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CONCEPTUAL DESIGN – EHANCEMENT OF A DESIGN ASSISTANT SYSTEM FOR LIGHTWEIGHT STRUCTURES

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1. Introduction

Computer support in the embodiment and detail design stage, the so called late design stages, is today considered to be satisfying. On the other hand this support is insufficient in the early stages of the design process e.g. the conceptual design stage. Aim of the collaborative research group 396 is the enhancement of the application area of an assistant system for lightweight components from the late design stages into the conceptual design stage. The assistant system mentioned above is based on the "KSmfk"-System [Meerkamm/Weber 1991]. This System has been implemented at the Chair of Engineering Design for the more than a decade as the software result of multiple research periods. The main goal is to determine possibilities and methods to increase the robustness of product development processes for lightweight components. This relies upon a minimation of time up to the first, well designed principle solution. All relevant design methods have to be added to and accordingly implemented into the existing assistant system. Within the collaborative research group 396 a motorcar door has been chosen as demonstrator. On real existing object the improved design methods and implemented software will be verified.

2. Exploring behaviour of lightweight structures in terms of classic design processes in the conceptual stage

The main characteristic of the design process within the conceptual design stage is the appearance of only non-geometric-detailed design objects. These objects are created in the beginning steps of the embodiement design stage while bridging the gap between principle solutions and first detailed geometric structures. At the bottom line the conceptual design stage can be splitted into two non-geometric main steps of activity: a.) the functional design and b.) the searching for possible principle solutions for the lightweight components to be designed.

2.1 Synthesis and analysis of main- and subfunctions

In classic context, the first step during the conceptual design stage is the synthesis of the main function of the technical system. This is achieved by splitting down the main function into subfunctions and creating a function structure by connecting all subfunctions with different kinds of flows, like material, energy and signal flow.

Different examples of lightweight components were analyzed in reference to their subfunction structure. This task was accomplished by identification of all different subfunctions and through

consideration of all possible function structures which emerge while connecting all subfunctions with the different kinds of flows.

As a result of this work two main conclusions concerning lightweight components were drawn:

a.) All subfunctions found are of one of the following types:

One type of subfunctions found is on a very high abstraction level and it is not possible to split it down into more specific subfunctions. These functions thus have a very "passive" behaviour.

The second type found are functions splittable down to very elementary subfunctions, e.g. "convert electric energy into mechanical energy". These functions have in a certain way an "active" character, all input- and output flows are clearly given.

b.) It is improbable if not impossibile to create or identify a "classic" function structure as defined by Pahl/Beitz [Pahl/Beitz 1997] for a lightweight component because of the large number of "passive" subfunctions.

Further on the attempt to classify the found subfunctions into hierarchy levels showed, that four different hierarchy levels are meaningful. An example within the motorcar door is given in Figure 1.
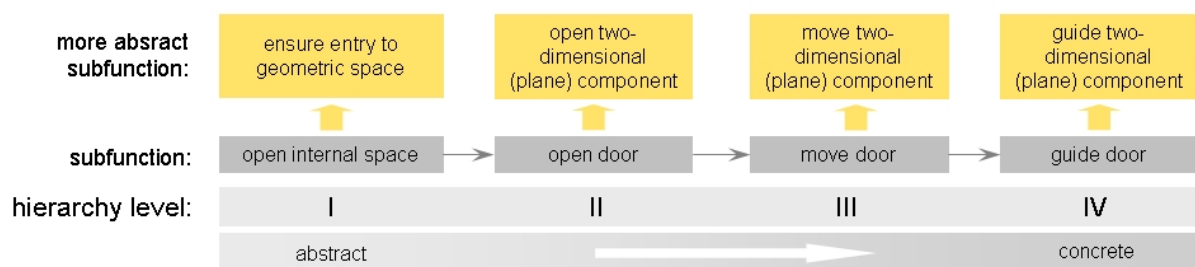

Figure 1. Hierarchy levels of the basic subfunction "open internal space"

Outcome of a more exact exploration of the part functions is that many functions are to be found frequently in certain categories of lightweight components. Therefore it seems meaningful to deposit all current part functions in a database, available to the assistant system. These should be classified after the different categories of lightweight components, as well as prior designed parts as e.g. door flaps, car body parts, housing parts (group household appliances) etc. and after the four different hierarchy levels defined above.

The main demand during the functional design peroid in the conceptual design stage is an effective synthesis of all subfunctions of the lightweight component to be designed. After that step different working principles have to be found to realize all different subfunctions by one or more principles. The creation of principle solutions as a last nearly non-geometrical step finalizes the activities in the conceptual design stage. Before considering the transfer between function modelling and principle modelling by searching for different working principles and working structures, let's have a closer look to principle modelling at the end of the conceptual design stage.

2.2 Principle modelling for lightweight components

During stage I and II within the collaborative research group 396 different building structure variants were analyzed in reference to a variety of criteria. A high level of geometric detailing is characteristic for these building structure variants. To come to assured conclusions concerning manufacturing processes, costs or other criteria within the second part of the conceptual stage, more abstract solutions have to be analyzed. But before an analysis can be started, the abstract principle solution has to be sythesized.

The synthesis of principle solutions of lightweight structures can be done in a classic way by creating the solution with different standard parts out of a kind of construction kit. But not only standard lightweight parts like e.g. Tailored Blanks should be included. Also new materials and composites, mainly developed in other part projects within the collaborative research group 396, will be

considered. The creation of a principle solution for lightweight components in detail will be shown in chapter 3.2.

The analyze of a principle solution of a lightweight component can be realized in reference to the following criterias: Every single main part of the principle solution includes information about the manufacturing process to be used to produce it, like the material or composite it consists of. Further the rough size (length, width and depth) of the part is known. This is by the way the only geometric information used to build up principle solutions here. Based on these informations and additionally data out of the used PDM-System (Product Data Management System) conclusions can be derived concerning the possibilities to produce the part by machines within the company. Further the level of modularisation possibility can be analyzed via the given principle solution. Are there for example many standard parts like tubes used in a certain geometric position, the level of modularisation possibility will be quiet high.

Company own knowledge concerning the implied manufacturing processes, the rough size, the materials e.g. composites and the assembly technologies can be used for an qualitative estimation of costs based on the principle solution.

2.3 Bridging the gap between functional and principle modelling

As shown above it is not possible to create a classic functional model of a lightweight component. The main reason is the occurrence of a large number of "passive" subfunctions. Due to the very abstract level of many subfunctions, the search for definite working principles for these functions is very complicated. Also combining them to working structures is nearly impossible. It can be asserted that by regarding the basic design structure of lightweight components some classic design methods during the conceptual stage can not be applied to lightweight structures. Figure 2 shows an overview over the approaches and procedures during the conceptual stage.
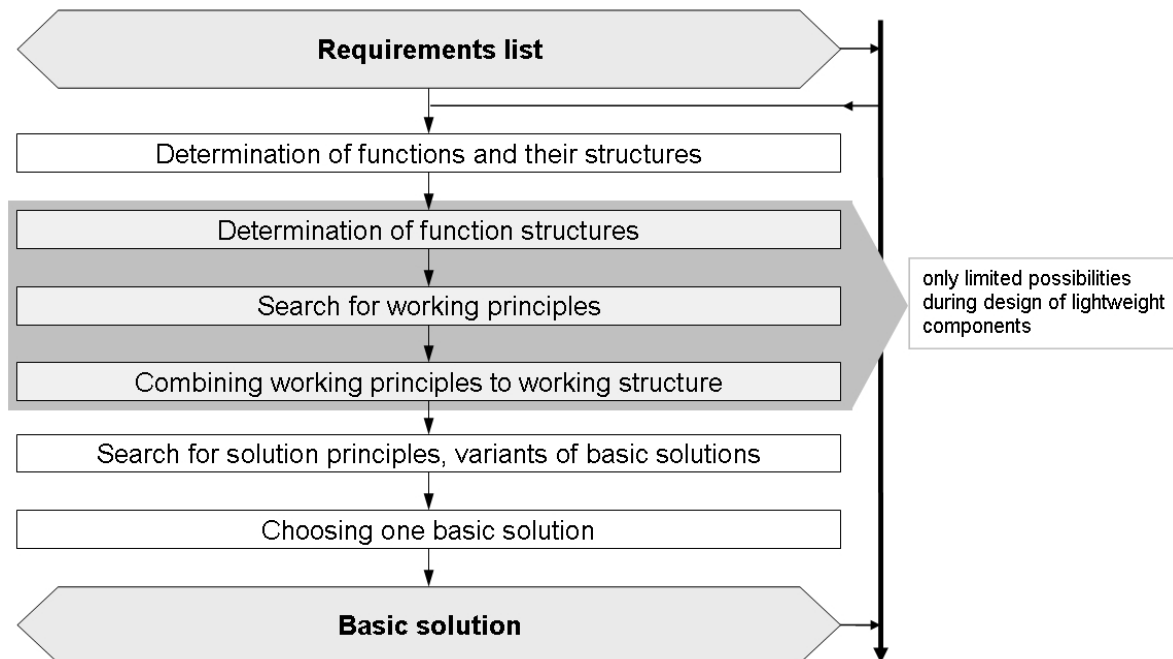

Figure 2. Design process of lightweight components and difficulties during the conceptual stage

3. Concept of enhancing the assistant system

As shown in chapter 2 the concept to enhance the assistant system into the conceptual stage can also be splitted in a functional and a principle solution part.

3.1 Computer support during functional modelling

As mentioned in chapter 2 it is not possible to identify classical function structures of lightweight components. So a computer based support of the designer during functional design is only possible with reservations. One solution is to classify all sub functions of different types of lightweight components and store them into a database, which is connected to the assistant system. So the first step in the design process within the conceptual stage will be the selection of the type of lightweight component to be designed. Then the designer has to choose all main functions at the most abstract level (defined as "level I"), which matches the given design object. If functions are not available, the system offers functionality to define and add new functions or to edit existing sub functions. After defining all functions on the "level I", "level II" becomes active (accessible) and the designer has to find corresponding sub functions to each main function of "level I". This approach will be continued until all sub functions of "level IV" are defined. In a later step (during principle modelling) all defined sub functions will be linked to the different design parts of the principle solution. By analyzing these links the level of functional integration can be evaluated. Another possibility of computer support within functional modelling is the enhancement of the so called "HYMIS" Hyper Media Information System, implemented during stage I and II of the collaborative research group 396 [Meerkamm/Wartzack 1998]. This browser-based program has mainly the character of a help-desk. The system offers non-formalizable data during and concerning the entire design process. It seems meaningful to save the designknowlege by inserting the different sub functions of lightweight components and corresponding principle solutions into this system. Linking other information like certain boundary conditions to this data can also support the designer by answering occurring questions during the design process in the functional state.

3.2 Computer supported generating of principle solutions (synthesis)

Considering the creation process of classic mechanical principle solutions it becomes obvious, that these solutions are build up via a certain type of modular construction system. This means, the solutions consist of a variety of standard elements like bearings, axes, boxes etc. This concept can also be transferred to lightweight components. In this case typical lightweight structure elements are needed. Figure 3 shows an overview over these components. The single component is called "Concept-Feature-Component". The "geometric component" can be splitted down into "geometric part". The "geometric parts" can consist of either a "tube", an "integral part" or an "area part". Exact definitions of the different components are given in Figure 3.
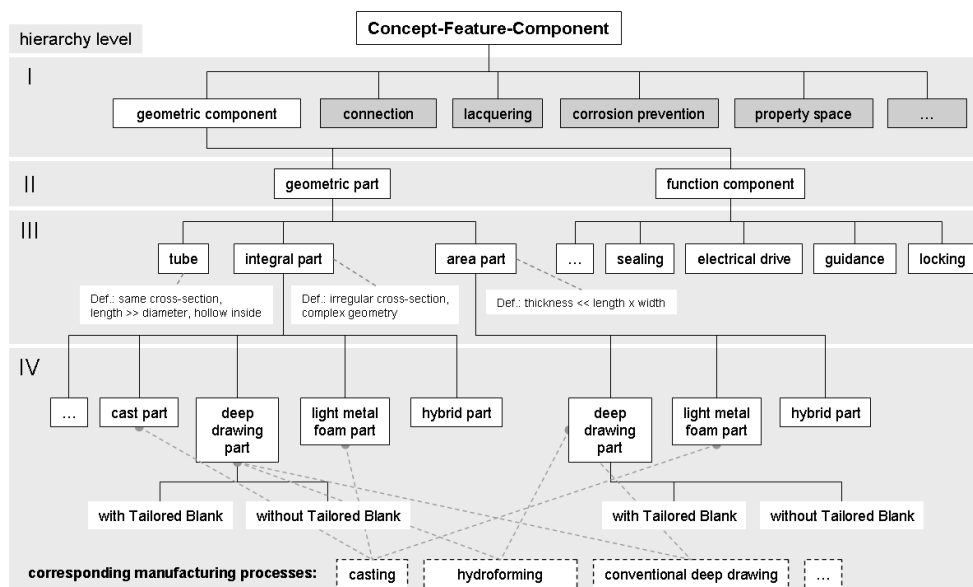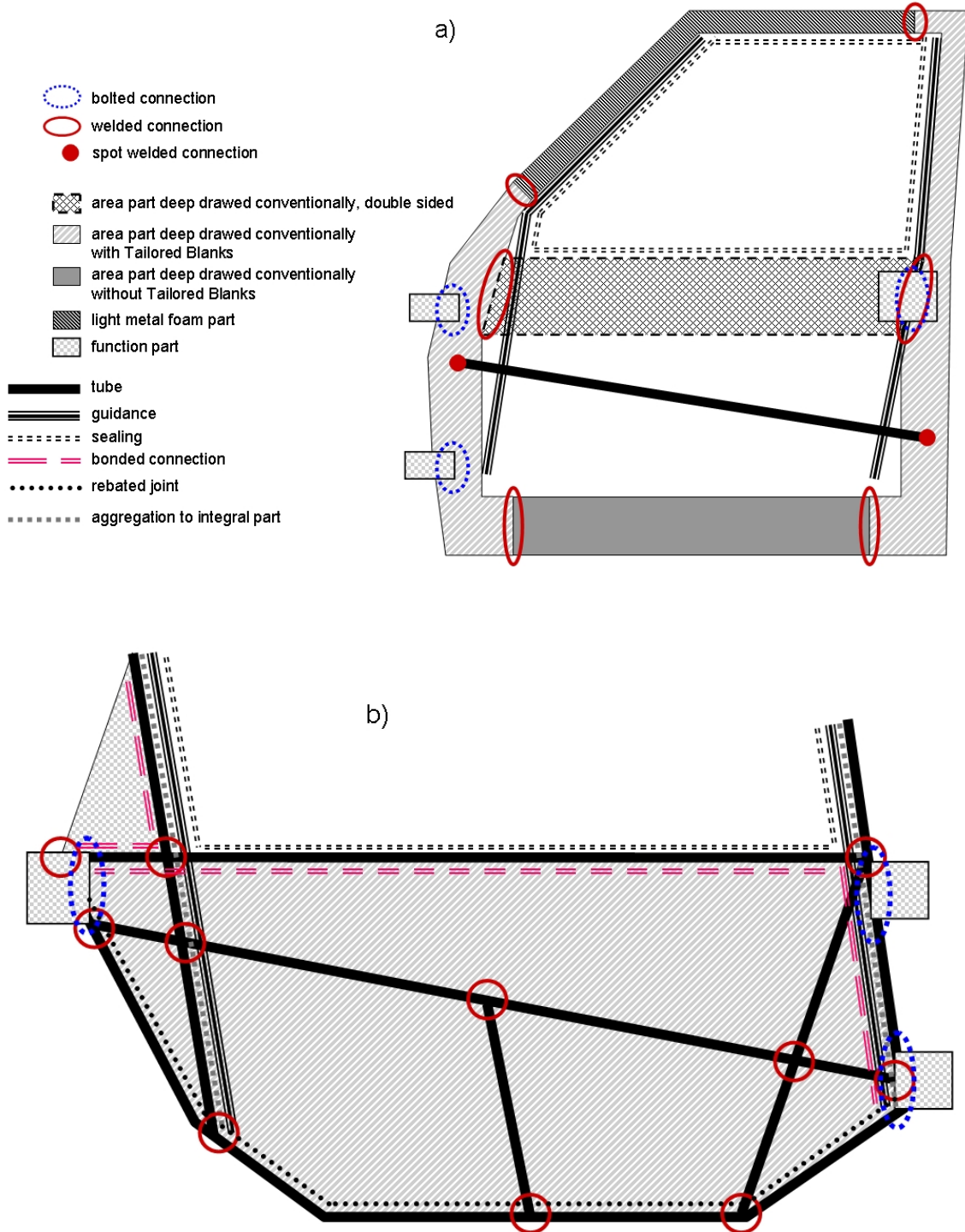

Figure 3. Hierarchy of Concept Feature Elements

An Element of level III consists of other components (level IV) which are manufacturing-dependend. This connection opens the possibility to draw conclusions within an analyse concerning manufacturing possibilities or costs of different manufacturing processes. Also more abstract Feature-Components can be used like "connection" or "lacquering", shown in the top area of Figure 3.

a)

- - - - bolted connection
——— welded connection
● spot welded connection

area part deep drawed conventionally, double sided

area part deep drawed conventionally with Tailored Blanks

area part deep drawed conventionally without Tailored Blanks

light metal foam part

function part

——— tube
——— guidance
= = = = sealing
——— bonded connection
• • • • • rebated joint
• • • • • aggregation to integral part

b)

Figure 4. Principle solutions of motorcar doors designed with concept-feature-elements
a) conventional design structure; b) door of the city car "SMART"

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The concept feature component "geometric component" can also consists of a so called "function component", which is characterized by a more complex behaviour. An example for such a component would be the door lock mechanism component of the motor car door regarding the demonstrator object within the collaborative research group 396. Figure 4 show examples of car doors designed using concept-feature-components.

Regarding computer support for building up principle solutions of lightweight components the use of a database is necessary to provide all different concept-feature-components to the designer. The design process is done by drag & drop on a graphic user interface. Hereby it is mentionable that almost no geometric information is saved in the system. Only the rough dimension of a concept-feature-element and its position has to be defined. The first step in modelling a principle solution is the defining of all plane components. Then different assembly technologies between the single feature-components and all other components like "function components" have to be assigned to the model. At this research stage it seems sufficient to save the build up principle solution as a two-dimensional model. Further analysis will show, if a three-dimensional model is more advantageous.

While choosing different standard concept-feature-components like e.g. tubes the designer can be supported by the PDM-System used in the company. For that reason the assistant system has to be linked to the PDM-system. Further on the system offers the functionality to search the PDM-system for parts that fulfill some given subfunctions of the lightweight component to be designed. A requirement driven out of this approach is the necessary linking between parts and their functions within the PDM-system.

The last step during the synthesis of a principle solution of a lightweight component is the defining of links between each single concept-feature-component and its corresponding subfunction. This approach can also be realized via drag & drop. Figure 5 shows the graphic user interface of a first prototype implementation of the system.

3.3 Computer supported analyses of principle solutions

Analysis of principle solutions of lightweight structures is possible in many different ways. A main goal is to generate different variants of the technical object to be designed and to analyse them.

On the one hand a fully automated analysis of each single solution by the assistant system in reference to different criteria is possible. This means that there is no evaluation between the different variants. The manufacturing possibilities can be analysed because of knowing the rough size, the material all parts consist of and the necessary manufacturing processes. This analysis is supported by the PDM-System as knowledgebase for all manufacturing processes available within the company. An analysis regarding the recycling becomes possible due to established materials and corresponding assembly technologies. Further on, the cost each principle solution causes can be evaluated qualitatively [Ehrlenspiel/Kiewert/Lindemann 1998]. It is also possible to estimate the level of functional integration by comparing the number of sub functions fulfilled by one single component of the principle solution.

The system also checks the linking between the sub functions chosen at the beginning of the conceptual stage and the components of the principle solution. Each single sub function has to be linked to at least one part of the principle solution.

The second possibility to analyze the generated design variants is an evaluation among other considered criteria. This is an important step after the automated analysis for each solution mentioned above. In this case the assistant system proposes possible criteria to the designer, who has to make a choice, finding a reasonable strategy for evaluation. The whole evaluation is supported by the software tool "EVALUATOR" [Adunka/Wartzack 1999] which was developed at the chair of engineering design. An interface to the assistant system is under development at the moment.

Further on, the level of abstraction of the researched principle solutions is quite high. This speaks for the introduction of an element of uncertainty for each criteria during the evaluation.
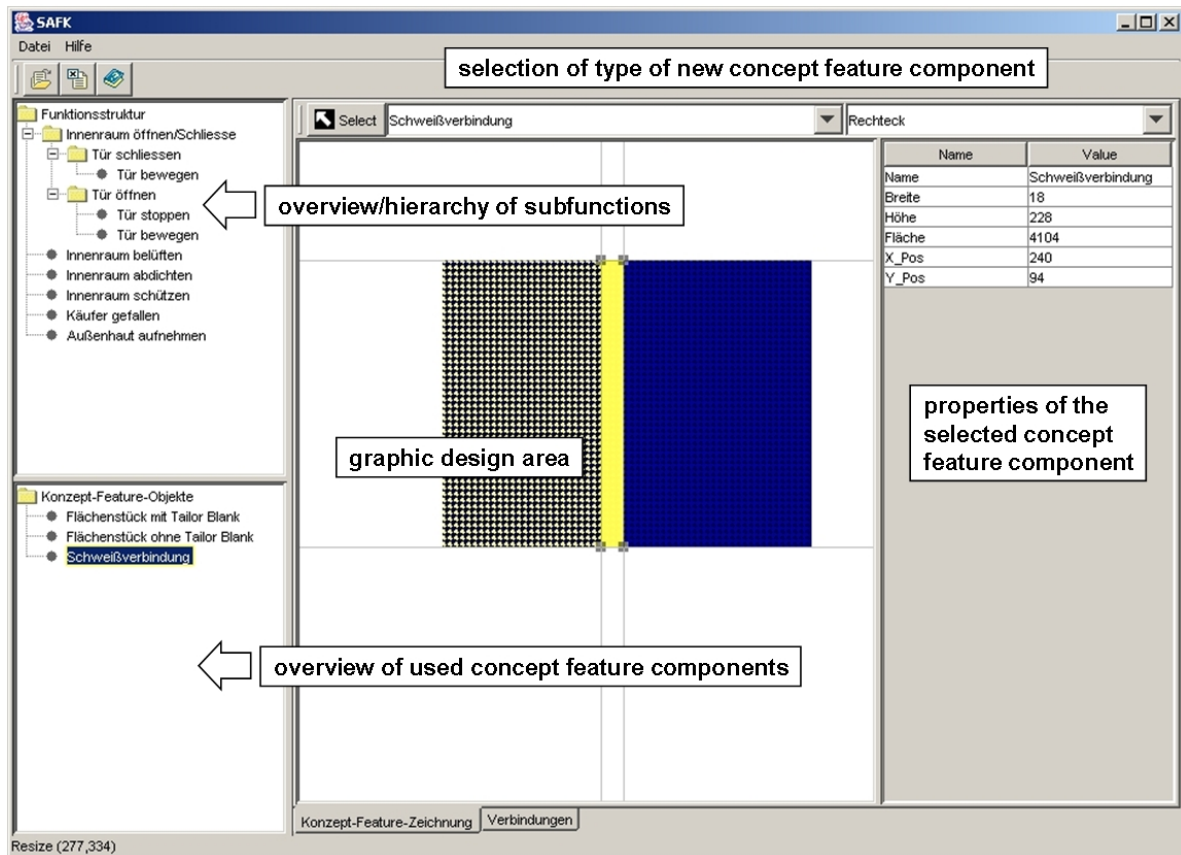
Figure 5. Main GUI of the assistant system enhancement for lightweight structures

4. Summary and future prospects

This paper has proved the appropriateness of an enhancement of the existing assistant system for lightweight components into the conceptual stage.

igner is supported during functional and principle modelling. Our research focused on the principle modelling. Different ways of analyzing principle solutions of lightweight components were presented. The next logical step in the future is the enhancement of the assistant system for supporting the early stages of the design process like the planning stage. These stages have the highest optimization potential for the designed object. On the other hand, all activities are on very abstract level so that providing computer support will require further research.

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