is to deduce tree-dimensional design-spaces from the two-dimensional function structure. Therefor several basic algorithms for sorting, arranging and assembling the design spaces according to the function-structure have already been implemented into a module for the Engineering Workbench *mfk*. Further – more complex – algorithms are developed in the moment to handle more complex function structures. These algorithms have been designed to bridge the above described divide between two-dimensional information and the tree-dimensional world of CAD-systems.

4. Conclusion and perspective

In this paper the author reveals at the example of the real design task "positioning fixture" that there have to be developed several (software-)tools for the early stages of design, which offer methodical support to the designer. Such tools have to work hand in hand with the used 3D-CAD-system. This allows to realise a continuous computer support and thereby a flow of product data without interruption. In the later stages of the design process a connection of different stand-alone-tools using a unique and standardised product model [Koch and Meerkamm 2001] would help to solve many problems not only to simplify the data transport, but also to ensure a lossless transport of information during the process of design.
A preliminary approach 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 has been shown in the following. 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 and can be used to build up rudimentary geometrical structures, which give important support while entering the later stages of design.
As a concluding remark it has to be mentioned, that this approach is a first rudimentary step for a continuous computer support of the design process. The ideas have been implemented on the geometrical level and it is a possible further increase to make the step from geometry to mechatronic products in the future. First approaches towards mechatronic products can be found in [Schön 2000].

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Prof. Dr.-Ing. Harald Meeramm
University Erlangen-Nuremberg, Institute for Engineering Design
Martensstrasse 9, D-91058 Erlangen, Germany
Telephone: +49-9131-8527986, Telefax: +49-9131-8527988
E-mail: meerkamm@mfk.uni-erlangen.de