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INVESTIGATING ELEMENTARY DESIGN METHODS: A PROCESS-ORIENTED AND MODEL-BASED APPROACH

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1. Introduction

Nowadays a large number of methods are introduced in literature. Most of these methods are not new but rather modifications or further developments of existing methods. A common challenge results from the proper adaption of design methods to the actual problem at hand. Method descriptions hardly ever give any support for this difficult task [Birkhofer 2007].
On the one hand, the collection of methods for product design/ development provides a valuable pool of tools, that can help to solve problems. However, this only displays the character of an evolutionarily grown collection rather than of a structured system.
Therefore the aim of investigating elementary methods is to develop a systematic approach for the deduction, description and improvement of design methods.
This paper presents first results regarding the creation of a system of elementary methods, founded on the basics of design methodology, such as process-orientation, work with (product) models and consideration of human performance and problem solving in product development. Therein a systematically justified and comprehensible definition of elementary methods is of great relevance.
In the long run the approach of elementary methods aims to raise the acceptance and prevalence of methodical working [Birkhofer 2008].

2. State of the art

Many approaches have been made to analyze the basic structure of design methods. Some of these attempt to do so by using a structured description (e.g. **P**rocess **o**riented **m**ethod **m**odel (PoMM) [Berger 2004]). In the PoMM approach the existence of meta- and sub- methods is assumed and method descriptions are geared to the process models.
Other attempts in the past were based on the definition of elementary methods. A convenient way to identify the formal structure of methods is „The Genome Approach of Elementary Design Methods" [Birkhofer, 2007]. Therewith it is possible to display even very complex methods as a structure of elements and operations. Therefore, eight different forms of elements (processes, functions, (physical) effects, (working) principles, (real) objects, properties, characteristics, values) as well as five operations ("list", "assign", "divide", "merge", "connect") are defined. In this particular approach, an elementary method is defined as the linking of two elements with one operation.
Another approach defines the elementary methods by basic actions of designers. These actions were identified in design management practice. According to this, most development methods support several basic actions, whereas an elementary method supports only one action at a time. [Zanker 2000].
Nevertheless, there is no consensus within the community about the preference of a specific approach.

A remarkable gap seems to be between the challenging demands of the individual researcher creating her/his own structure of design methodology and the perceptible benefit of these approaches for the research community.

3. Identifying processes and models in product development

Product development can be understood as a process. A process is defined as the transformation of a state using a procedure which transforms a defined starting state into a desired ending state (Figure 1) [Birkhofer et al. 2002]. The overall process consists of numerous sub-processes.

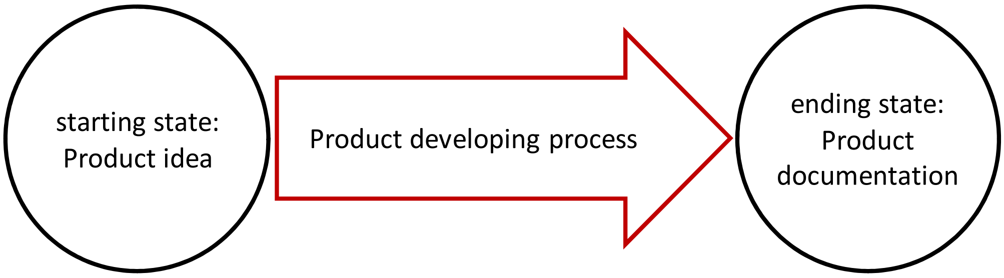

Figure 1. The product developing process as a transformation of a starting into an ending state

The process characteristic of product development and the fragmentation into sub-processes can be observed in important procedure models of product development (e.g. VDI guideline 2221 and Münchener Vorgehens Modell (MVM) [Linedmann 2009]).
The VDI guideline 2221 basically serves as a support for the planning of the designing process.
The MVM combines the advantages of existent procedure models of product development as well as basic psychological findings. It supports problem solving as well as analysing and reflecting the elaborated results.
Common development methods, such as requirements list and function structures or the systematic combination of solutions within a morphological box, possess a more sophisticated structure than procedure models.
The definition of development methods is based on the fact, that recurring sub-processes can be marked-off and standardized for the purpose of rationalisation. The designer uses an individual mix of methods. S/he selects the most suitable design methods depending on several factors, e.g. user skills, infrastructure and working aids.
Considering the design methods and their range, it is evident that sub-processes within product development differ considerably from each other in respect to character, complexity and granularity. For example, creativity technique methods like brainstorming cannot be easily compared with major development methods like Quality Function Deployment. Another problem appearing is that a complete and systematic coverage of all sub-processes by development methods cannot be expected due to the above-mentioned evolutionary growth of the method system.
The determination of a proper granularity and degree of formalisation constitute the central problems in the development of a system of methods on the basis of elementary methods.
The finer the granularity and the higher the degree of formalization of elementary methods, the more flexible the entire system can be constructed by a few different elementary methods. However, adverse consequences result in the form of high adaption and combination efforts, when development methods are to be deduced for practical application.
Rougher granularity leads to a higher number of different elementary methods for comprehensive support of product development. The system of elementary methods would be more vague and, therefore, the aspired clear understanding of the elementary methods cannot be reached
The above described process character of product development suggests to define elementary **methods** by factorising the overall design process into elementary **processes**.
Since the **systematic working with models** forms a basic aspect of the design methodology, elementary processes can be defined via the use of models. Starting states and results of methods are often described in terms of models (p.e. product models, such as functional structures or sketches).

Elaborated models comprise the intermediate results of the development work. They can be understood as a **virtual state within the development process** and therefore determine the sub-processes.
Elementary processes can be understood as the transformation of a model into a different or modified model. Therefore, in this approach, elementary methods are defined based on these elementary processes (Figure 2).

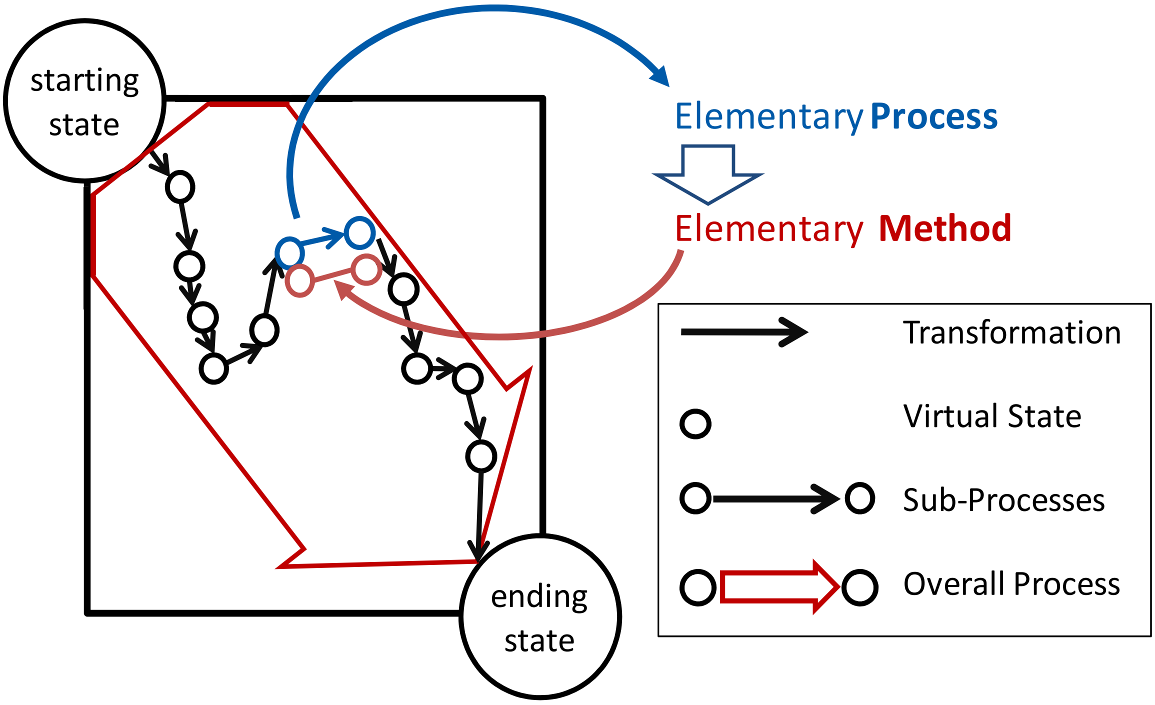

Figure 2. Identifying elementary processes and defining elementary methods in PD

Within product development, product models are the most commonly used models. They are strictly formalized and comparatively exact defined. In addition, the so called product model space is well structured. Therefore, it seems sensible to start with the identification of elementary processes and methods based on the product models.
Product models represent technical systems via an abstracting depiction [Sauer 2006]. On the most abstract level, these would be purely textual models. Through different stages, the concretion and complexity of the models increase from functional structures over sketches and design drawings to comprehensive digital or physical descriptions of the model.
Product models are iteratively concretized within the methodical product development. The product models are transformed from a **starting state** (e.g. abstract model) to an **ending state** (e.g. concrete Model). All product model spaces mentioned in literature (such as Ehrlenspiel, Andreasen and Hein, Sauer, Rude, Ponn and Lindemann) are structured on the state of abstraction or concretion (dimension of abstraction).
Early approaches only mentioned the **dimension of abstraction** of the product model. Ehrlenspiel, for example, described a product model pyramide, which also displays processes between different concretion steps [Ehrlenspiel 2007].
Rude [Rude 1998] as well as Ponn/ Lindemann [Ponn and Lindemann 2008] define two further dimensions in order to span a product model space of construction. These two dimensions are the **dimension of variation** and the **dimension of decomposition** of a model.
Within the product model space, the product development process can be displayed as a network of sub-processes (Figure 3).

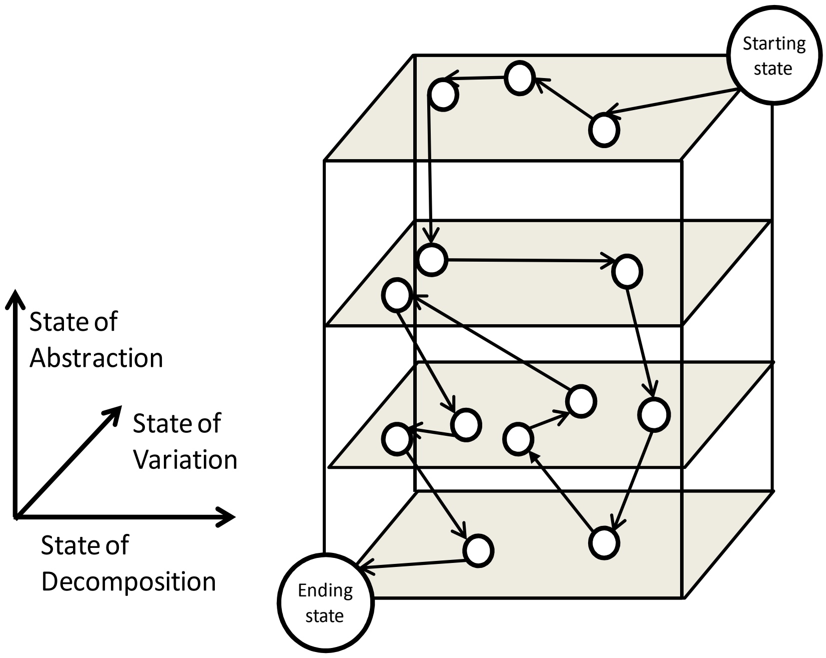

Figure 3. Sub-processes in the product models space

Two operations in the model space are defined for each dimension (Figure 4) [Sauer 2006][Rude 1998][Ponn and Lindemann 2008]:

- Dimension of abstraction: Abstracting – Concretizing
- Dimension of variation: Variation – Selecting/ Evaluating
- Dimension of decomposition: Decomposing – Composing

For the dimension of variation, this list is not consistent. Five of the six mentioned operations are representing a transformation of a product model. Whereas "selecting/ evaluating" is not a transformation of a product model. Nevertheless selecting and evaluating are common activities in the process of designing.

The other operations are able to describe every transformation of the product models (sub-processes) within the product model space and therefore they are called elementary transformations in this paper.

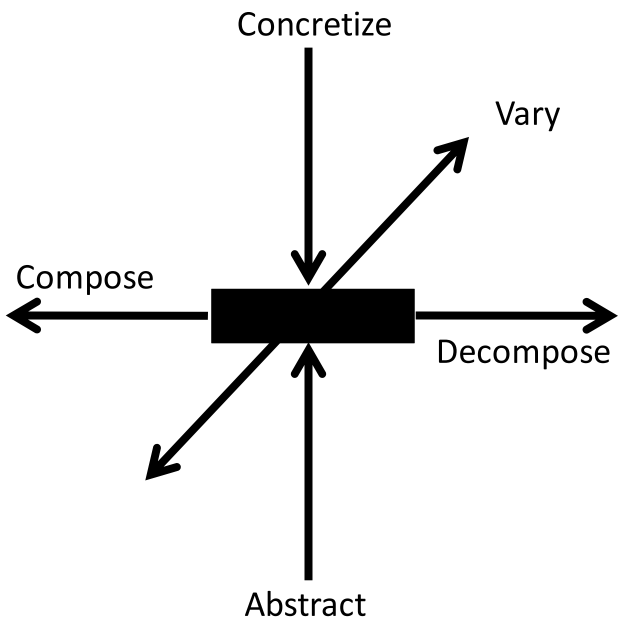

Figure 4. Basic operations in product model spaces define elementary transformations

Based on the elementary transformations, elementary processes of product development can be defined by assigning the starting state and ending state (e.g. product models) to the elementary transformation. The basic feature is, that they change one dimension of a product model and retain the current shape of the other two dimensions at the same time.

4. Identifying further model spaces in product development

Actual product development is more than only work with product models. In order to define a comprehensive set of elementary processes and methods, models beside of the product model space have to be considered.

For example, with the help of methods the following points can be accomplished [Lindemann 2007]:

- Complex problems can be reduced to manageable subproblems.
- Goal conflicts can be recognised and problem-solving oriented focuses elaborated.
- The intuitive solving of problems can be increased specificly.
- Thinking barriers, which complicate a specific action, can be overcome.
- Existing fixations in thinking can be overcome.

Ponn and Lindemann define and structure the product model space based on the basic principles of human acting.

However, to span the product model space only three of the eight basic principles of human acting described by Lindemann [Lindemann 2007] are used and described explicitly (bold):

- Basic principle of system thinking
- **Basic principle of problem breakdown**
- Basic principle "ensemble to detail"
- **Basic principle "from abstract to concrete"**
- Basic principle of discursive proceeding
- Basic principle of periodic reflection
- **Basic principle of "thinking in alternatives"**
- Basic principle of "change of modality"

Since the basic principles are not all considered, it is necessary to identify further areas of possible models and to define according model spaces. Based on these additional model spaces, the system of elementary methods can be extended and hopefully completed.

The two basic principles of **system thinking** and **discursive proceeding** are reflected in the working with procedure models. The need for a similar model space for **procedure models** is obvious.

Reflection and **change of modality** offer an orientation across the defined model spaces for the designer. Evaluating results and changing the thinking position allows a goal-oriented development process.

Ponn and Lindemann integrated requirements into the product model space, but also described their exceptional position [Ponn and Lindemann 2008]. Sauer differentiates between requirements and product models [Sauer 2006]. However, working with requirements and goals is a major aspect within product development. Considering elementary methods it appears to be reasonable to define a separate model space for **goal and requirement** models.

Creativity techniques also play an essential role in methodical product development. Up to now, no models have been defined for this and structuring possibilities have been described only rudimentarily due to the low state of the formalisation of solution ideas.

However, in the consideration of elementary methods it appears to be reasonable also to define a further model space for **solution ideas**.

Some methods (e.g. BCG Matrix) only handle **information**. Thus, a model space for information is added for the development of elementary methods.

Figure 5 shows the elaborated system of model spaces in design.

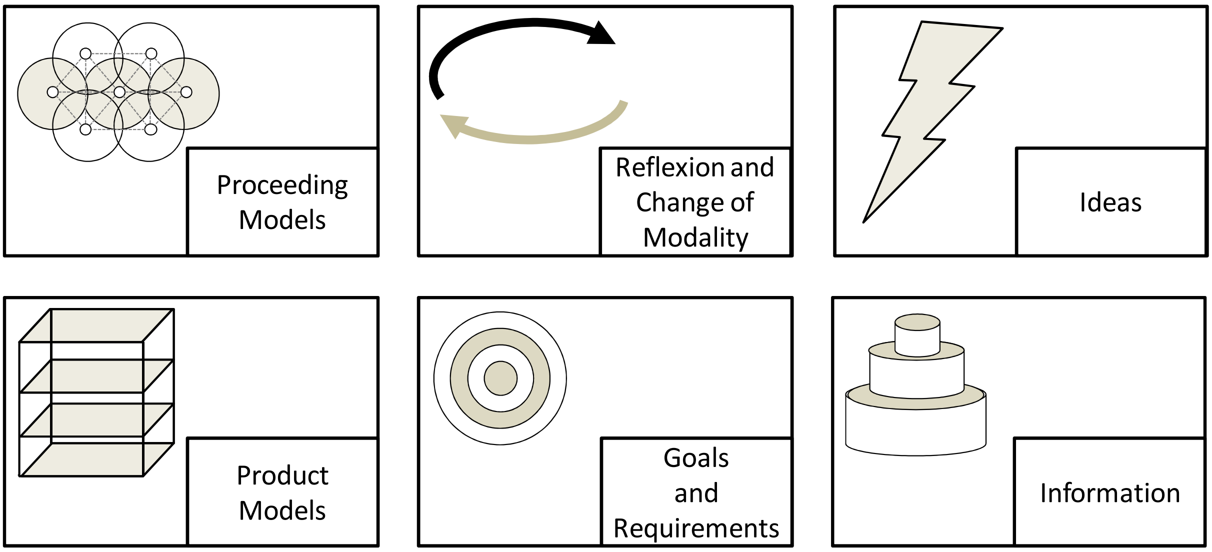

Figure 5. System of model spaces in design

5. Elementary processes and methods within the product model space

The described system of different model spaces aims to help in identifying a limited number of elementary transformations. By amending a starting and ending state (underlying model), these can be extended to elementary processes. Due to the high granularity of elementary processes a definition of elementary methods is possible (Table 1).
In order to reach a better, clear arrangement to display the single concretion steps of the product models are united. The elementary methods of the individual stages are similar.

Table 1. Elementary methods within the product model space

Elementary Transformation	Model Space	Elementary Process	Elementary Method	Example
Abstract	Product Model (PM) Space	Abstract PM	PM- Abstraction	Function Recognition (Black Box)
Concretize		Concretize PM	PM- Concretion	Solution Finding Methods
Vary		Vary PM	PM- Variation	Systematic Variation
Decompose		Decompose PM	PM- Decomposition	Function Structures
Compose		Compose PM	PM- Composition	Systematic combination

6. Conclusions and further work

This paper shows a systematic approach for investigating elementary design methods. Therefore, a system of model spaces in product development was created. Generally accepted basics of design methodology are the stable foundation of this system.

Triggered by the process oriented and model based understanding of design methods, elementary methods are defined as standardized elementary processes. Whereas an elementary process was defined as an elementary transformation of a starting state into an ending state. Starting and ending state of elementary processes are often different types of models.

The best formalized and defined models in design are product models. Due to this well-elaborated formalization, elementary transformations in product model space are evident. Since an elementary process is the result of adding a starting and an ending state to the elementary transformations, elementary processes can be distinguished either by the used elementary transformation or by the underlying model. For each identified elementary process elementary methods can be described.

Because there are other models besides product models used in product development, this approach was extended.

So the system of model spaces presented above is only the basis to review the sub-processes within product development. In the area of product models, obvious elementary processes have already been identified. The goal is to identify similar processes for all described areas in further research.

It is imaginable that the same elementary transformations like in product model can work in general and that elementary processes only differ in the underlying model (as starting or ending state of the elementary process).

In addition, elementary processes have to be identified which connect different model spaces. The question has to be answered, how the designer moves from elaborated requirements to a product model (e.g. functional structure).

Furthermore, it has to be examined, whether further model spaces have to be added.

After adding model spaces to the system of elementary methods and identifying elementary processes, elementary methods have to be elaborated. The genome approach of Birkhofer could be useful for the formal realisation. Finally, rules for the situative combination of development methods have to be created.

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