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A METHOD FOR DESIGNING VISUALISATIONS AS TOOLS IN PRODUCT DEVELOPMENT

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1. Introduction

Visualisations can be used as tools in product development. They provide features distinct from other types of design support tools, making them a unique set of tools for product development. Designing the concepts of such visualisations as product development tools is a challenging task for all who develop methodical design support, particularly design researchers. There are hardly any approaches or literature that supports the development of visualisation concepts. This is why current visualisations as tools in practice and product development research exhibit great potential for improvement [Gebhardt et al. 2014]. To contribute to improved development of visualisations as product development tools, this paper presents a new "Methodical Approach to the Design of Visualisation Concepts as Tools in Product Development". The approach was developed at the Hamburg University of Technology, based on the need for support of visualisation designers [Gebhardt et al. 2014], [Gebhardt and Krause 2015], the state of research in information visualisation and existing approaches to visualisation design (Section 2), as well as to development of design supports. The methodical approach is presented in this paper by an application case from industry (Section 4). The case is analysed for applicability and effectiveness of the methodical approach and the visualisation that was developed as a design tool (Section 5).

1.1 Research object

Visualisations can provide very useful support in product development, which is why Krause et al. put visualisations as a central strategy in the "integrated PKT-approach for developing modular product families" to enable analysis, communication and solution finding [Krause et al. 2013]. Many product development methods utilize visualisations as major tools in their procedures. Besides the integrated PKT-approach, UML diagrams [Eichelberger and Schmid 2009] and "Radical Simplification via Design" [Mortensen et al. 2012] are further examples of visualisations providing support in product development.
In this paper, a visualisation is understood as a simplified, static and graphical representation of product programs, families, products, their structures, properties and/or behaviours (Section 2.1 and [Gebhardt and Krause 2015]). Design researchers and process designers in industry adopt, adapt and develop visual tools and incorporate them into their methodical product development procedures. The visual tools have big impact on applicability, efficiency and acceptance of such methods: they are important user interfaces and major representations of specific methods. This may lead to a visualisation not meeting engineer expectations only because of its graphical design and coding, regardless of its potential support. Previous studies have shown that even small differences in the graphical design of a visualisation have a significant impact on its performance as a tool in product development practice [Gebhardt et al. 2014].

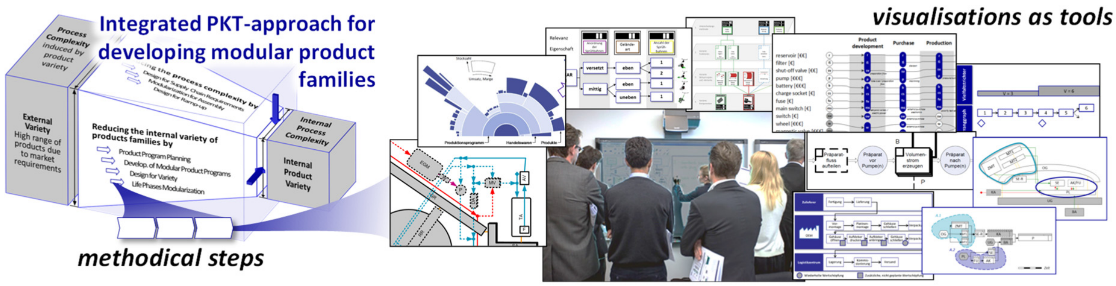

Figure 1. Examples of visualisations as tools in the integrated PKT-approach for developing modular product families, after [Krause et al. 2013]

Figure 2 shows two visualisation concepts, both dedicated tools for module boundary definition, yet strikingly different in their visual design, and thus certainly leading to different applicability.

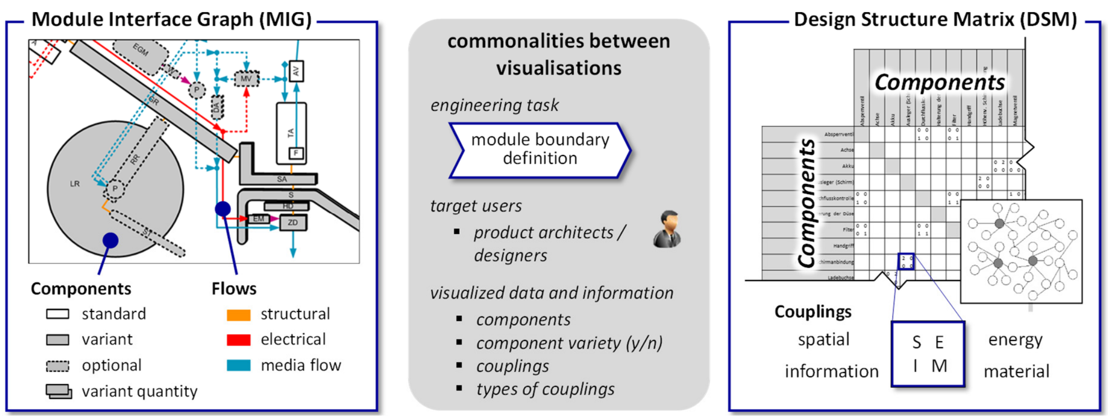

Figure 2. An example of disparity in the design of visualisations as tools in product development after [Krause et al. 2013], [Eppinger and Browning 2012]

This example emphasizes the importance of the conceptual design of a visualisation as tool in product development. Building on this, the focus of this paper is on the methodical procedure for developing concepts of visualisations proposed as tools in product development.

1.2 Problem description and research objective

In recent research the main factors influencing the design of visualisations in practice were analysed in a literature study and interviews with industry [Gebhardt et al. 2014]. A study on 13 research projects that each designed visualisation concepts as tools in product development has identified the need of visualisation designers for support [Gebhardt and Krause 2015]. Designers of visualisation concepts often do not sufficiently consider the factors that influence the design of visualisations and the knowledge of information visualisation necessary to design a visualisation concept as an efficient tool was often missing. Based on this, a Methodical Approach to the Design of Visualisation Concepts as Tools in Product Development was developed. It guides developers through the process of designing a visualisation concept that will be an efficient tool in product development methods. It was developed based on the procedural needs visualisation designers for support [Gebhardt and Krause 2015], state of research on information visualisation and existing approaches to visualisation design (Section 2). The aims of the approach are to consolidate the knowledge of information visualisation and to contribute an applicable procedure both necessary for designing a visualisation concept as a tool in product development: both of these are currently missing from literature and practice and can help considerably improve product development.

Visualisation concepts are just one type of product development support (some other examples are design methods and guidelines, checklists, and simulation tools [Blessing and Chakrabarti 2009]) and are therefore most likely only part of a design support. A methodical approach to the design of a visualisation concept should be easy to integrate into general approaches to developing design support. The above mentioned literature of Blessing and Chakrabarti provide valuable insight in this regard.

2. The current state of research

2.1 Clarification

The term visualisation has different definitions in e.g. engineering, computer science, and social science. It can be interpreted as artefact as well as a process or mindset [Kerren et al. 2007]. Therefore, the following working definitions were made for this work, cf. [Gebhardt et al. 2014]:

- **Visualisation**: a simplified, abstract and static graphical representation of products and their structures, properties and behaviour to aid product development – *a concrete artefact*
- **Visualisation concept**: the schematic idea of a visual coding. It describes purpose-oriented visual support for particular steps in product development – *a 'blue print' for a visualisation*. It consists of **visual principles** (general type of spatial layout of a visualisation, e.g. matrix, node-link, rendering, bar plot, sketch) and **visual techniques** (visual coding used for an entity of data or information, e.g. colour, position, shape, size, text or icons).

These definitions comply with the fundamental literature on information visualisation; although multiple terms are used for the same conceptions, cf. [Gebhardt et al. 2014].

2.2 The role of visualisations as tools in product development

Product development methods like the integrated PKT-approach ([Krause et al. 2013] and Figure 1) incorporate visualisations as tools (further examples are given in [Gebhardt et al. 2014]). Maier et al. recognize visualisations as models and describe their role and effectiveness by their contribution to beneficial decision-making for a given purpose and context [Maier et al. 2014]. The role of a visualisation concept as a tool in product development is described using an application model, shown in Figure 3, and explained further in the following paragraph.

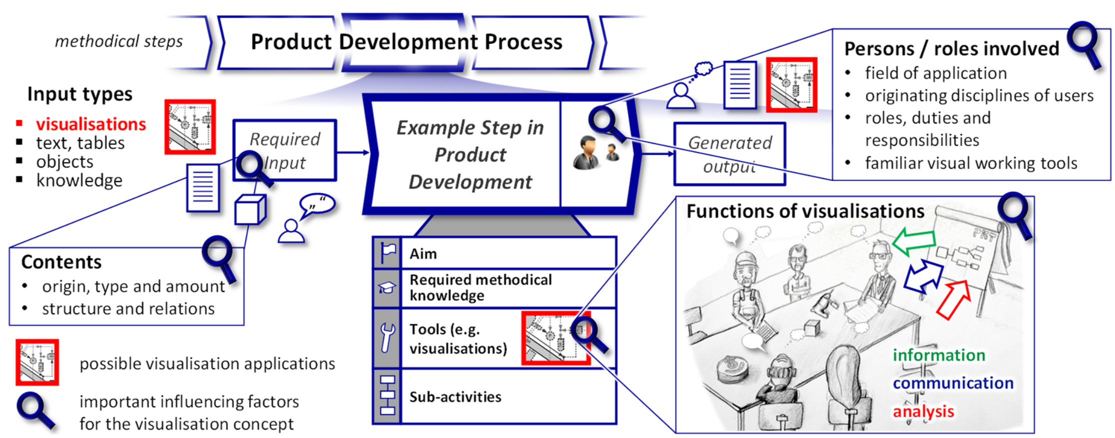

Figure 3. The role of visualisations in a product development process

A product development process can be described by single method steps, their sequence, required and created information/knowledge, as well as work and communication formats [Beckmann and Krause 2013]. In this context, visualisations can act as information input, a support tool during a process step, and results documentation. Literature about visualisation describe a consistent set of influencing factors important for designing the visualisation; which is listed in [Gebhardt et al. 2014]. Adapted for visualisation concepts as tools in product development, these influencing factors are shown in Figure 3 as "Contents", "Persons" and "Functions of visualisations".

2.3 Systematic design of visualisation concepts generally and in product development

Literature provides some guidelines on how to design visualisation concepts. Available work mostly stems from general information visualisation and specified application fields. Literature on general

information visualisation, such as [Mazza 2009], [McKim 1990] and [Spence and Witkowski 2013], gives insights into human visual cognition, visualisation principles and techniques, and their composition. Due to their general nature they are not appropriate for detailed and efficient application to designing visual tools for product development without long familiarity with the matter. References to the operating conditions in product development processes are not easy to derive [Gebhardt et al. 2014]. The visualisation of high volumes of data dominates literature; there is far less work on the types of data and information specific to product development.
Literature specifically on visualisations in product development is provided, e.g. by Tjalve, who guides the designer through the choice and design of drawings and illustrations [Tjalve 1979]. Waßmann offers a systematic approach to choosing visualisations for mechatronic systems [Waßmann 2013]. Meyer and Lengler and Eppler do the same for management [Meyer 1999], [Lengler and Eppler 2007], the latter using a "Periodic Table of Visualization Methods for Management". Yoon proposes six graphical forms of visualisation for technology planning [Yoon 2010]. Kissel describes node link graphs for product data, based on filters and rules [Kissel 2014]. When analysed from the perspective of designing visualisation concepts as tools in product development, literature on visualisation in product development mostly focuses on a single task (e.g. ideation), a narrow application area (e.g. mechatronics), one visual principle (e.g. node-link graphs) or a particular media (e.g. sketching or virtual reality). This is the reason why no suitable work on the methodical design of visualisation concepts as tools in product development is available.

3. Need for support

Inventors of visualisation concepts as product development tools have quite different initial situations and approaches to the design of visualisations, often lacking knowledge and experience on possible visual principles and techniques [Gebhardt and Krause 2015]. Available literature on alternative visualisation solutions does not support their immediate needs and understanding – at least not in passable time ([Gebhardt et al. 2014] and Section 2). The exact purpose of the visualisation concept as a tool is often not understood or defined clearly.
The aim of the new methodical approach presented below is to support the process of designing visualisation concepts as product development tools. The procedure should support typical initial situations of a design researcher or process designer in industry. The aim is to make available the necessary knowledge on information visualisation, and the scope of visualisation principles and techniques, from literature. The research question is how to support the methodical design of visualisation concepts as efficient tools in product development. Suitable measures are to be provided for:

- recording and modelling factors influencing the visualisation concept
- modelling the product development process to be supported
- applying them in the choice of visualisation principles and technique
- composing possible visualisation concepts
- integration of a visualisation concept as a tool in a product development process.

4. Methodical approach to the Design of Visualisation Concepts as Product Development Tools

The "Methodical Design of Visualisation Concepts as Product Development Tools" was developed at the Hamburg University of Technology to improve the situation described above. It will be presented here using an application case from industry. First, an overview of the main phases and steps is given in Figure 4. As a general application directive, there will always be solution ideas in mind from the start. Hence, constant sketching of visualisations as well as creative thinking should be applied. The following application case further illustrates the actions taken in each phase and step. In Section 5 an analysis of the case study - for applicability and effectiveness of the visualisation as a result of the methodical approach - is presented.

Figure 4. Phases of the "Method for Designing Visualisations as Tools in Product Development"

4.1 Case introduction

The German company Lutz Elevators develops, produces, installs and maintains highly customised elevators. As well as highly individualised elevators, marine applications for cruise liners, yachts and offshore rigs are another vital market for the medium-sized enterprise. During a joint research project with the Hamburg University of Technology, the engineer-to-order strategy of the company was partly transformed into a configure-to-order business based on a new modular product family. This included the setup of a new product development group responsible for designing the module kit [Krause and Gebhardt 2015].

As part of the project, a visualisation concept was developed that supports the new module development group and the head of production in assessing and approving newly designed modules. The aim was to support them in identifying possible reductions in production variety and costs by changes in production (planning, systems, layout, etc.) or module design, or both together.

4.2 Presentation of the methodical approach on the case of Lutz Elevators

Phase one: goal setting

Initially, the goal in designing the visualisation concept is defined by a simple, written statement describing the outcome situation and targets to achieve. The focus should be on the desired impacts on the product development process. Additional constraints, for example, from stakeholders or IT infrastructure, can be included as well.

For the case on Lutz Elevators, the goals were described by the target group and management board as being to:

- Support module developer and head of production in approving new modules
- Identify possible reductions in production costs by changes in production, module design or both aligned.

Phase two: application analysis

In this phase, the important influencing factors (Section 2.2 and Figure 3) are recorded and, if necessary, further elaborated. This is done in three fields:

1. Necessary data and information, and their interdependencies and properties (Figure 5)
2. Users or target groups (Figure 6)
3. Product development steps to be supported (Figure 7).

Analysis in each field is supported by a spreadsheet and. This may be performed iteratively because all three fields might undergo subsequent changes. Noteworthy, influencing factors from Fields 2 and 3 are not always essential: If the target user group works in similar practice to the visualisation designer, Field 2 can be omitted. If only an informational visualisation is asked for, there is no product development procedure – hence no Field 3.

For the case at Lutz Elevators, the necessary data and information elements were recorded by scanning process documents and interviewing the target users. The spreadsheet used for documenting and analysing types of data and information, as well as the structures of their dependencies (both necessary for the later choice of visual principles and techniques in phase 4), is shown in Figure 5.

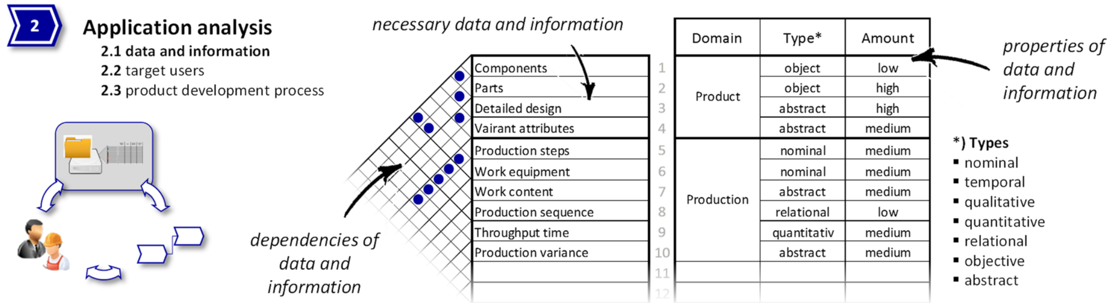

Figure 5. Specifying data and information elements using a purpose-built spreadsheet

Necessary information on the target users and their requirements of the support solution was captured through interviews and visual designs of everyday work documents (Figure 6).

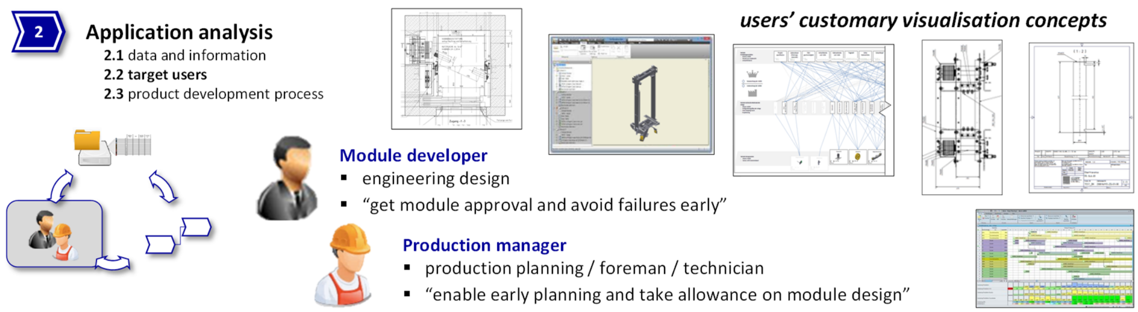

Figure 6. Target users analysis (pictures of visualisations courtesy of Lutz Elevators)

The product development steps to be supported were defined by the target users, who agreed on separate information preparation by module developer and production manager first, before aligning knowledge and identifying potential cost reductions (Figure 7).

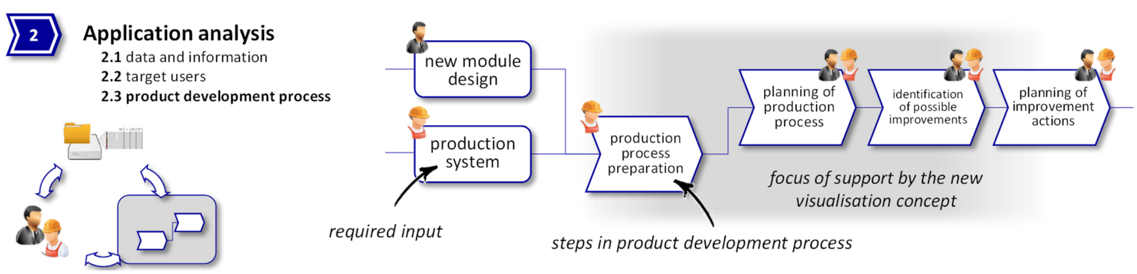

Figure 7. Product development steps to be supported

Product development steps may be supported by more than one visualisation. At this point, it is important to reflect the three fields of analysis (necessary data and information, target groups and product development steps to be supported) to clarify the potential or even necessity of using several visualisations. Using different visualisations can be beneficial, for example, capturing main and ancillary information, or necessary if too many or diverse data and information is to be visualised.

For the case at Lutz Elevators, the high volume of information on product design could make it necessity to split visualisations. The goal of integrating the views of module developer and production manager favoured the use of one visualisation, though.

Phase three: research on existing visualisation concepts

Results from phase two give tips on what to look for when searching for existing solutions, e.g. in literature. To support this further, two handbooks were compiled. The first lists approx. 100 visualisation concepts typically used as product development tools to showcase possible solutions and support ideation by analogies. The second handbook lists typical professions in engineering companies, with

descriptions of visual conventions and visualisation examples. The handbooks can be downloaded from (www.tuhh.de/pkt/institut/mitarbeiter/gebhardt.html).
For the case at Lutz Elevators, using the results from phase two as key aspects, a literature review provided some initial ideas for visualisation concepts showing similar data, addressing similar tasks or coming from similar professions (examples are shown in Figure 8).

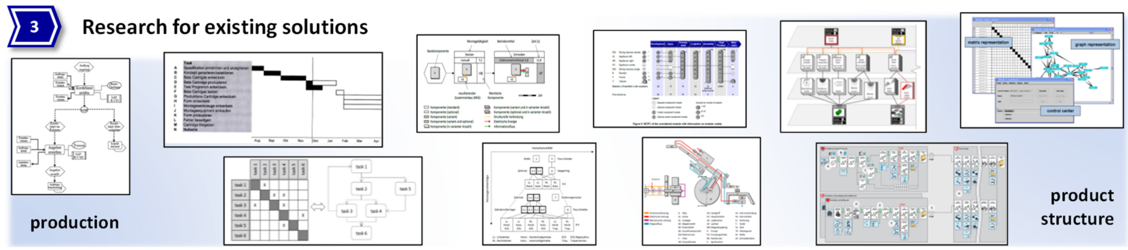

Figure 8. Selected search results for existing visualisation concepts: production-related, left; product structure, right, [Krause et al. 2013], [Mortensen et al. 2012], [Eichelberger and Schmid 2009]

Phase Four: generation of alternative concepts - step one: choosing visual principles

Phase four encompasses the synthesis of visualisations concepts as solutions to product development support based on analysis results of Phases 1 to 3. Guided by the essential literature on visualisation research, the concept phase is divided into choice of visual principles and visual elements/techniques (Section 2.1).
Visual principles constitute the main spatial layout of a visualisation. Their selection mainly depends on interdependencies between data and information elements [Mazza 2009]. If, for example, the product structure is to be visualised, a visual principle able to display a hierarchical structure should be chosen, as it will match the mainly hierarchical nature of a product structure. A third handbook was written, providing suitable visual principles and their ability to represent particular structures of data and information elements (Figure 9, right). Appropriate visual principles from the list can be collected in a morphological solution space, sketched and tested before continuing.
As explained in Figure 9, first the data and information elements are prioritized by their relevance to the task (Figure 9, left). In this case, the "product structure" and "production steps" were chosen as the primary information. Their dependency structures are hierarchical (product structure) and temporal/sequential (production steps). Suitable visual principles from the above-mentioned handbook were taken into consideration (Figure 9, right).

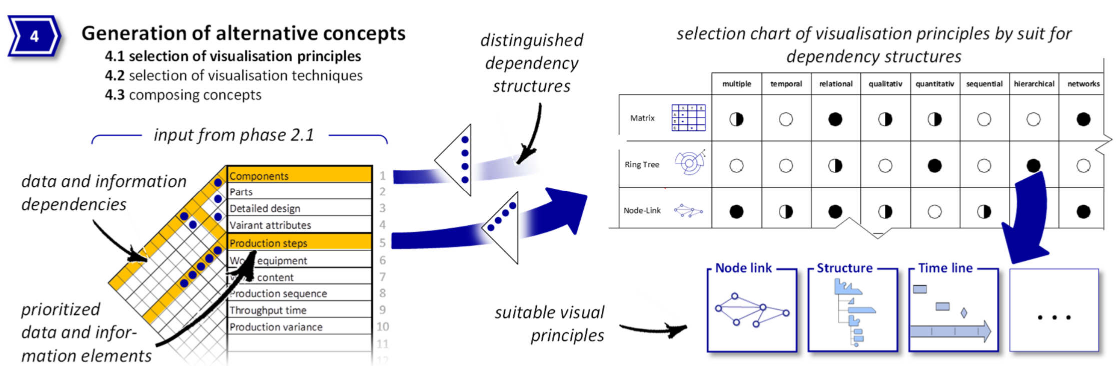

Figure 9. Selection of suitable visualisation principles

Phase Four: generation of alternative concepts - step two: choosing visual techniques

Visual techniques are the exact visual encoding of data and information (Section 2.1). Their selection depends on the type of data or information, expected amounts and certainty, as well as user visual conventions. A handbook supports the choice of suitable visual techniques according to their

appropriateness to data and information types and volumes. The aspect of meeting user visual conventions is taken into account by comparison with the everyday working environments of the target user group recorded in Phase Two.
As shown in Figure 10 (left) in the case of Lutz Elevators, visual encoding of data and information is based on input from Phase 2. Selection is supported by a solution table that lists possible visualisation techniques and their appropriateness for data and information types and their volumes (Figure 10, right).

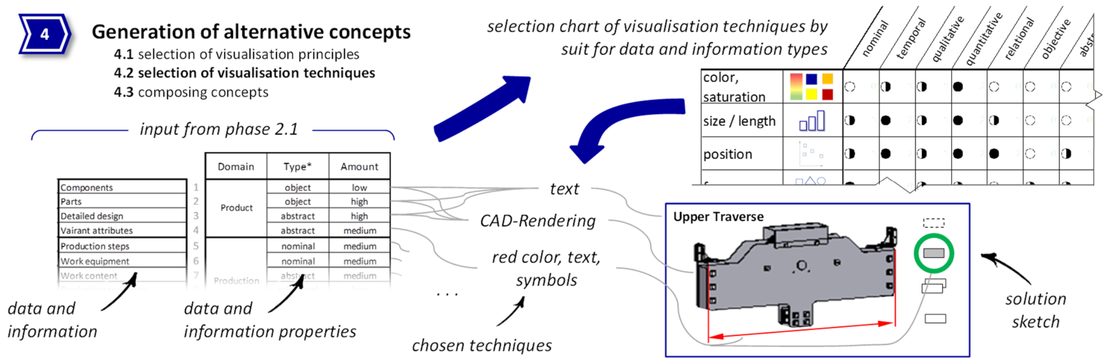

Figure 10. Selection of suitable visualisation techniques for data and information

Phase four: generation of alternative concepts - step three: composing concepts

Alternative visualisation concepts can be composed using the pre-selected visual principles and techniques from Steps 4.1 and 4.2 as a morphological set of possible partial solutions. When combining principles and techniques, suitable principles are first sketched. Secondly, the principles chosen are completed by adding visual techniques for detailed data and information encoding, leading to one or more complete visualisation concepts (e.g. Figure 11).
In the case of Lutz Elevators, two alternative concepts were developed, one being primarily oriented on product structure, the other on production sequence (Figure 11). During this step of the method, both concepts for visualising the necessary data and information seemed promising (although contradicting) and were therefore tested.

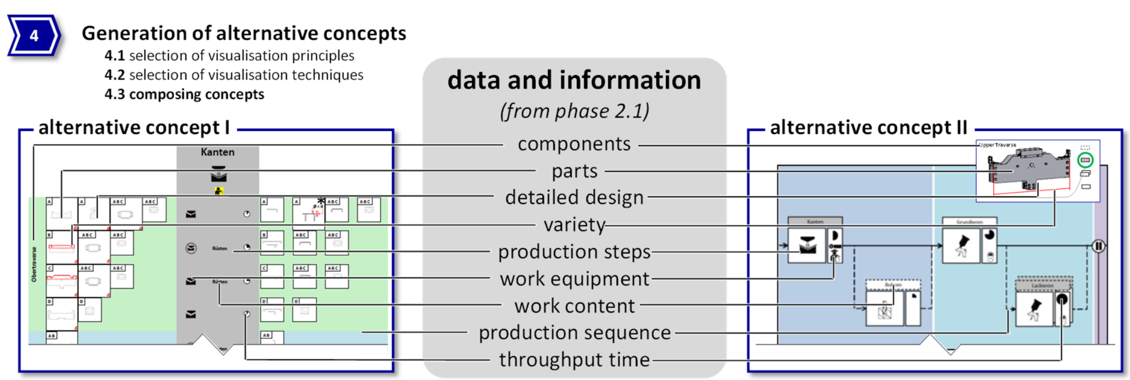

Figure 11. Alternative visualisation concepts from the application case

Phase five: testing and finalisation

It is most likely that more than one alternative visualisation concept will result from Phase Four. Thus, a testing scheme was composed to facilitate evaluation and final selection (Figure 12). It supports the testing of the main evaluation criteria proposed in literature. Observation, interviews and analysis of the results documents are used for data acquisition and supported by spreadsheets and schedules.
In the application case, evaluation found that the preferred approach was "concept II", with some minor need for improvement. Some favourable visualisation techniques could be adopted from "alternative I". The final concept had been prepared by application instructions, and pre-printed posters and cards

(Figure 12). After an oral presentation to the users, the case was evaluated using the scheme described in Section 5.1.

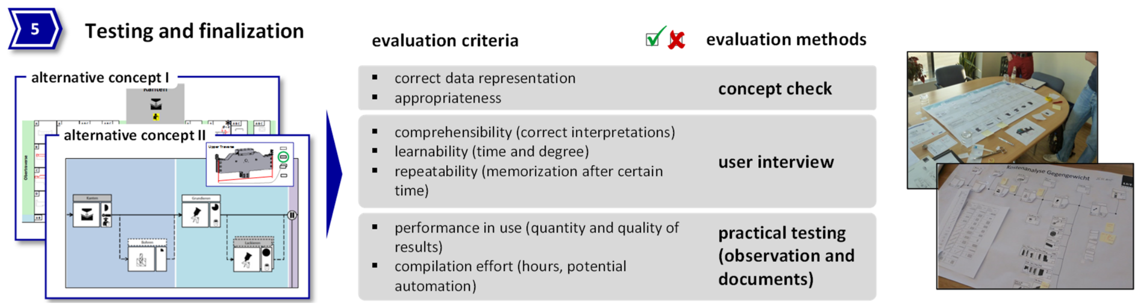

Figure 12. Evaluation of the final visualisation concept at Lutz Elevators

5. Analysis of the application case

5.1 Success indicators and their measurement

In the case study, the aim was to support the product developer and production manager to identify possible production cost reductions in the new module using a visualisation concept. This represents a suitable evaluation case. Furthermore, this aim was in strong focus of both management and users, which was interpreted as beneficial to the suitability of the case since more thorough testing and feedback was expected. The development of the visualisation was undertaken as part of the joint research project by an engineering student under the authors' supervision, fostering neutrality during the methodical procedure.

The indicators of success were identified cost reductions and overall work load. The user's way of using the visualisation as a tool and use of other supports, tools and techniques were observed to assess possible disturbances to the case study. An uninvolved observer performed data collection, result document analysis and supplementary interviews. Observations included working procedures, oral statements on the module and production design, and the visual tool, as well as actions taken with the visual concept. Supplementary interviews covered overall success estimation, understanding of the visualisation concept, estimation of support provided by the visualisation concept as a tool in the process, and estimation by the users of expected results without the support of the new visualisation concept and suggestions for improvement.

5.2 Results of the case analysis and conclusions

In a two-hour meeting, the module designer and production manager were able to identify major cost reductions. It required 30 minutes each in preparation and all visualisation efforts had been included in preparation or the meeting. A major part of the improvements were described as not likely to have been otherwise identified. Observations by an uninvolved person indicated correct use of the visual concept, apart from minor mistakes, which were judged as non-critical. The visualisation concept was well received as a tool and is still used in the company today.

The Method for Designing Visualisations as Tools in Product Development had good applicability and good performance of the resulting visualisation concepts (only the latter was presented here). This paper points towards a possible way of Designing Visualisations as Product Development Tools within a single consistent method; the approach presented proved to be an applicable and effective solution in the presented case. Evaluation involved one company: developing visualisation concepts as product development tools was not tested generally. However, presentation to product developers from other companies garnered positive feedback.

6. Summary and outlook

Visualisations can be very supportive tools in product development. The simple visual design of arranging and encoding data and information has a huge impact on the performance of visualisations as product development tools. The "Method for Designing Visualisations as Product Development Tools" presented in this paper provides aggregated knowledge and an applicable procedure for designing visualisation concepts as tools. It consists of pre-readings, a five-phase procedure and several selection tables that make all genuine visualisation principles and techniques applicable. An application case in a medium-sized elevator production company demonstrated the applicability and effectiveness of the methodical approach. Further tests are currently being undertaken in companies to improve the procedure in the future, particularly with the addition of further visualisation solutions.

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