INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 05 MELBOURNE, AUGUST 15-18, 2005

ANALYZING AND IMPROVING METHODS USING *e*MAP ANALYSIS – ***E*LEMENTARY METHOD ACTIVITIES FOR DESIGN PROCESS** ANALYSIS

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Keywords: Method analysis, method optimization, elementary activities

1 Introduction

Many methods for DfE exist on the market, but only a few are utilized in the day to day work of designers [1]. Araujo found that the attitude and motivation of the designer are essential to a method's success [2]. Both factors can be increased by good methods, successful marketing, on-the-job training and a supportive work environment. Good methods are, analogous to good products, the foundation for successful method use. However, many methods have not been fully developed, lack intensive field-tests or have a low effort-benefit ratio. To avoid these problems, Lindemann suggested establishing a quality certificate for methods [3]. For this, a systematical process for method development must be developed. The basic idea is to handle the method development process similar to the product design process, i. e., establish a requirements list, systematically analyze the method, build an improved method and verify it. The focus of this paper is the analysis of the method based on a "function structure" for the methods and a systematical modification to find an optimized method structure.

2 Fundamentals of Method Analysis

The basic idea is to use the principles behind functions and function structures in the optimization of products for the improvement of methods. Functions are used to describe the relationship between the input and output of a technical system in an abstract way [4]. Thus, in the case of methods, the relationship (task) between the start and end point must be described as well. To build a function structure of methods, the methods must be divided into smaller parts, analogous to products which are divided into functions. Analogies of dividing tasks into smaller ones can be found in REFA [5], where mainly work processes are broken down into elementary activities with the goal of optimizing them. Besides the REFA methodology, Lompscher [6] and Dörner [7] divided mental processes into operation and subtasks. Transferring the ideas of the function structure, the REFA methodology and the mental operations to the method application produces elementary activities which are easy to grasp and clearly defined. They should also be manageable and few in number.

Many researchers have already defined numerous elementary activities concerning method use; six of them are arranged in a table for comparison Table 1. It was found that some of the activities are similar and others are different, which is not only due to the specific purpose for which they have been developed. One of the biggest problems is that they are not clearly distinguishable from each other. Even worse is that some of them have the same synonyms representing different tasks. Thus, the challenge is to find a level of detail which is still elementary but not too abstract, distinguishes the activities sharp and is suitable for analyzing methods.

Table 1. Comparison of elementary activities by different authors (excerpt)

Ambrosy (1996), p. 85ff.	Birkhofer (2002c), p. 123	Ehrlenspiel (1995), p. 205	Pahl/Beitz (1997), p. 86	Hubka/Eder (1992), p. 120	Zanker (1999), p. 62, 63
		draw up			create
					carry out
recognize characteristics			recognize		recognize
collect/ search/ complete		seek solution	seek variations		search
					collect
		ascertain functions			
abstract			abstraction	abstract	abstract
…	…	…	…	…	…

all terms (expect for Pahl/Beitz, 1996) are translated by the author

Therefore, to overcome this problem of unclear definitions, a formalized description (following function structures) is used, where the activity is drawn as a black box with a defined in- and output [8]. The elementary activity, like a function, transforms the input to output. Activities starting with or leading to different in- / outputs are different, and so must be differentiated. Thus, this black box representation supports the understanding and the differentiation of the activities. The in- and outputs of an activity can be either a material or information in a wider sense.

The existing elementary activities from different authors were analyzed and the most common activities were extracted and transferred to a black-box representation. Those activities were applied to different methods by different users until a set of nine method activities was identified. The application revealed that, in a first step, it is important to separate the method from the designer, analogous to the product from the user, when analyzing the method. This is necessary in order to focus only on the method activities themselves. Later on, when the method is optimized, the designer behavior is added using a modified FMEA [11]. Otherwise, it is too difficult to analyze the method since different designers handle one method or even single activities differently.

Those nine activities can be divided into different groups: the operational activities, similar to the physical functions, and the assessing activities, analogous to the logical functions. The operational activities transform elements; they have elements as in- and output (Table 2).

In contrast, assessing activities compare elements using criteria and do not change the element or their number. Rather, they change the order of the elements, assign them to a group, or designate an assessment value, such as ‘smaller’ or ‘bigger’, or even a concrete value as an output (Table 3).

Table 2. Elementary operational activities

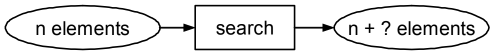
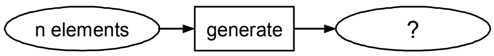
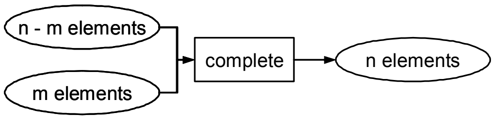
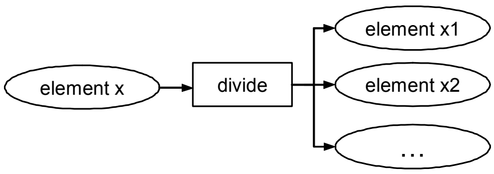
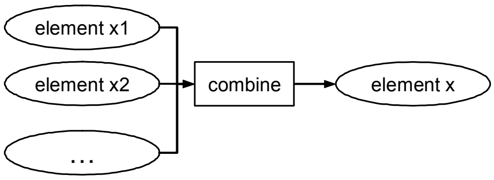
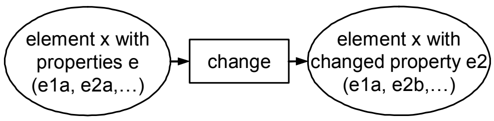
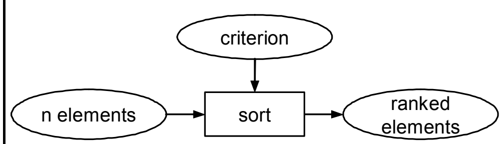
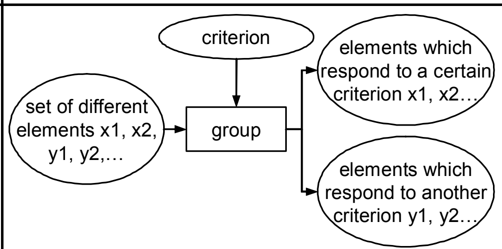
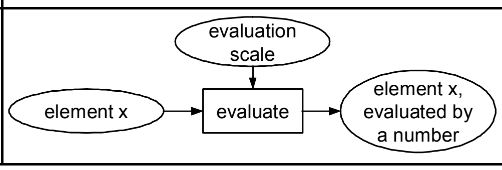
Elementary operational activities	Black-box representation	Synonyms	Explanation and examples
Search		Research, collect information	Search is an activity, in which the number of the elements is increased. Examples are searching for the manufacturer of a certain product or for literature on a certain theme.
Generate		Create, establish	Generate is an activity, in which new elements are created from an (un)known number of elements or from scratch. An example is generating ideas by brainstorming.
Complete		Gather, add details, enrich	Complete is an activity, in which some elements are already known, but the completeness of the existing systematic is supplemented by adding new elements acquired throughout, e.g. search or generate. An example is completing a variant-tree.
Divide		Part, separate	Divide is an activity, in which an element is split up into several sub-elements. An example is dividing a complex product into its components.
Combine		Join, merge, link, calculate	Combine is an activity, in which two (or more) sub-elements are combined to a single element. An example is combining elements in a matrix to a new element. The basic arithmetic operations are also considered as combining (higher Mathematics do not belong to the application of product development methods).
Change		Exchange, vary, convert, prepare, present, document	Change is an activity, in which one or more properties of an element is altered. Examples are changing data presentation (generating of graphs, drawings and sketches) or products (systematic variation of product properties).

Table 3. Elementary assessing activities

Assessing activities	Black-box representation	Synonyms	Explanation and examples
Sort		Rank, order	Sort is an activity, in which elements are first compared according to a criterion and then are ordered. Sorting is a repetition of comparing until all elements are “assigned” or “ranked” Example for sorting is the alphabetical sorting of names or requirements according to their weight.
Group		Classify, cluster, select, simplify, leave out	Group is an activity, in which elements are according to a criterion assigned to a cluster. Examples are grouping words generated during a brainstorming or variants into suitable and non suitable.
Evaluate		Judge, measure, weight	Evaluate is an activity, in which the degree of goal fulfillment is judged by comparing an element to a scale and allocating a value to it. An example for evaluating is the weighting of product requirements.

On closer inspection, some of the activities are not really elementary activities, because they are integrated. But in order to avoid excessive abstraction and to ease the drawing of function structures, activities like complete are used. Complete could also be combined with the activities search or generate and combine. Also, the assessing activities are really integrated activities since they all have the elementary activity compare embedded in them The sort activity can even be seen as a loop of the multiple group activities. As it can be seen from the critical examination above, the activities defined do not form the only possible division and classification, but it is goal-oriented and suitable for the systematical analysis of methods and method steps. Therefore, in order to simplify the system, keep it manageable and ease the drawing of activity structures, frequently used integrated activities are also defined as single "elementary" activities.

It can also be seen that the problems arising from the sharp differentiation between the activities are not completely solved. However, the formalized representation using the black-box description and the examples for each activity make it easier to establish a common ground.

None of the elementary activities described so far, include activities like 'recognize', 'understand', 'think', 'question', 'derive', 'agree' and 'ask'. These activities occur frequently and are necessary when using a method, but it is not possible to completely foresee when and how often they occur. This depends more on the individual designer or the design team carrying out the method than the method itself (note: of course, the method can support or hinder the embedded activities). Thus, it is hard to distinguish those activities from the operational and assessing activities. They are more embedded within the process and are therefore called embedded activities. They are not directly nor exclusively supported by a single method step. The operational and assessing activities are sequential, whereas the embedded activities influence the operational and assessing activities at different times. They could be also called "second level" activities, since they "underlie" the operational and assessing activities (Figure 1). This differentiation between embedded, operational and assessing activities can be compared to the user behavior within a functional structure or even a computer processor within a flow chart. Looking at the operations of the processor, its internal mathematical operations (thinking and recognizing processes) are also not considered in a flow chart of a program. Therefore, the embedded activities are at first not considered when analyzing the method and composing the *e*MAP.

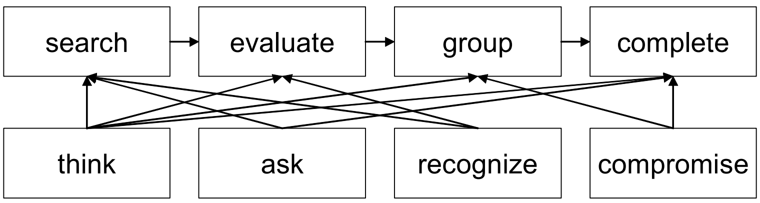


Figure 1. Interaction between embedded and operational or assessing activities

This is also similar to the function carrier in function structures. The function is independent from the carrier and, in the case of activities, the carrier is the method or the method step. But looking further at the use process of a technical function and its carrier, the user behavior often plays an important role. The same applies to the activities: looking at the application of the elementary method activities and its method, the user with the embedded method activities also plays an important role.

Thus, by differentiating between embedded, operational and assessing activities, it is possible to analyze the method independent of the designer.

Of course the suggested classification and division of the activities in elementary method activities is only one possible solution, but it is a suitable and goal-oriented solution.

3 Visualizing using *e*MAP demonstrated on an Eco-QFD

As stated before, the elementary activities are visualized using the black-box representation (cf. see also Table 2 and Table 3) to facilitate their definition and support the differentiation between them. These black-box representations can be used to build an elementary activities structure for analyzing the method, called *e*MAP (*e*lementary **M**ethod **A**ctivities for design **P**rocess analysis). Within *e*MAP all elementary activities, their arrangement, as well as their relationships are visualized. Besides the visualization effect, the method designer has the possibility of moving to a higher level of interrelationship in order to reduce complexity and emphasize the essential characteristics of the method (principle of abstraction, see also [4]). By doing so, it is possible to identify the core activity of a method and to systematically improve the method. But to understand the single activities and the relationships between them when building the *e*MAP, the characteristic verb (activity) must be combined with the noun (object), describing what is performed, e. g., ‘search information’, ‘generate solutions’, ‘combine modules’.

In the following, the building of *e*MAP is demonstrated on an extended QFD which also takes environmental requirements into account, the so-called Eco(ological)-QFD [13].

At the beginning of the process the Eco-QFD was independently broken down by two researchers into its elementary activities using a table representation (Table 4). This theoretical analysis can be carried out by the method developer or an experienced user. In the table representation the sequence, as well as the in- and outputs of the activities, are analyzed. The results of the two researchers had different orders of sequences and numbers of steps. In general, both table representations were correct. The differences were mainly based on an inexactly defined method process and on individual adaptations based on personal experiences. Therefore, it was necessary agree on an overall representation when transferring the table representation to the *e*MAP (Figure 2).

Table 4. Table representation of the elementary activities carried out during an Eco-QFD (excerpt)

Task	Elementary activities	Input	Output
Search product requirements (PR)	**Search** customer demands (CD)	Customer or expert opinion; data from databases, …	CD list
	Group CD	CD list	Assorted and irrelevant CD
	Evaluate CD	Assorted CD	CD with positive, negative and no correlation
	Group redundant CD	CD with positive, negative and no correlation	Redundant and non redundant CD list
	Generate redundant free CD	Redundant CD list	Redundancy free CD list
	Combine CD	Redundancy free and non redundant CD list	CD list (without redundant CD)
...	...	...	...

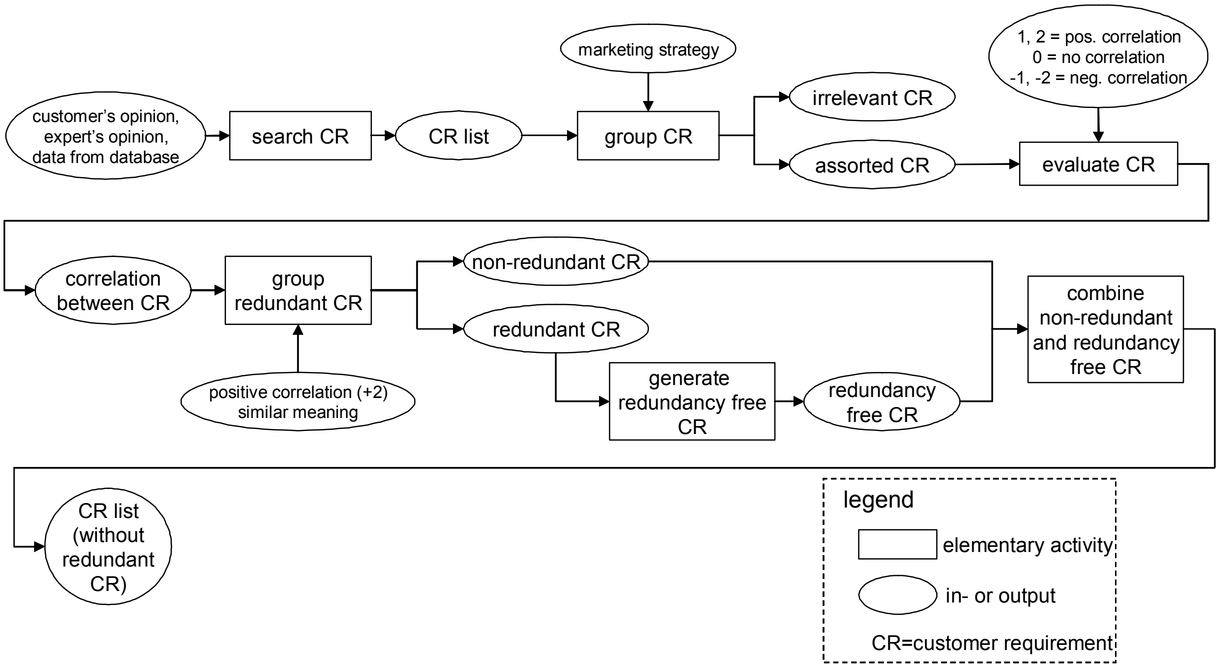


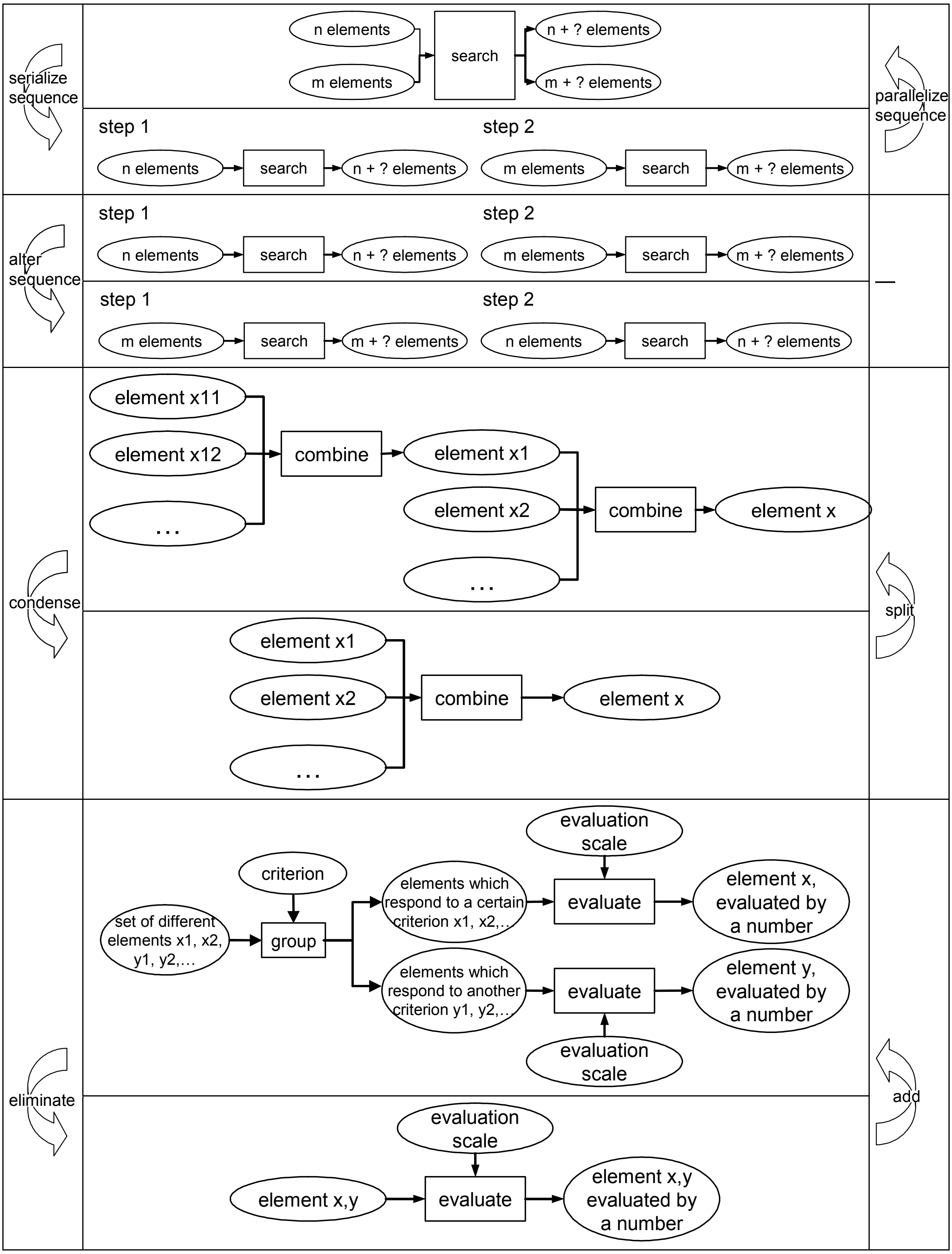
Figure 2. *e*MAP an Eco-QFD (excerpt)

The *e*MAP is composed in much the same way as a function structure, and it is possible to identify superfluous, ineffective or mandatory activities. Starting with the core elementary method activity, the other activities can be added, omitted and varied to improve the effectiveness and efficiency of the method. As in optimizing a function structure, different variation strategies have been developed, e.g., changing the method (system) boundary, changing the arrangement of activities (parallel, serial or alter the sequence), condensing or splitting activities, and harmonizing the methods (fragments) used for similar activities (Table 5). Thus, it is possible to identify essential activities and to tremendously reduce the effort for carrying them out. Since not all of the non-essential elementary method activities are impractical, it is possible to provide both an optimized and a modularized method. Depending on the conditions and the desired outcome of the method, the user can select different modules and even different methods to fulfill the elementary method activities, making it possible to provide a customized method.

Using the *e*MAP in Figure 2, the Eco-QFD process has been analyzed. It was found, for example, that only 6 out of 44 possible activities are mandatory to carry out a basic Eco-QFD. Therefore, the effort for carrying one out can be tremendously reduced. Small improvements were identified by changing the order of the steps. Finally, different modules which can be individually added were identified. One such module is the interrelation matrix, which indicates contradicting and supporting customer and environmental demands. Therefore, it is possible for the designer to select different modules, depending on the circumstances and the desired outcome of the Eco-QFD.

From the results above it can be seen that, even for a fully established and hackneyed method (in terms of research), it is still possible to identify improvement options by systematically analyzing the method. With *e*MAP it is possible to increase the effectiveness and efficiency of methods in order to provide more practical methods that are ready for industrial application.

Table 5. Systematical variation of *e*MAP (following [8])



4 Conclusion and Outlook

The three kinds of elementary activities presented (operational, assessing and embedded), represent a structured system of activities for breaking down the method use process. They have been made as simple, clear and differential as possible. In any case, it is clear that the classification presented in this paper can only be considered an experiment. A definitive classification is very difficult due to varying ideas about the meanings of various terms. The variety of the activities that occur during method use make such a classification even more difficult. But so far, the experiences with the elementary activities indicate that the exact differentiation between the activities is not as important as the fact that the method is analyzed step by step on an abstract level. Therefore, it is not a problem if other researchers customize the definitions to their own work. At the same time, it is important to keep the embedded activities separate from the operational and assessing activities, so that the method can be analyzed independent of the product designer in the initial step.

5 Acknowledgement

This paper is based of the 9 year work from the collaborative research center 392 ‘Design for Environment – Methods and Tools’ of the Darmstadt University of Technology, which is funded by the Deutsche Forschungsgemeinschaft (DFG). Within the collaborative research center, 19 PhD researchers and 9 professors from 3 different departments work on supporting the designer in the DFE-process, using the integrated product and process development approach. The results of the collaborative research center are implemented over the next 3 years in industry within the transfer center 392 ‘Design for Environment using optimized processes, methods and tools‘.

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