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Product Modeling Tools: Approach to a targeted Application in User-Centered Product Design

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Abstract

Since the focus on the user is becoming increasingly important, the requirements on product modeling tools to design user centered products increase in equal measure. The range of applicable tools is vast. However, the selection of appropriate tools is challenging and depends on a variety of interacting factors that have to be considered.
In this paper, an approach to categorize and describe tools of Industrial Design Engineering based on the tasks and models in the design process is presented, aiming at optimizing the specific application in the design process and thus increasing effectivity and efficiency. The potential tools, identified by an extensive research, are initially clustered regarding the essential work on the model (shaping, visualization and transfer). Additionally, for a further categorization, the tools are described by means of parameters according to their characteristics. For a higher-level assignment between tools, models, users and tasks in the design process an evaluation of the tools by use of defined requirements is necessary. Therefore, a study was conducted to investigate the evaluation, exemplarily on 3D modeling tools (Clay Modeling and Polygon Modeling). At first, design processes using those tools were defined in order to derive criteria as basis for the evaluation. Secondly, the visualization and the informative content of the product models with regard to the later product properties were evaluated by conducting a survey with 25 subjects.
The results of the study confirm the strong and weak points of the examined modeling tools in relation to the work on the product model in the design process. Considerable differences between the defined tools were observed in terms of complexity of the creation and adaptation process, which can lead to insufficient results by an incorrect application. In addition, the user with his prior knowledge and experience is crucial concerning the perception of the product model and thus the evaluability of the later product characteristics. The developed categorization and evaluation of the modeling tools and the product models provide a good groundwork to reach a targeted application of tools based on the tasks in the design process, the development objectives and environment, as well as the abilities and needs of the user.

Keywords: Design Methods, Industrial Design Engineering, User Centered Design, Design Tools, Product Modeling, Prototyping

1 Introduction

During the early stages of product development, the shape of user-centered technical products is significantly influenced by the interdisciplinary work of Industrial Design Engineering (IDE) (Seeger, 2005). The resulting, partly conflicting requirements of engineering, design and ergonomics have to be implemented in the best possible way. This is often done using abstracted product models (Lindemann, 2009). Therefore, an undefined variety of potential tools of different areas can be applied. As the focus on the user is becoming increasingly important (Pahl et al., 2007) in product design and additionally, tools influence the efficiency of designing significantly (Lutters et al., 2014), there is a great potential for a targeted coaction of tools, models and tasks in the design process. However, regarding a holistic approach of IDE tools in terms of product models and tasks in the design process, current research is limited. Often the mainly technical development process based on an integrated product model is considered (Ehrlenspiel & Meerkamm, 2017). However, in this case, the consistent product model is a limiting factor regarding a targeted and optimized shaping. Other studies focus on tools of a specific field of application regarding their particular work (Self et al., 2009; Stolterman et al., 2008), without considering the interdisciplinary work sufficiently.

In this paper, an approach to categorize and describe tools based on the tasks and models in the design process is presented, aiming at optimizing the specific application in the design process and thus increasing effectivity and efficiency.

Therefore, a study consisting of two parts was conducted. The first part focuses on the modeling process itself to characterize modeling tools. The second part is a subject based study to explore the need of different models to define and evaluate the later product properties according to the product sub-gestalts named assembly, shape, surface/color and graphic by Seeger (2005). This has led to the following hypotheses:

H1: Physical models are necessary for ergonomic investigations regarding the assembly of a product gestalt.

H2: To judge the later properties of a product regarding the sub-gestalt shape, physical models are more suitable than images.

H3: For an appropriate evaluation of surfaces and colors an elaborated model, like a rendering is necessary.

2 Process, models and tools of Industrial Design Engineering

The coaction of models, tools and tasks of the process is a key factor for an effective and efficient product development (Bryden, 2014; Lutters et al., 2014). The tasks of the process depend on a variety of factors, for example the goal of development, the extent of the process, the product itself, the amount of product design, the product categories or the availability of tools (VDI 2221, 1993). When it comes to a user centered design of products, as it is described by Seeger (2005), a variety of different influence factors by the fields of engineering, ergonomics and industrial design have to be considered in addition. Each of these areas has their own processes and special tools. The consolidation of them is a tough challenge for Industrial Design Engineering (IDE). As the different interpretation of terminologies in this field of activity is an issue in research and application-related considerations and this paper is a basis for further investigations, an assignment and definition of the examined aspects have to be done. This work focuses on IDE defined as a development of products regarding a holistic consideration of Engineering Design, Industrial Design and Ergonomic Design. The relevant aspects of IDE are described in the following sections.

2.1 Industrial Design Engineering process

The underlying process of this paper is the design process by Seeger (2005). In focus of this process is the product gestalt, which has to be detailed from abstract to concrete. The product gestalt is a three-dimensional and material structure, composed of the sub-gestalts assembly, shape, surface/color and graphics. The three-dimensional assembly elements of a gestalt are the function gestalt, the interface gestalt and the structure gestalt. This definition is essential for the further considerations of this paper. The designing of the product gestalt arises in interaction with humans. The user of the product sets up requirements regarding the visibility and perceptibility (VP) as well as on operation and use (OU), also referred to as human-product-requirements, which have to be taken into account when developing user-centered products. The described interrelations point out the importance of different product models to iteratively design the product gestalt.

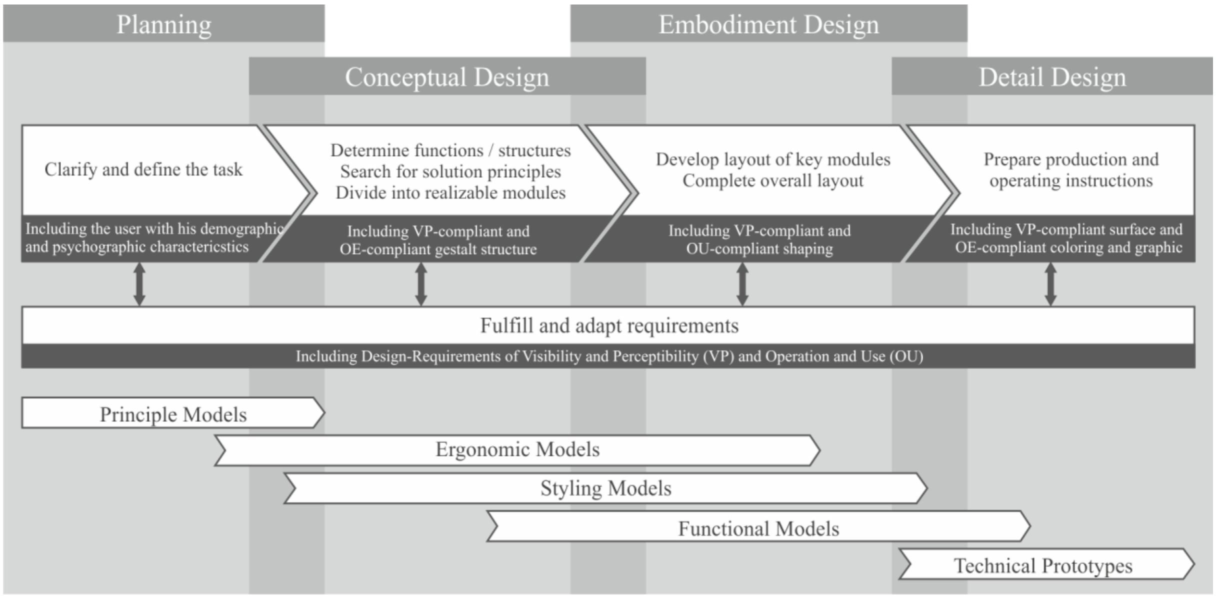

Figure 1. Design Process of Industrial Design Engineering

Figure 1 shows the development process according to VDI 2221 (1993), supplemented by the aspects of IDE (Seeger, 2005) and the corresponding product models. In the following, these product models will be discussed in detail.

2.2 Models within the IDE process

According to literature, there are different definitions for product models in engineering and design research. The understanding of product models differs not only in content and scope of requirements but also in terms of their application. Basically, the definitions of a product model can be separated into two classes (Kohn, 2014):

- Abstracted figure of a product or its properties (Ponn & Lindemann, 2011)
- Integrated product model – entirety of all product information generated in the product development process (Grabowski et al., 1993)

Models in the sense of the first definition are material or immaterial constructs (e.g. models of intuition, prototypes, construction drawings, circuit diagrams, but also models of thought or mental models, ideas, images, etc.) created to represent a product or its properties for a particular purpose. Models can thus be understood as simplified illustrations or reproductions of originals (Vajna et al., 2009). According to the second definition, the product model summarizes all product data from all phases of the product life cycle in a unified data model and results from the integration of application-specific product models (Grabowski et al., 1993). Considering the process described above and the importance of models to define the product gestalt, this work focuses on the first definition, as an integrated product model would constrict the shaping process especially within the early stages. A great part of design specification is made in the early stages of development (Seeger, 2005), both from a formal aesthetical and a functional ergonomic point of view based on the product model in its entire range, from the form of representation above the purpose of evaluation to the level of detail. The key factor is to use the corresponding model for a particular task, created by a suitable tool.

2.3 Product Modeling Tools

The conducted research points out, that there are many investigations about design tools in general as well as their application. But similar to product models, there is a variety of different directions of investigation. This affects among others the technologies of tools, their (interdisciplinary) application or the positioning within the design process. Common to the considered approaches is that they either operate at a completely abstract level without making concrete specifications for different product models and process tasks or focus on a single tool, such as additive manufacturing, virtual reality or prototyping, without pursuing a superordinate strategy to link the different technologies. For example, as one side pushes forward the digitalization of tools (Bjoerkli, 2014; Rademacher, 2014), the other side focuses on physical prototyping (Isa et al., 2015; Menold et al., 2017). However, these works are substantial for an understanding and characterization of the technologies. In addition, there are studies which are primarily limited to the tools of one area, like Industrial Design (Biahmou Tchebetchou, 2005; Self, 2011; Stolterman et al., 2008). A holistic view of IDE with its models, subtasks and the tools available for it does not exist. Another issue that arises is the definitions of tools, technologies, methods and approaches. Product models, methods and tools are directly linked to each other. Tools support the application of methods to generate product models (Ponn & Lindemann, 2011). In literature approaches from the classical engineering theory frequently address also methods in addition to the tools defined here (Araujo, 2001; Lutters et al., 2014; Nieberding, 2010). The focus is usually on the data handling of the entire development process, but not on the specific development of the product shape in its full complexity, as it comes to bear in the holistic view, where functional, ergonomic and styling aspects have to be considered. In this context, this paper focuses on tools meant as utilities to generate and visualize the gestalt of the later product carried out on a product model as a representative. These tools focus on the work with product models in the early, creative phases of IDE considering engineering, ergonomic as well as styling aspects.

Indeed, a simple collection of tools available on the market is not very expedient for this purpose, as it could never claim to be complete or up to date, nor could it depict the complexity of the application in the design process and is therefore not intended in this work. Rather, an overview and assignment of possible tool technologies should be created based on the manifold tasks and models in the design process. To be able to choose a suitable tool or to set up a tool-combination, it is necessary to have a detailed knowledge of both the requirements placed on the tool (input) and the capabilities of the corresponding tools (output). Therefore, to create a meaningful assignment to the tasks of the product design process, firstly an overview of available basic tool technologies has to be established, which characterizes them by their functional specifications. In the following a first approach is presented.

3 Methodical approach of tool characterization

This approach pursues the aim to achieve a targeted assignment of tools, models and tasks of the design process. Therefore, a basic understanding of these three aspects is necessary, as described above. To make a decision about tools and models, the different perspectives have to be considered. On the one hand the defined process sets up requirements about the tasks which have to be done. This is crucial for the choice of the corresponding model. To achieve the required result, there is not just one appropriate tool for it, but a range of different possibilities. Therefore, it is an interaction of different constraints e.g. task-/process-based, economic-based, user-based and function-based factors. The requirements often influence each other e.g. the factor of time is depending on the aim of the development task as well as the skills and preferences of the user, which makes it impossible to establish an one and only general rating of tools. On the other side of these requirements are the tools with their specific characteristics, which can match or mismatch in many ways. Figure 2 shows this coaction with its influencing factors.

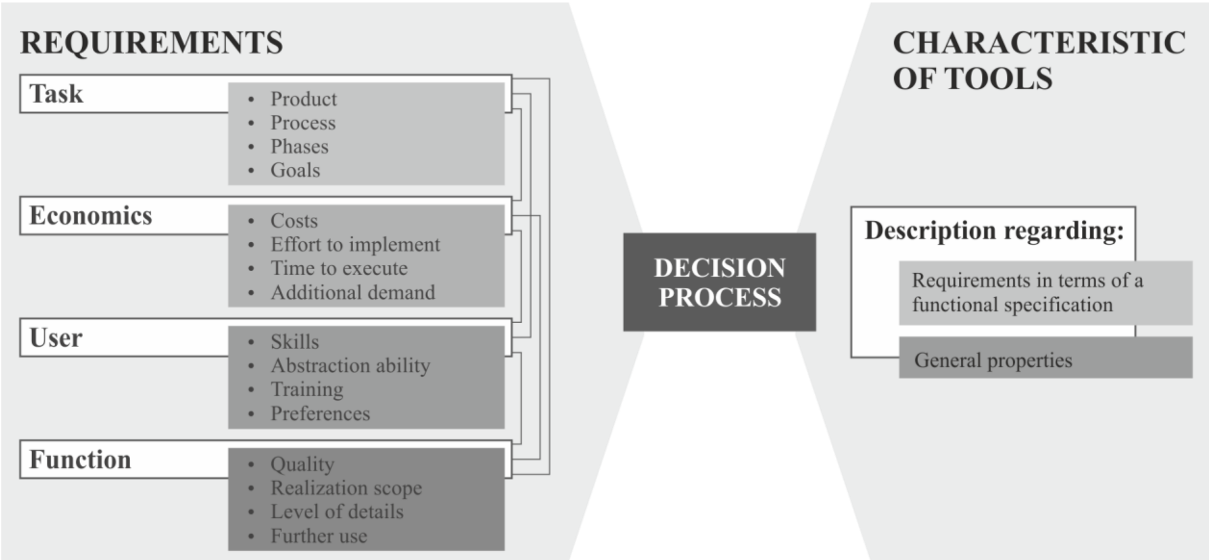

Figure 2. Coaction of requirements and tool characteristic

To achieve a targeted coaction of tasks, tools and models a characterization in terms of a functional specification of the tools based on the requirements is necessary and pursued in this work. In a first step, tools of engineering, ergonomics, industrial design and other related areas were collected by an extensive research and abstracted to their basic technologies. This is done by a classification on different levels. The basic idea of this approach is the work on the product model with respect to the tasks of the development process. Considering this idea, the work on the model can be categorized into two main aspects, named shaping and visualization. This is the elementary work on the product model. The one side (input) concerns the shaping of the product model, which is the active part of designing. To evaluate the done work it is indispensable to visualize the product model. Depending on the kind of evaluation, e.g. ergonomic or functional appraisal, different forms of visualization or in other words models can be necessary. Depending on the environment of development (physical or virtual) a transfer between these two worlds is necessary, which is also conducted by the use of specific tools. This is how the triangle of essential work on the product model is built up, as shown in Figure 3. The basis of this triangle is always the product model with its sub-gestalts and assembly elements on which the whole work is done.

This triangle is also the first clustering level of the tools to define their characteristics. On a second level the tools are clustered according to their type (software and hardware), the characterizations of the underlying model which they initially use (virtual, physical or hybrid), their dimension (2D or 3D) as well as the different basis technologies of the tool. An overview of the considered tools and their classification is shown in Figure 4.

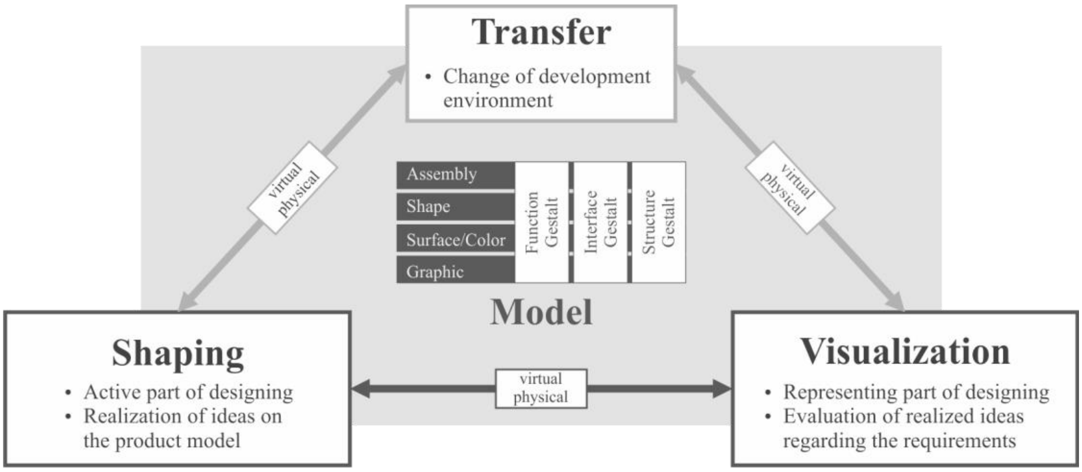

Figure 3. Triangle of essential work on the product model

The advantage of this classification is the possibility to extend it with new tools and tool technologies, thus it does not claim to be complete at this point. This classification is the basis for a further functional specification of the considered tools regarding the described requirements to build up suitable tool combinations for the desired task according to the triangle of work on the model. To be able to integrate the tools into the product development process in the right place and in the right combination, it is necessary to evaluate the tools regarding to their functional specification deducted from the criteria shown in Figure 2.

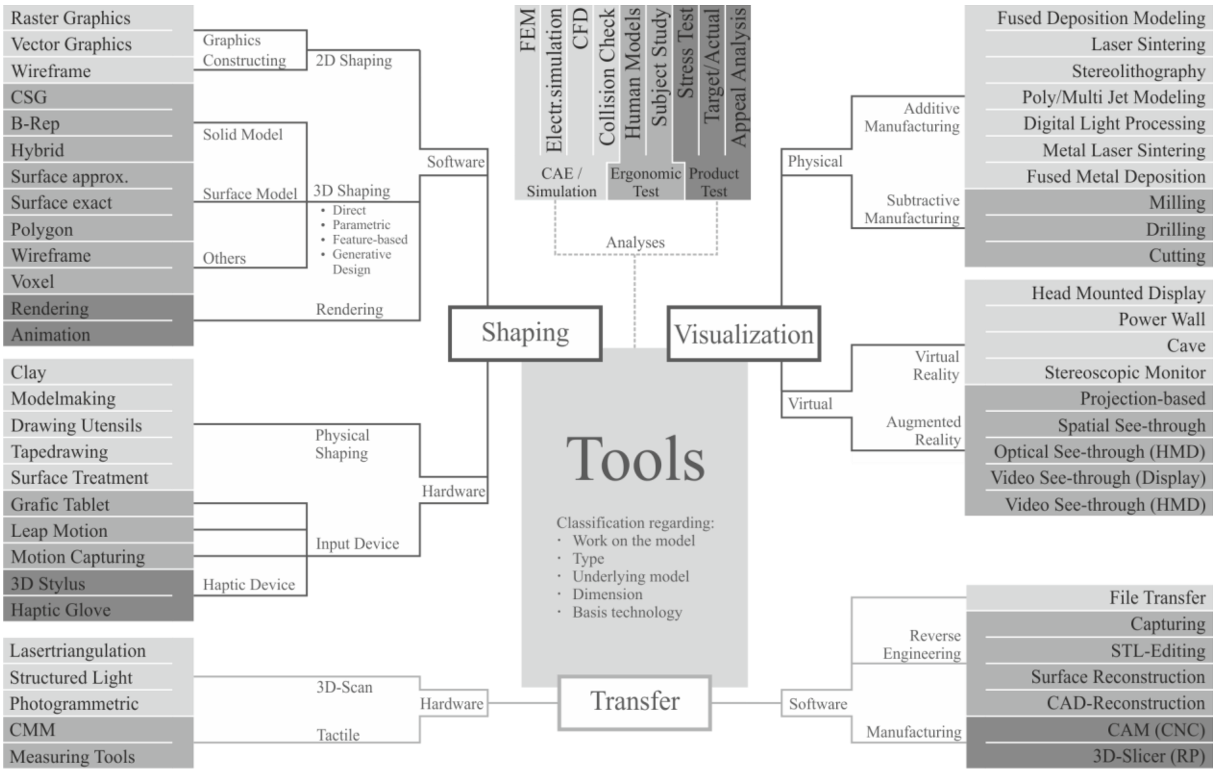

Figure 4. Classification of relevant tools

Using the section of shaping, the following study analyzes exemplarily the possible use of polygon modeling in comparison to physical modeling with clay to deduce a characterization.

4 Investigation on Clay- and Polygon-Modeling

An essential point regarding the assignment of tools to tasks and models in the process is the extensive knowledge of the possibilities and capabilities of tools. In accordance with the approach described above, a study was conducted to identify the differences and characteristics of digital and physical modeling as well as the represented models. Especially in the early stages of development with their high degree of freedom regarding specific dimensional and shaping requirements, conventional tools have so far led to problems. Above all, typical CAD systems have limitations due to their proceeding of model making, especially in the case of complex surfaces that are ergonomically or aesthetically driven (Vajna et al., 2009). Polygon-Modeling (PM), which is often used in character design, is characterized by organic forms and offers many possibilities to realize ideas easily and quickly, without paying any attention to restrictions like dimensions (Bryden, 2014). Thereby, it is in competition with Clay-Modeling (CM), which enables rapid and direct modeling of organic and anthropomorphic forms, too. An essential aspect of modeling in the early form-finding stages of development is the perception and assessment of the models. For this reason, not only modeling requirements, application and integration were considered in the study, but also requirements for the perception of the various possible presentation forms of the models. The study evaluating the modeling tools is divided into two parts. On the one hand, modeling is carried out on example products of user-centered design based on the process of IDE to characterize the tools according to defined criteria. The second part of the study focuses on the perception of possible models arising in this process (Polygon-Model, Rendering, Rapid-Prototyping (RP) Model and Clay-Model). For this purpose, a study was carried out with 25 subjects, questioning the requirements for models relevant to the design (Speer, 2017).

4.1 Characterization and evaluation of the modeling techniques

Based on the approach in Chapter 3, this evaluation focuses firstly on the functional aspects of the tool characterization. As the other aspect strongly depends on the environment and its restrictions in which the tools will be used later, they are not considered at this point. Therefore, generally oriented evaluation criteria for the procedure of modeling, which can be extended anytime, were defined, to describe the properties of the modeling tools. To achieve a targeted application to a specific development use case later, this description can for example be used in accordance to a requirement-based evaluation like the VDI 2225-3 (1998), by translating this description to a value using a rating scale. The criteria are clustered into the four categories usage, implementation, proceeding and further use, as shown in Table 1.

Due to the fact that CM can be seen as craftsmanship, the requirements to the user are much higher than to PM to achieve high-class results, although the realization of ideas is much more intuitive, because of its direct way of modeling. This is a relevant factor considering a time-based aspect. The creation of variants is more time-consuming in CM than in PM, since each model has to be built up from scratch. The advantage of CM is the possibility of realizing changes directly on the model and being able to examine and evaluate them immediately, both visual and haptic. But a further use of the generated model is tied to a comprehensive Reverse Engineering process. The modeling is restricted by filigree elements and very large components. In addition, the models have only limited dimensional stability under force. Overall, the procedure is intuitive and supports a natural approach of model creation.

Digital modeling based on a polygon mesh makes it easy to create any geometry of all major dimensions. Due to the possibility of easily duplicating digital data as well as reversing work steps, the method is particularly suitable for variant design. Another positive aspect is the small amount of time required for modeling and customization, as well as the opportunities to reuse the created model. Due to the process of PM, however, a direct haptic feedback is not possible. An ergonomic examination of the later product is in this case only possible with the help of human models, body dimension templates or other mathematical descriptions of the human body (Bullinger-Hoffmann & Mühlstedt, 2016) or by deducing physical models by means of Additive Manufacturing to evaluate haptic aspects. This would exemplarily be a tool-combination as mentioned in Chapter 3. A summarized and shortened characterization of CM and PM is shown in Table 1.

Table 1. Characterization of the product modeling tools Clay-Modeling and Polygon-Modeling

	Category	Criteria	Characterization	
			CM	PM
Function Modeling	**Usage**	Intuitivity	high intuitivity due to direct modeling first results easily and directly realizable	initial training for a software necessary simple results easily realizable via drag and drop
		Skills of the user / Learnability	craft skills required for high-class results (partly learnable)	learnability through training for prof. usage possible
		Degree of abstraction	direct realization of imagined shapes, no abstraction necessary	abstraction of desired results due to necessary application of addicted operations
		Evaluation (collateral)	simplified visual and haptic (without force effect) evaluation while modeling	simplified visual evaluation while modeling
	Implementation (scope)	Sub-gestalts	mainly suitable for shapes and surfaces assembly partly realizable	preferably suitable for assembly, shape and surface color and graphic simplified
		Assembly elements	structure not realizable due to stiffness reasons, function limited to aesthetic and ergonomic	all assembly elements realizable according to visualization, not functionality
		Accuracy	mainly conceptual quality (visual estimate) or additional demand	limited to conceptual quality (visual estimate / review difficult)
		Level of detail	high level of formal details possible / filigree limited	high level of formal details sharpness limited
		Geometry / Dimensions	increasing effort due to size / optimum hand-operated to car	no limitations regarding size
		Complexity (construction)	assemblies hardly possible only few parts	assemblies possible no limitations to parts
	Proceeding	Documentation	no documentation of operations and meta information	documentation of operations and meta information
		Deduction of variants	additional effort necessary (RE / Milling)	direct deduction of variants / copies
		Undo	no undo due to manual process	chronological undo
	Further use	Direct use	detailing, visualization and analyses based on physical model	detailing, visualization and analyses based on STL model
		Transfer	full Reverse Engineering necessary for further usage	reconstruction necessary due to limited further development of simple surface model

4.2 Subject study on the perception of product models

The aim of this study is to determine in which way each model reflects the characteristics of a later product and how well properties regarding the product gestalt from a IDE point of view can be evaluated by the model to choose a fitting visualization form for a particular analysis of the result. Based on the knowledge about the models and the tools a suitable combination according to the triangle in Figure 3 can be deducted to improve the process and shorten the required time.

4.2.1 Procedure

The study was conducted in terms of a presentation of models in a randomized order to the subjects. The models, as shown in Figure 5, were created in an exemplary execution of a design process as described above. In this case, a system camera was designed as a handheld user-centered device. After the presentation of a model, the assessability of different aspects were gathered by means of a questionnaire, which consisted of ten items with a five-level ordinal scale from bad to excellent. The items have been defined according to the sub-gestalts assembly, shape and surface/color as described in Chapter 2. The asked items are shown in Figure 5. (Speer, 2017)

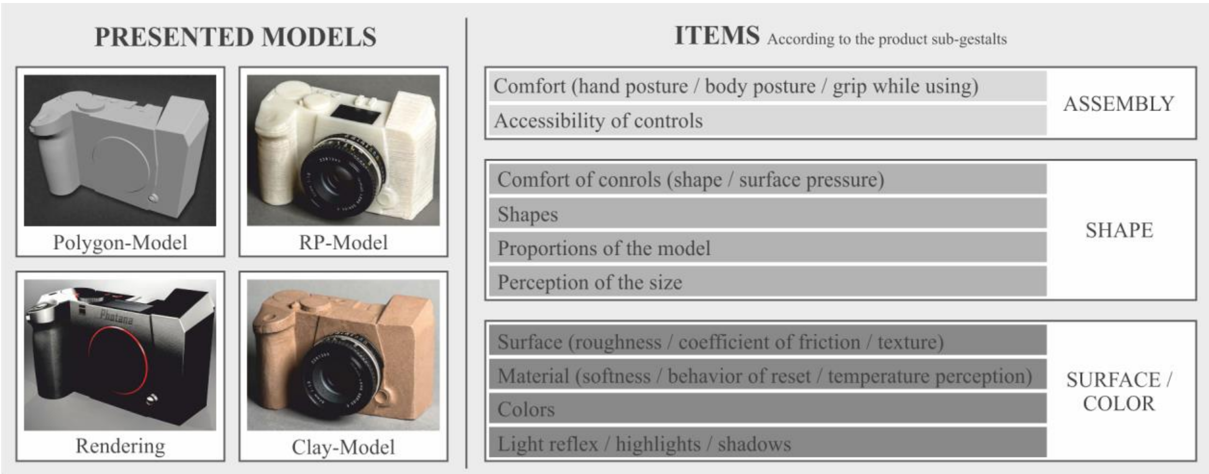

Figure 5. Presented models (on the left) and items (on the right) of the subject study, model images according to (Speer, 2017)

In order to obtain representative statements, the subjects were selected from the IDE environment at the university or with a technical background, so that they have knowledge of ergonomics and design either in general or in particular with regard to cameras. For the representativeness and the subsequent statistical evaluation with a manageable study effort, a sample size of more than 20 according to Raab-Steiner & Benesch (2008) was intended.

4.2.2 Results

Altogether 25 people were interviewed, with a range from 18 to 61 years as well as 48 % females and 52 % males. Of the respondents, 36 % had experience in using 3D graphics software before answering the questionnaire. 56 % of the volunteers wore glasses. One of the subjects (4 %) also had a visual impairment in form of a dyschromatopsia. There was no case of impairments on haptic perception. (Speer, 2017)

The examination of the results regarding significant pairings was done by the use of the Friedman test, a non-parametric test method, and a subsequent Bonferroni post hoc analysis. According to the results of the study in Figure 6, physical models are significantly ranked above virtual models in terms of judging the assembly properties of the later product like accessibility of controls and the overal comfort, which confirms hypothesis one. Considering the sub-gestalt shape of the later product, the results are not that unambiguous as the structural properties. There is a significant difference between the Polygon-Model and the RP-Model as well as the Clay-Model regarding the judgement of the comfort of controls. Also the proportions of the model and the perception of sizes is significantly ranked above virtual models by physical models. In total, hypothesis two can also be considered as confirmed therefore. When it comes to the surface and color properties of the later product, virtual models, in particular renderings are in advantage over physical prototypes due to the higher amount of detailing, which approves hypothesis three.

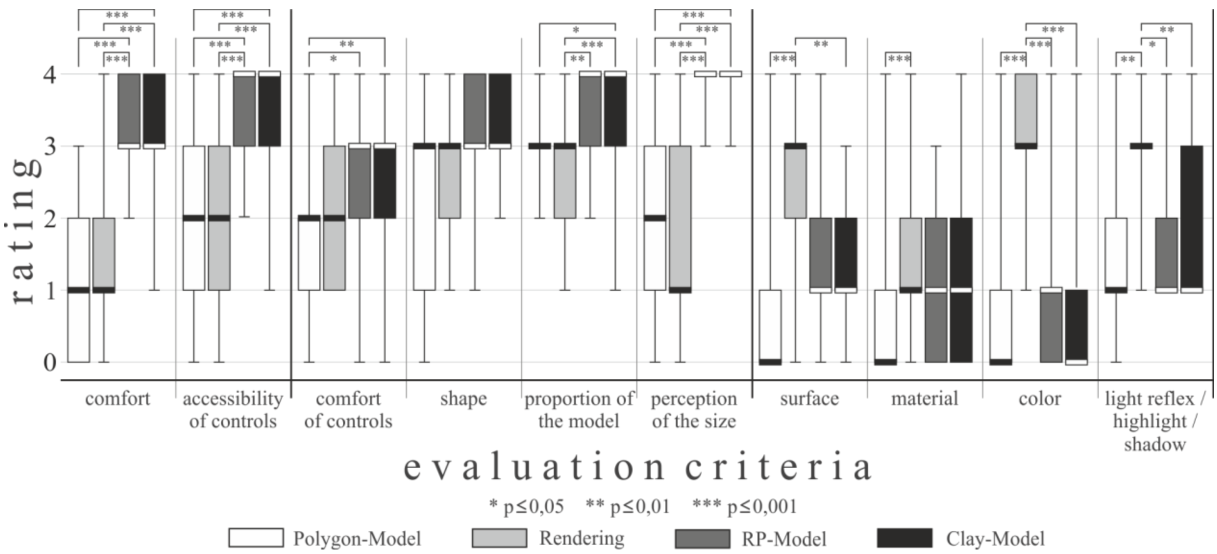

Figure 6. Results of the study

The executed study shows the differences and thereby the strong- and weak-points of the analyzed models concerning the assessability of the sub-gestalts of the later product. This is an elementary knowledge about the models to choose a suitable model- and tool-combination, deducted from the triangle in Figure 3, with regard to the task of the development process to increase effectiveness.

5 Conclusion

One of the main aspects concerning the design of products is the choice of a suitable tool or tool-combination for a particular task. Considering the differences of tools regarding visualization, shaping and transfer, the right choice is challenging. To achieve a targeted application of tools, models and task a fundamental knowledge of these three aspects is necessary. The presented approach in Chapter 3 is a first attempt to build up a basis therefore. As it is not expedient creating endless lists of possible tools, which can never be complete anyway, with the aim to find the one and right tool, this approach pursues the concept of abstracting the tools to their basic technologies with the possibility to extend it with new ones and characterize them by the functions regarding the models and the tasks of the development process in user-centered design, also referred to as IDE. With this basis, a methodology will be achieved, focused on the user with his skills and preferences to choose appropriate tools and in particular combination of tools to fulfill the postulated task of development. Through this knowledge it is possible to arise effectiveness and efficiency by choosing the suitable tools and models for the desired task, as there are big differences when it comes to the assessment of properties of the later product with the aid of the different models on the one hand, as well as to the capabilities of the tools on the other hand, which was shown by the conducted study.

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