Product Models in Embodiment Design – an Investigation of Challenges and Possibilities

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Abstract
In product development, many different models of the product and the development process exist. These models are used for different tasks according to the phases of product development. A phase, in which product models play an essential role, is the embodiment design phase. The product is defined under consideration of requirements and boundaries of the development task. Finding a suitable model for a task can be challenging, as by now many different models are available. The aim of this contribution is to develop a support for selection of a suitable model for a task in embodiment design. Criteria from other model structuring approaches described in literature are used. The considered product models are identified in a systematic literature review with the focus on currently used product models in embodiment design practice and research. The developed support consists of a framework for structuring the models according to purpose and engineering phase and a table for structuring according to model properties. A guideline on how to identify suitable models by using the framework and the table for tasks in embodiment design is given.

Keywords
Product development, Embodiment design, Product model, Design research

1 Introduction

The usage of models in product development is mandatory, since the original product doesn't exist until the development is finished. Product developers have to use many different models to fulfil their tasks. In this contribution, the basic understanding of a model follows the definition of Andreasen et al., who describes models as a depiction of an object or phenomenon with similar properties (2015). Models used in product development can be differentiated into models of the *product* and models of *processes*. Models of processes often have methodological character and are investigated and improved through research. Examples for these models are the VDI2221 (2018), the "Münchner Vorgehensmodell" MVM (Lindemann 2009), the "Autogenetic Design Theory" (Vajna et al. 2005) or the "integrated Product engineering Model" (iPeM) (Albers et al. 2016). A structured overview over these models is given by Wynn and Clarkson (2018), who categorize models of the design and development process in a framework based on scope and type of the process model.

Models of the product on the other hand are mostly tool-based and the methods for using them, if they exist at all, focus on how to use the tool (for example CAD, Multibody simulation etc.). Ehrlenspiel and Meerkamm show, that many different models with different levels of abstraction, perspectives and representation mode exist to describe products in development. Model building enables the reduction towards the essential (2017) and is therefore necessary for successful embodiment design.

A wide variety of these product models is used in the phase of embodiment design, as many different aspects of the product have to be taken into consideration. The embodiment design comprises the "concept phase" and "design phase" and ends with the final definition of the documentation of the manufacturable product according to (Matthiesen 2019 in print). Here, the design engineers define a product embodiment that is supposed to fulfill the functional requirements defined for the product under boundary conditions like the production costs and legal requirements. They create mental product models of how they think a products embodiment has to be defined to fulfil its functions. Experienced design engineers are often able to build up powerful mental models of the product (Meboldt et al. 2012), that support them in fulfilling the tasks necessary to define the embodiment. From these mental models, explicit models like sketches, prototypes, FEM-Simulation models and many others are derived. These models are used as tools and documentation of the design results (Andreasen et al. 2015). However, much of the knowledge contained in the mental models remains implicit, as it is not needed to complete the explicit model. For example, many of the thoughts of a design engineer while defining a CAD-model are not documented there, as it is only necessary to define parameters and not to give a reason why they are defined this way. When a model is built up, it can also happen that gained insights are not integrated into the explicit model as their documentation is not supported. For example, when the influence of a tolerance width is investigated, the identified tolerance that has to be maintained in manufacturing can be documented in the product model "technical drawing". The insight, why this tolerance was chosen remains implicit as it is not important for manufacturing and the product model contains no element for storage of this information. The necessity to support the thought processes of design engineers has been described by Matthiesen (2011) One way to support these processes is to provide suitable models that enable design engineers to explicate their knowledge and insights. These models have to contain suitable elements to express the mental model. When no suitable model is present or known, new models are developed in research organizations and companies. However, these models often are insular solutions, as it remains unclear whether suitable models already exist and where connectivity might be possible. Differentiation is necessary to identify suitable models from the pool of already existing models. Andreasen et al. show the possibility of differentiation of models in product development according to their purpose (2015). Fuchs differentiated models in product development according to their content, structure and purpose to support model selection in

problem solving processes (Fuchs 2005). For process models, Wynn and Clarkson created a framework where researchers can position their models and practitioners can gain an overview over these models (2018). For product models in the field of mechatronic design, Weidmann et al. conducted a study on industry relevant product models and compared the overlapping usage in the involved disciplines mechanical, electrical and software engineering in mechatronic product development (2017). It can be seen that research on model structuring approaches is already done in product development. In embodiment design however, a structure that enables an overview and clusters product models is still missing. For design engineers, the challenge emerging from this is finding a suitable model from the plethora of existing product models in embodiment design. This challenge contains three sub-challenges: Many different models exist, it remains unknown how they differentiate and for which application they are suitable.

The research questions derived from these challenges are:

Research question 1: Which models exist in embodiment design?
Research question 2: How do they differentiate?
Research question 3: For which purpose and situation in embodiment design can they be used?

The aim of this paper is to develop a support for selection of a suitable model for a task in embodiment design. The development is based on a systematic literature research to find existing product models in embodiment design. These models are structured by using categories derived from prior research in the field of modeling. The results are combined in a guideline to provide a structured approach on product model selection for practitioners in embodiment design.

2 Materials and Methods

The research was conducted using a systematic literature research approach to investigate the research questions. The results are processed and assigned to categories based on studies by Weidmann et al. (2017) and Wynn and Clarkson (2018) to differentiate product models in design engineering. In the following subsections the used methods and materials are described in further detail.

2.1 Systematic Literature Research

The systematic literature research is based on the method by Dresch et al. (2015). The overview of this literature research is depicted in Figure 1.

Fig. 1 Structure of the research methodology based on Dresch et al. (2015)

The flow diagram of the literature review defines the activities during the research. First step of the systematic literature review is the *question definition and mindset*. The research question defines the scope of the investigation as well as its depth and breadth. The derivation of the research question for this contribution is described in the introduction. According to the mindset, the subject area in which the research questions take place is restricted to the

relevant topics. In this case, the subject area is defined as embodiment design which is described in the introduction as well.

The *research strategy* includes the search terms and the sources that are considered. For the research the following terms have been used, based on the understanding of embodiment design and activities in embodiment design described by Pahl et al. (2007) and Matthiesen (2019 in print): *embodiment design, product model, embodiment function relation, function model*, system* modeling, embodiment design AND model, embodiment design AND analysis, embodiment design AND synthesis.* The search terms were used in open access databases as well as in databases with restricted access. The used databases were *Researchgate, Scopus, TEMA, IEEE, ASME digital collection, Web of Science* and *google scholar.* The software citavi 6 (www.citavi.com) served as a documentation platform for the found articles and literatures.

The publications found in the *Research* are further processed based on their *Eligibility*. Duplicate articles are automatically identified through their citation data. The initial criteria for the inclusion in the citavi project are:

1. Published after 2008, as models that have been mentioned in the last 10 years are considered relevant for present product modelling.
2. Published in the field of design engineering, as only this area is of interest for the research.
3. Published in English, as models that are published on international platforms are considered relevant for international researchers and design engineers.

To fit the initial criteria filters of the used databases were applied. The result over all databases and search terms are 1.093 source titles. To evaluate the eligibility of the publications the following inclusion criteria are formulated for the initial screening of title and abstract. The publications are included if they fulfill all of the following criteria:

1. Mentioning of a model or modeling process in the abstract and/or title
2. Context of embodiment design is indicated through key words

Out of this screening process remained 140 papers for the full text analysis. For this analysis additional inclusion criteria were added:

1. The described model is a product model
2. The type of depiction and the type of information provided by the model are described in the paper
3. The quality minimum for the publications to be included is publishing in a peer-reviewed journal or conference.

The result of the full text analysis phase is the pool of 48 publications for the result table (see Figure 1). The result table for the product models was derived by further processing them in the differentiation according to the identified criteria for structuring product models described in section 0. The synthesis of results is done in form of the differentiation of the product models that is presented in section 3.1.

2.2 Building the Product Model Framework

As basic structure, the framework for design and development process (DDP) models by Wynn and Clarkson (2018) is used. This framework gives an overview on the levels and varieties of process models for product development. It contains the dimensions of model scope and model type that are differentiated into more detailed categories (Wynn and Clarkson 2018), S.164. Models for products and product development processes show certain similarities, as they can be categorized in a common framework (compare Fuchs (2005)). He distinguishes product and process models according to the categories of content-wise orientation, structural orientation and purpose. The scope dimension of the framework for product models is based on the "engineering phase" of Weidmann et al. (2017). It is further differentiated and limited to "concept" and "design", as the framework structures product models in the phase of embodiment design. To fill the "model type" dimension with appropriate criteria for product

models, the dimension of "model application" from Andreasen et al. (2015) is used, which differentiates product models according to their application and enables the evaluation of their purpose.

2.3 Product Model Differentiation

The method to differentiate the product models is based on similar work on model categorization. Weidmann et al. (2017) categorize product models for mechatronic design according to discipline, type of depiction, engineering phase and type of information. These categories are used to structure the research results in detail and give an overview of their focus and range. From this approach, the categories to differentiate the product models used in embodiment design are derived. The template of the table of product models with the categories is shown in Table 1**.** A description of the categories is given in the following subsection.

Table 1 Template of the table of product models

#	**Product Model** (Source)	**Type of depiction**					**Type of information**			
		Analytical	Graphical	Table/Matrix	Textual	Physical	Function	Behavior	Embodiment qualitative	Embodiment quantitative
	Example model									

2.3.1 Type of Depiction

The type of depiction for the models was defined in the same way (Weidmann et al. 2017) differentiated product models in mechatronic design. They distinguished between analytical, graphical, table/matrix, textual and physical representations of the product. Analytical representations are solvable mathematical representations or program code. Graphical representations contain visual depictions close to the real product as well as symbolic and simplified depictions. Table/matrix summarizes the representations using categories to structure the model. The structure has to be defined as well as the way to get the input, e.g. an analysis method. Depiction in textual form means any kind of prose and a physical depiction means a physical model, e.g. a prototype.

2.3.2 Type of Information

The four categories of information are function, behavior, embodiment qualitative and embodiment quantitative. They are based on Weidmann et al. (2017) and adapted to embodiment design using more detailed categories from Pahl/Beitz (Matthiesen 2019 in print). The basic terms function and behavior are used according to (Gero and Kannengiesser 2014). The category of *function* describes the teleological aspect of a system. It describes the purpose of a system and is not necessary dependent on its embodiment. The category of *behavior* contains a description of what the system does. The behavior is directly dependent on its embodiment. In embodiment design, it is important to differentiate qualitative and quantitative embodiment. The categories of embodiment extend the definition of structure by Gero and Kannengiesser, who describe it as "what the artefact consists of" (2014). The differentiation of *quantitative* or *qualitative* embodiment is necessary to differentiate models for concept and design phases. The information has to include values of parameters to be considered as a quantitative embodiment representation. The specification of components or description of

parameters without assigned values as necessary part of the model is marked as qualitative representation.

2.4 Derivation of the Guideline

Since neither the framework nor the differentiation in the table provide a structured approach or give enough information on how to select a product model the guideline is derived. Goal of the guideline is to methodically support the decision process during model selection and provide the needed information through utilization of the framework and model differentiation.

3 Results

In this section the results of the literature review are presented. A framework based on the described dimensions of modeling purpose and engineering phase is derived and the identified models are integrated. For this, questions derived from Andreasen et al. (2015) were used. In addition, the models were assigned to categories from the table of product models. A guideline that connects the framework with the table of product models is presented.

3.1 The Product Model Framework

To derive the framework, information about the purpose of the models and the phase in which they can be used, is necessary. For that information, the engineering phase dimension of Weidmanns framework (2017) is used as well as the modeling application categories of Andreasen et al. (2015). The engineering phases according to Weidmann et al. (2017) are reduced to *design & concept* and *design*, because no model was identified that could only be used in concept phases. On the other hand, models that need a complete and/or quantitative representation of the product can only address the design phase because the concept has to be already defined. Models for the concept phase work as well for tasks in the design phase but can also depict an idea without the need for a reference product or the object of the design task itself for the model building process.

The five modelling application categories selected as dimension for the product model framework are *capture the unknown*, *define the design*, *communication*, *obtain insight* and *manage.* They are used to describe the key satiations to support the progression of the design process (Andreasen et al. 2015). *Capture the unknown* means that a model is used to explicate an idea or a mental model of the product. The externalization during the synthesis process is key to this feature of a model. These models can be used to evaluate the principle of the design. *Define the design* means that the model supports the process of product specification. This enables the designer to transfer the characteristics into the documentation for manufacturing or into other models. Models that aid in *communication* don't have closely defined specification. The core requirement is that the model supports the communication. This requires that the model is adequate for the object, the properties, the purpose and the receiver of the communication. Communication is not included in the framework, as all the identified models show aspects of communication and therefore it is not fit to differentiate models. Models that aid in *obtaining insight* enable the designer to further clarify the solution or to create knowledge about the relations between characteristics and properties without the production of a full-scale prototype. The last sub-category *manage* includes models that support the design processes. These models are used to give the design a structure including interaction, interfaces and dependencies of individual parts of the products. Concluding, models supporting management give an overview on the product as a system and enable the engineering team to define work packages or user stories. (Andreasen et al. 2015), S.44-51.

Models of the design process do not fall under this category and are not in the scope of this contribution. Of these five application categories only four are used for clustering the models since communication is a task that can be obtained by all model because it includes a depiction of the reality. A ranking of the ability to support communication is out of the scope of this contribution as this would require a differentiated view on the communication purpose and the

participants of the communication. Therefore, the category *communication* has been excluded from the framework.

In the built up framework, the cluster V (*capture the unknown / design*) is crossed out because the definition of *capture the unknown* and the understanding of models for design exclude the combination in one model. This leaves a total of seven clusters for the product models that are shown in Figure 2. The visualization of these clusters is chosen in similarity to the framework developed by Wynn and Clarkson (2018), which has proven value in presenting large amounts of information in a structured way. The assignment of a model to the cluster is based on the description and usage in the reference literature. For the product models that haven't been described but simply used in the literature (like FE-models) it is referred to standard textbooks like Vajna et al. (2018). The systematic approach for filling the framework is based on the following questions. First the engineering phase was assigned using two questions based on Weidmann et al. (2017) and Matthiesen (2019 in print), then the modelling application was tested using eight questions (two per area, based on Andreasen et al. (2015)):

Design or design & concept
    a. Does the model need quantitative knowledge about the dimensions and material of the embodiment? (Yes = design; No = design & concept)
    b. Do you need a defined product to build the initial model through analysis? (Yes = design; No = design & concept)

Modelling application
    a. Can the model be used in synthesis of design? (Yes = capture the unknown)
    b. Can the model be used for ideation? (Yes = capture the unknown)
    c. Can the product be structured in subsystems with the model? (Yes = manage)
    d. Can the model support the management of design activity? (Yes = manage)
    e. Can the model be used to depict requirements? (Yes = define the design)
    f. Is the product specified in the model? (Yes = define the design)
    g. Can the model be used to gain more knowledge about the relations of embodiment and function or behavior? (Yes = obtain insight)
    h. Can the model be used to validate the product? (Yes = obtain insight)

In case of models being applicable to more than one cluster, discussion with experts on product models was planned, however on this level of detail, the models could be sorted using the described questions. Abbreviations in Figure 2 are explained in Table 2, where the product models are listed with source and detailed aspects.
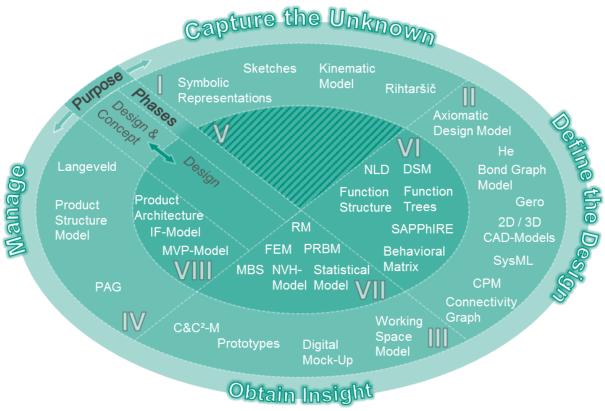
Fig. 2 The product model framework

3.2 Product Models in Embodiment Design

The column Framework-Cluster is added to the table of the product models and the product models resulting from the systematic literature review are listed. Each model is evaluated based on its description in the source and assigned to the categories of depiction and information. The models are listed alphabetically. For each model listed in the table, an additional research has been conducted to identify its original source. The document containing these findings is published under DOI 10.5445/IR/1000086190 at https://publikationen.bibliothek.kit.edu/1000086190 as research data.

Table 2 Categorized product models table

#	Product Model (Source)	Type of depiction					Type of information				Framework-Cluster
		Analytical	Graphical	Table/Matrix	Textual	Physical	Function	Behavior	Embodiment qualitative	Embodiment quantitative	
1	**2D / 3D CAD-Models** (Atherton et al. 2018) (Eifler and Howard 2018) (Dantan et al. 2013)		x							x	II
2	**Axiomatic Design Model** (Leu et al. 2009)	x		x			x			x	II
3	**Behavioral Matrix** (Cao and Fu 2011)	x		x				x		x	VI
4	**Bond Graph Model** (Muenzer and Shea 2017)		x	x				x	x		II
5	**C&C²-Model (C&C²-M)**		x				x	x	x		III

#	Product Model (Source)	Type of depiction					Type of information				Framework-Cluster
		Analytical	Graphical	Table/Matrix	Textual	Physical	Function	Behavior	Embodiment qualitative	Embodiment quantitative	
	(Albers et al. 2009) (Boersting et al. 2008) (Freund et al. 2015)										
6	**Connectivity Graph** (Ameri et al. 2008)		x	x					x		II
7	**CPM** (Köhler 2009) (Zhan and Huang 2018) (Weber 2014) (Weber 2005)		x	x				x	x		II
8	**Design Structure Matrix (DSM)** (Eppinger and Browning 2012) (Bonev et al. 2015) (Browning 2016)			x			x	x	x		VI
9	**Digital Mock-Up** (Danjou et al. 2008) (Riascos et al. 2015)	x	x					x		x	III
10	**FEM Simulation Model (FEM)** (Danjou et al. 2008) (Rajaguru et al. 2010 - 2010) (Eifler and Howard 2018)	x	x					x		x	VII
11	**Function Structure** (Ameri et al. 2008) (Chakrabarti et al. 2011)		x				x				VI
12	**Function Trees** (Nagel et al. 2008)		x				x				VI
13	**Integrated Function Model (IF-Model)** (Gericke and Eisenbart 2017)		x	x				x	x	x	VIII
14	**Kinematic Model** (F. Gao et al. 2015)	x	x					x		x	I
15	**Langeveld (Product Structure)** (Langeveld 2011)		x				x		x		IV
16	**Models according to He (He)** (He et al. 2013) (He et al. 2015) (He and Huang 2016)		x				x		x		II
17	**Models based on Gero (Gero)** (Mokhtarian et al. 2017) (Goel et al. 2012) (Gu et al. 2012)		x	x	x		x	x	x		II
18	**Multibody Simulation (MBS)** (Danjou et al. 2008)	x	x					x		x	VII
19	**Node Link Diagram (NLD)** (Bonev et al. 2015)		x						x		VI
20	**NVH Model** (Danjou et al. 2008)	x	x					x		x	VII
21	**Parametric Associativity Graph (PAG)** (Ameri et al. 2008)		x						x	x	IV
22	**Product Architecture** (Feldhusen and Grote 2013)			x			x		x		VIII
23	**Multi-View Product Model (MVP-Model)** (Rasoulifar et al. 2012)		x						x		VIII
24	**Product Structure Model** (Baxter et al. 2008)		x	x			x			x	IV

#	Product Model (Source)	Type of depiction					Type of information				Framework-Cluster
		Analytical	Graphical	Table/Matrix	Textual	Physical	Function	Behavior	Embodiment qualitative	Embodiment quantitative	
25	**Prototype** (Andreasen et al. 2015)					x	x	x	x	x	III
26	**Pseudo Rigid Body Model (PRBM)** (Berselli et al. 2016) (Bilancia et al. 2017) (He et al. 2012)	x	x					x		x	VII
27	**Remanufacturability Model (RM)** (Fang et al. 2014)	x	x							x	VII
28	**Rihtaršič** (Rihtaršič et al. 2012)		x					x	x		I
29	**SAPPhIRE** (Sarkar et al. 2017)			x			x	x	x		VI
30	**Sketches** (Andreasen et al. 2015)		x				x	x	x		I
31	**Statistical Model** (B. Künne and D. Wieczorek 2010)	x	x					x		x	VII
32	**Symbolic Representations** (Andreasen et al. 2015)		x				x	x	x		I
33	**SysML Model** (Wölkl and Shea 2009) (Chakrabarti et al. 2011) (Zingel et al. 2012) (Rasoulifar et al. 2012) (Eisenbart et al. 2017) (Zheng et al. 2017) (Gadeyne et al. 2014)		x	x			x	x	x		II
34	**Working Space Model** (Beetz et al. 2018)		x				x	x	x		III

In total, 34 product models have been gathered. The models #12 (function trees), #16 (Models according to He) and #17 (Models based on Gero) contain different variants of a model that follow the same basic modeling principle. They were gathered in one entry because of their similarity. For example, the *function trees,* that are for themselves no product model, as they do not necessary contain aspects of a product, in the identified publications were integrated in different context and connected with a kind of depiction of the embodiment itself. In some of the identified publications, more than one model is described. These publications were assigned to the model in which their focus lay. For example, Leu et al. (2009) used *function trees* and other models to derive their *axiomatic design model.* This publication was assigned to the axiomatic design model, as this was its focus. Nagel et al. (2008) integrate *function trees* in system boundaries and different states of the product to allow the exploration of the flow of energy, material and information throughout different states of the system.

A total of 28 out of the 34 product models include a graphical depiction. A deeper pattern analysis was not conducted as the research question focusses on structuring and differentiating of the identified models.

3.3 The Guideline for Model Selection

As described in the materials and methods, the guideline is a method for product model selection in embodiment design. Figure 3 depicts the steps of the guideline.
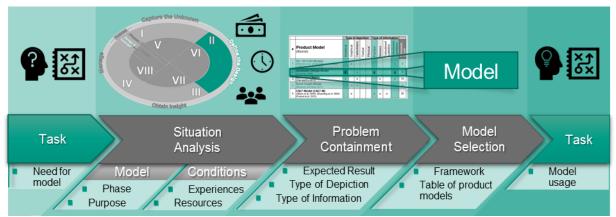
Fig. 3 Flow diagram of the guideline

To further illustrate the work with the guideline, the steps are explained with two examples from studies on an impact wrench. For details on the study see (Matthiesen et al. 2018).

Situation analysis: In the first step of the guideline, the situation must be analyzed. The task and its boundary conditions are explicated, from which the phase of the embodiment design can be derived as well as the purpose of models to be used in the task. The main question is what is expected from the work with the model. In the example of the impact wrench, understanding of the systems dynamic behavior is necessary to improve the precision of its torque application. Therefore, a model has to be built from an impact wrench that allows to simulate the kinematics and forces in the mechanisms to fulfill the function. The design already exists and is available in form of a 3D-CAD model and a reference product. The phase in this situation is the "design phase", as the product is already defined. The purpose for using a model is "gain insight". As resources a test rig exists to investigate dynamic behavior of the impact wrench. This sets the cluster of the framework from which the product model is chosen later on.

Problem containment: In the next step the problem has to be contained to identify a suitable model of the cluster. Here the necessary aspects of the model to solve the problem or to fulfill the given task need to be clearly stated. Therefore, it is useful to explicate an expected result of the modeling process. In the case of the impact wrench the task is not only to understand the mechanics but to as well simulate its behavior quantitatively. This requires a model with an analytical depiction of the system and as the type of information behavior and quantitative embodiment.

Model selection: When the situation and the problem are clarified to satisfaction, the model selection itself can be made. After selection of the cluster,

Table 2 provides the overview on the different aspects of the included models. If this leaves more than one model a decision based on resources and experiences with the models should be made. If the framework doesn't contain a model that could be used for the task either a research for a model that hasn't been included in the framework can be conducted or a model that is close to fulfill the task can be modified. Concluded for the impact wrench the model needs to be selected from cluster seven. From

Table 2 can then be seen which models of cluster seven fulfill the requirements for an analytical depiction, quantitative embodiment information and information about the behavior. This leaves MBS, FEM and PRBS. Since the processes in an impact wrench are dynamic, a MBS model was developed.

The MBS model was then used to investigate dynamic behavior of the impact wrench. In validation of the model, an unknown behavior led to a new situation, were a different model was required. Measurement data included a phenomenon, that couldn't be explained with the MBS model. The design engineers didn't expect this behavior, so their mental models didn't cover it. The analysis of the 3D-CAD model and the MBS didn't provide any solutions, as they were built on the mental models. From this situation, an additional model was necessary to

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obtain insight on this phenomenon. While going through the guideline again, a lot of information about the requirements and restraints is already there. But the problem has changed and therefore the model requirements change from "quantitative embodiment" information and an "analytical" description towards a "physical" depiction in an experimental setup and a graphical depiction of relations of embodiment and behavior to aid the process of gaining insight. This led to the selection of a prototype and a C&C²-Model from the cluster "concept and design" and "obtain insight". The prototype enabled the researchers to observe the processes in situ. The C&C²-Model was used to gain insights about relevant design parameters for the observed behavior. From these insights, the MBS model was improved (Matthiesen et al. 2018).

4 Discussion

The findings of the systematic literature review confirm the premise of the paper that a large variety of models exists in embodiment design and is subject to ongoing research. The research question 1 "*Which models exist in embodiment design?"* can only be answered in a limited range, as no complete overview over product models in embodiment design can exist due to new developed models. A large number of Models found in this research were as well mentioned in the collection of product models associated with mechatronics presented by Weidmann et al. (2017). This has been expected, as the mechanic discipline of Weidmanns research comprises the embodiment design. However, through the more focused research of this contribution on embodiment design, more specialized models like CPM, DSM or C&C²-M were identified. Still there are probably other advancements of different product models that have not been identified at all, as they might not be published in English or don't use the search terms of the conducted literature review. For these models, the developed framework and table can support in classification and finding connectivity to already existing models.

Research question 2 "*How do they differentiate?"* is answered through the developed framework and categorization, which show that the differentiation of product models is possible based on proven criteria from literature. An assistance in handling the large variety of product models is given. However, the allocation of the phase category of the framework turned out to be difficult as most of the identified models had no description on when they might be used in embodiment design. Therefore, only the differentiation whether the necessary input is only present in the design phase (parameters, CAD-models etc.) or not, could be made. The classification of the product model framework showed an ambiguity in identification of the main application of the model as well. Stronger criteria for sorting the methods according to their main application were necessary. The questions designed to categorize models for the framework lead to some elimination of this ambiguity. For the creation of the presented framework the questions provided in section 3.1 solved this problem for the authors.

This provides the answer to research question 3 "*For which purpose and situation in embodiment design can they be used?"* as purpose and engineering phase are the dimensions of the framework. The seven clusters of the framework provide an overview of product models for these key aspects. Since the viewing level of the framework doesn't provide enough detail to select a model, the combination of the framework with the categorization based on type of information and type of depiction is necessary. The guideline provides an approach to support the situation-appropriate model selection process based on the framework and the categorization of the models from the practitioners' point of view. The clarification of modelling purpose and phase of embodiment design guide users towards the suitable cluster of models. With the further specified needs for type of depiction and information included in the product model a model can be selected. This systematic approach offers the possibility to support the selection of suitable models from the vast variety of product models in embodiment design. Further it is now possible to position developed or identified model in the identified categories. However, the effect of this approach on model selection in practice still has to be further validated.

5 Conclusion and Outlook

In conclusion of this contribution it can be stated that product modelling is widely spread and diverse in engineering practice and research. This leaves the design engineers with an expanding variety of models and tools to choose from to help them in the embodiment design process. The proposed framework can help to identify product models in the field of embodiment design by providing a structure with modeling application criteria and a reference for the engineering phase the models are suitable for. There still remain tasks for further research, since the models included at this point are based on a literature research in scientific publications. This leaves out commercial tools and specialized models developed for the industry as well as models that are presented without usage of the chosen search terms. By providing the product model framework this contribution gives a basis for continuing research. The framework gives practitioners in embodiment design the chance to reduce the variety of available models to one set of models appropriate to their needs, resources and available competences in their design project.

Future research will continue to further detail the product model framework, going deeper into the details of the modeling application. With the developed framework, the question of which models can be suitable, can be answered on a high level. With a more detailed framework, this question can be sharpened to how far the range of different models goes. This would make research on how to determine when a model has reached its limit and which models might be used subsequently possible.

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