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AN ADVANCED PROCEDURE MODEL FOR PROPERTY-BASED PRODUCT DEVELOPMENT

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ABSTRACT

Increasing functionality, increasing individualization as well as the enormous complexity of modern products lead to steadily increasing challenges in the domain of product development. This causes a necessity of a novel approach for a purposeful guidance to lead developers through the process of product development. Therefore the objective of this work is to present an advanced procedure model for property-based product development which is showing effects of characteristics specifications based on a structured mapping of product properties. Due to its structure and the integration of a multitude of individual approaches that are developed within this paper, the presented procedure model provides product developers with a detailed guidance to the process of product development. Moreover, developers are supported not only in the field of preventative avoidance of unnecessary design iterations but also in in dealing with unavoidable iterations. By continuously monitoring the product's degree of maturity information about the achievement of the required properties and about necessary changes can be deduced.

Keywords: design methodology, property- property-based product development, design process, process modeling, design management

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1 INTRODUCTION

Product development takes place traditionally between conflicting priorities. While product and development cycles are constantly becoming shorter, product developers have to develop high-quality products with increasing functionality and complexity. Moreover, these modern products have not only to be checked for proper functioning but also have to meet the increasingly differentiated customer's requirements. This leads to an ever increasing individualization and diversification of offered products. Therefore, companies try to launch many different products onto the market at the same time in order to meet these numerous requirement profiles stipulated. Hence, a close cooperation between specialists from various disciplines is essential whereby the product development is increasingly characterized by interdisciplinary collaboration and spatially separated developers.

1.1 Status quo of the product development process and problem description

Due to this increasing complexity of modern products, the challenges in the field of product development are steadily increasing. Despite these challenges and the iterative procedure in product development and ever shorter product lifecycles, developers must be able to develop efficiently and effectively products that meet the required properties sufficiently. Because prospective customers buy a product only if the product’s overall-behavior will meet their demands, the product’s behavior caused by the product’s properties is a relevant measurement for fulfillment of the desires of the customers. Consequently, developers have to develop products that offer an adequate profile of properties, which is expressed by the term property based product development.

Following the perspective according to Weber (2005), after which suitable characteristics have to be defined during the product development process in order to achieve certain properties, it is not possible to determine just a specific property profile easily. A property profile of a product rather arises as a result of a variety of complex cause-effect chains (Weber, 2005). It thus becomes clear that in the product development complex networks between characteristics (= cause) and resulting properties (= effect) quickly occur. With an increasing product complexity, the transparency of this dependency network decreases significantly, which impacts negatively on the traceability of the holistic product development process. This lack of transparency complicates targeted modifications to the product and also increases the risk of unnecessary and unforeseen iterations.

If the required property profile of a particular product is not reached, often only the effects are combated or stemmed in the context of improvements (= iterations), but their causes are not eliminated. Due to the multiple dependencies of defined characteristics and resulting properties it is not always possible for developers to detect causes reliably, to identify possible alternatives and to analyze and evaluate their consequences completely.

1.2 Overall objectives

In consequence of these challenges, that product development is confronted with, a detailed guidance through the product development process is needed to ensure the complete fulfillment of a required property profile. This causes a necessity of a new approach for a purposeful guidance to lead developers through the process of property based product development. The procedure model shows the product developers, how certain required product properties can be reached effectively by taking into account the complex dependencies and how the function fulfillment can be ensured by monitoring product behavior during operation. In addition, this procedure model has also to support the developer in assessing the currently reached requirement fulfillment. Moreover, in cases where the product does not meet the required behavior or the required property profile is not reached, targeted assistance is needed in order to identify possible action alternatives as well as to evaluate them with regard to their success.

Thus, a procedure in property based product development is necessary, which ensures particularly in cases of complex products through a continuous safeguarding of the reached product maturity level as well as through a suitable iterations management that the behavior of the realized product fully meets the stated requirements. Therefore, the overall objective of the authors is to develop a procedure model for iteration and product maturity management in the property-based product development, which guides the developer step by step through the product development process. Consequently, the procedure model has to consider in particular the product properties, as the behavior of the product during its operation is ultimately crucial for the customer. However, it is important to note that issues of requirements management, as described in Danner (1996), are not the focus of this work.

2 STATE OF THE ART AND RELATED WORK

This chapter describes the relevant state of the art regarding the objective pursued. Hence, first of all existing design methodological approaches and process and procedure models are considered and thereafter these are evaluated in detail regarding the objectives of this paper. Based on this the need for action for a comprehensive procedure model for the property-based product development is derived.

2.1 Different existing process and procedure models of product development

The most common design methodological approaches and process and procedure models can be divided into three categories: "micro-cycles of product development", "phase and condition-based approaches", "action-oriented approaches". These are listed in the following paragraph solely with a reference to further literature.

The Problem-solving Process of the Association of German Engineers (VDI) guideline 2221 (VDI, 1993), the Problem-solving Cycle according to Daenzer and Huber (1994), the Munich Procedure Model according to Lindemann (2009), the Cyclical Design Approach (Daniel et al., 2007) are part of the micro-cycles of product development. Important representatives of the phase and condition-based approaches are the Procedure Model according to Pahl and Beitz (2003), the Procedure Model according to VDI guideline 2221, 2222 Part 1 and 2223 (VDI, 1982 and VDI, 1993 and VDI, 1997 and VDI, 2004) and (Jänsch and Birkhofer, 2006), the Procedure Model according to VDI guideline 2206 (VDI, 2004), the Munich Product Concretization Model according to Ponn and Lindemann (2008), the Forflow Process Model (Krehmer et al., 2010). In contrast, the Characteristics-Properties Modeling (CPM) and the Property-Driven Development (PDD) (abbreviated CPM/PDD approach) according to Weber (2005), the Function-Behavior-Structure (FBS) Framework developed in (Gero and Kannengiesser, 2000, 2004, 2006), the Axiomatic Design according to Suh (2001) are allocated to the action-oriented approaches.

2.2 Evaluation of process and procedure models of product development

With regard to the objective of the present work, the above mentioned approaches are evaluated in this chapter regarding their suitability to support the designers in the product development process, their suitability for property-based product development, their suitability for monitoring the product maturity and finally their suitability to support in dealing with iterations.

Their first task, guiding the product developer through the product development process and its modeling is done by the outlined procedure and process models in different ways. The VDI guideline 2221, 2222 Part 1, 2223 and 2206, the Procedure Model according to Pahl and Beitz (2003), the Forflow Process Model structure the product development process into individual phases or steps. While this is done in Pahl and Beitz (2003) and in the VDI guidelines on a relatively abstract level, the Forflow Process Model reaches a much higher level of detail. The Munich Product Concretization Model divides the development process based on steps of concretization into individual sections. In contrast, Suh (2001) is focusing on the mapping between its different domains. Despite the differing approaches are their basic procedures very similar. These proceed from requirements and thereafter the corresponding functions are formulated which are subsequently assigned to certain effects (exception: Axiomatic Design). Then the product is described in detail by geometry and material specifications. This corresponds in the main to the synthesis of the PDD approach. However, the corresponding counterpart, the analysis of the PDD is missing in the VDI guidelines, in (Pahl and Beitz, 2003) and in Lindemann (2009). The PDD approach models the product development as cyclical running through sequence of synthesis, analysis, comparison and evaluation. Thereby, in contrast to process-oriented models, the product as well as its design is less focused on structuring of the development process. However, it is not distinguished between early geometry-poor and late geometry-rich phases. Gero describes a delicate separation of individual activities that gives priority to the thinking of the developers. Contrary to other models, the FBS-framework incorporates both the subjectivity of the developer as well as the influence of knowledge and experience. Although the separation of individual phases simplifies the guidance through the process, this implies also, however, a distinct sequential procedure that supports not enough particularly in the design of the product. So the process-oriented approaches and models provide no instructions on how a specific product behavior or certain properties can be attained. Only the PDD-approach supports the iterative design and detailing of the product. However, this approach offers no assistance in early phases, which are central especially in the VDI guidelines and in (Pahl and Beitz, 2003). There, the early phases are characterized by the formulating of (partial-)

functions, the assignment of physical effects as well as the development of the product structure. This gives particularly the VDI guidelines 2221, 2222 Part 1 and 2223 as well as the Procedure Model according to (Pahl and Beitz, 2003) their strengths in supporting early phases of problem solving. On the other hand, however, it is possible with the PDD-approach to map and to support the iteratively proceeding product design.

The process and procedure models differ from each other also in terms of their focus on the properties. Most of the approaches concentrate on steps and phases, only the VDI 2206 and the PDD-approach consider the required target properties. While the VDI guideline ensures this through the consistent monitoring of properties, Weber (2005) focuses on using the detailing of the properties by defining related characteristics. Thus, not only the properties are placed in the center, but also the deviation of the realized to the required properties is defined as decisive influencing factor of the development process. As in other approaches, is no distinction made between part-, subsystem- and overall system properties (exception: Forflow Process Model). So, none of the models presented supports detailing the required overall system properties up to part level. Hence not with any of these approaches the interaction between single characteristics (e.g. component stiffness) and superordinated properties (e.g. convenience, security) can be described or understood.

The outlined approaches are also different with respect to their suitability for monitoring the product maturity. While some approaches do not provide any support, at least the Procedure Model according to (Pahl and Beitz, 2003), the Forflow Process Model, the Munich Product Concretization Model and the VDI guidelines mention a basic testing and evaluation of the achieved results after certain working steps. The VDI guideline 2206, for example, only mentions that the degree of product maturity increases with each macro-cycle run. But this guideline does not indicate how to measure or evaluate the product's degree of maturity. Even the milestones of the V-Model (Pahl and Beitz, 2003) do not allow a monitoring of maturity, since it is only possible to recognize the completion of certain process sections with this approach. By comparing the expected behavior with that which is derived from the structural behavior, Gero's FBS-framework describes ultimately a capturing of the maturity. For this purpose, the actual and target state is set into relation to each other. The comparison between the target and actual properties in the PDD approach points out weaknesses and deficiencies of the product at any time. As a result, this approach is to be evaluated positively in terms of its suitability for monitoring the product maturity in contrast to other approaches. In the PDD approach is the difference between target and actual properties decisive for the completion of product development: If it is sufficiently small, the scheduling condition is fulfilled and the cyclical process can be terminated. Although the capturing of the product's degree of maturity is essential for this purpose, the PDD approach cannot provide a monitoring of the product maturity throughout the entire process due to lack of support in the early phases. Moreover, the PDD approach does also not support a product maturity at part-, sub- and overall system level. It becomes apparent that none of the existing procedural models enables the capturing and monitoring of the product's degree of maturity about the entire product and throughout the product development process. Merely the PDD approach and the FBS framework consider certain aspects that can be used as a basis of a monitoring of the product maturity.

Finally, the last evaluation criterion is the suitability of the prevailing process and procedure models to support the product developer in dealing with iterations. Neither Pahl and Beitz, nor Lindemann, nor Suh nor the VDI guidelines 2221 or 2222 Part 1 provide support in dealing with iterations. The VDI guideline 2223 and 2206 only mention the possibility of corrective actions what roughly corresponds to an iterative process. However, these guidelines describe the iteration not in more detail. Although Pahl and Beitz and the VDI guideline 2221 admit the need of iterations, this procedure models are still linear. An iterative back and forth jumping between different process phases or single steps is given. Therefore, iterations are accepted, but are not further supported. Iterations are also only admitted in the Munich Product Concretization Model, whereas a detailed assistance in handling them is not offered. In contrast, iterations in the PDD approach are not only accepted to be an unavoidable matter of fact, but also its role as a learning process and its benefits for increasing the information level is recognized. Due to the cyclic modeling of the product design, iterations are not only explained but also depicted and supported. However, no comprehensive iterations across multiple phases are considered. In the FBS-framework, iterations are also understood as a learning process. Thus, by its steps 6, 7 and 8, three different iterations in product development are depicted. With their different extent (reworking the structure, the expected behavior or the required function) they constitute three consecutive stages of escalation. Such a classification of iterations cannot be found in other procedural model at all.

2.3 Deduction of need for action for a procedural model for property-based product development

It has been shown that existing procedure models provide targeted support for iterations only in a minority of cases. Furthermore, they neglect the detection of product maturity on the basis of realized properties (exception: PDD approach). The approaches that focus on the representation of properties, however, do not provide a procedure for achieving them or for capturing of the product's degree of maturity or for dealing with iterations. The procedures for analyzing and capturing the product maturity offer on the other hand no suitable procedures to support the product development from the synthesis side. The approaches from the iteration management deal with specific aspects of iterations, but there exists no comprehensive approach that supports both the product developers in avoiding iterations and in dealing with them. Due to these weaknesses, the following three dimensions of need for action arise and have to be considered in the development of the advanced procedural model for iteration and product maturity management in the property-based product development:

- Dimension "behavioral and property-based product development"
- Dimension "monitoring the product's degree of maturity"
- Dimension "support in dealing with iterations"

In the following it should be noted that the focus of the present papers is on the first dimension. Furthermore, it is also important to know that this paper is on the one hand partly based on the thesis of Krehmer (2012) and on the other hand it complements and extends this work.

3 THE PROCEDURE MODEL FOR PROPERTY-BASED PRODUCT DEVELOPMENT

After the explanation of some basic terms in the following sub-section, the new procedure model for a behavioral and property-based product development is presented in an overview. Afterwards the synthesis and analysis is described in each case with a few corresponding steps.

3.1 Terms in the context of property-based product development

In order to create a common understanding for the present work it is referred to the detailed explanation of the terms explained in Krehmer et al. (2011). Subsequently only the terms function, structure, behavior, characteristic and properties are defined, since these terms are essential for understanding the following procedure model.

In this work the term function of a technical system or product means the abstract and solution-neutral description of those changes that the system to be developed at its input, output and state variables is carrying out. Therefore, the function is the sense or task or aim of the system. That means for which purpose the system is designed for or what effect(s) can be reached with it.

The structure of a product is to be understood to mean its components with their layout and thus also their relations among themselves. Hence it is possible to derive the behavior from the structure of the interaction of the individual components and with respect to the usage and environmental conditions.

The product's behavior specifies its interaction with its environment and how it fulfills its required function. The behavior of a technical system or product results in particular from its specific property profile, its concrete realization (= structure) and is furthermore determined by the later use and existent different environmental conditions.

Following the CPM/PDD approach by Weber (2005), characteristics are used to describe the parameters through which a developer is able configure and influence the properties of a product. Characteristics define the product and therefore they determine the structure, geometry (e.g. shape and dimensions), surface and material (e.g. wood, steel and plastics).

To define the term property in the context of technical systems, the present work follows also the understanding of the CPM/PDD approach. Accordingly, the properties of a technical product cannot be determined directly from the developer. The properties are rather the direct consequence of the definition of characteristics and have a determining influence on the behavior of the product during its later use. Properties can be quantifiable (e.g. weight, stiffness, cost) or even qualitatively appraisable (safety, easy assembly, environmental friendliness, aesthetic appearance). According to (Weber, 2005) and (Weber, 2009), less the characteristics rather than the resulting properties of a product are relevant for the customers. Therefore, customer requirements can be understood partly as required product properties (Weber, 2005).

3.2 The property-based product development as an approach for a behavioral procedure in product development

The advanced procedure model for property-based product development depicts with its process steps the basic procedure of the product development process. This modified V-model differs significantly, apart from the shape, from the models mentioned above. The new procedure model for property-based product development consists of six phases. Two each of these phases are at the overall system level, the subsystem level and part level. As shown in figure 1, this design leads to a bifurcation of the procedure model into in the left synthesis-side and the right analysis-side.

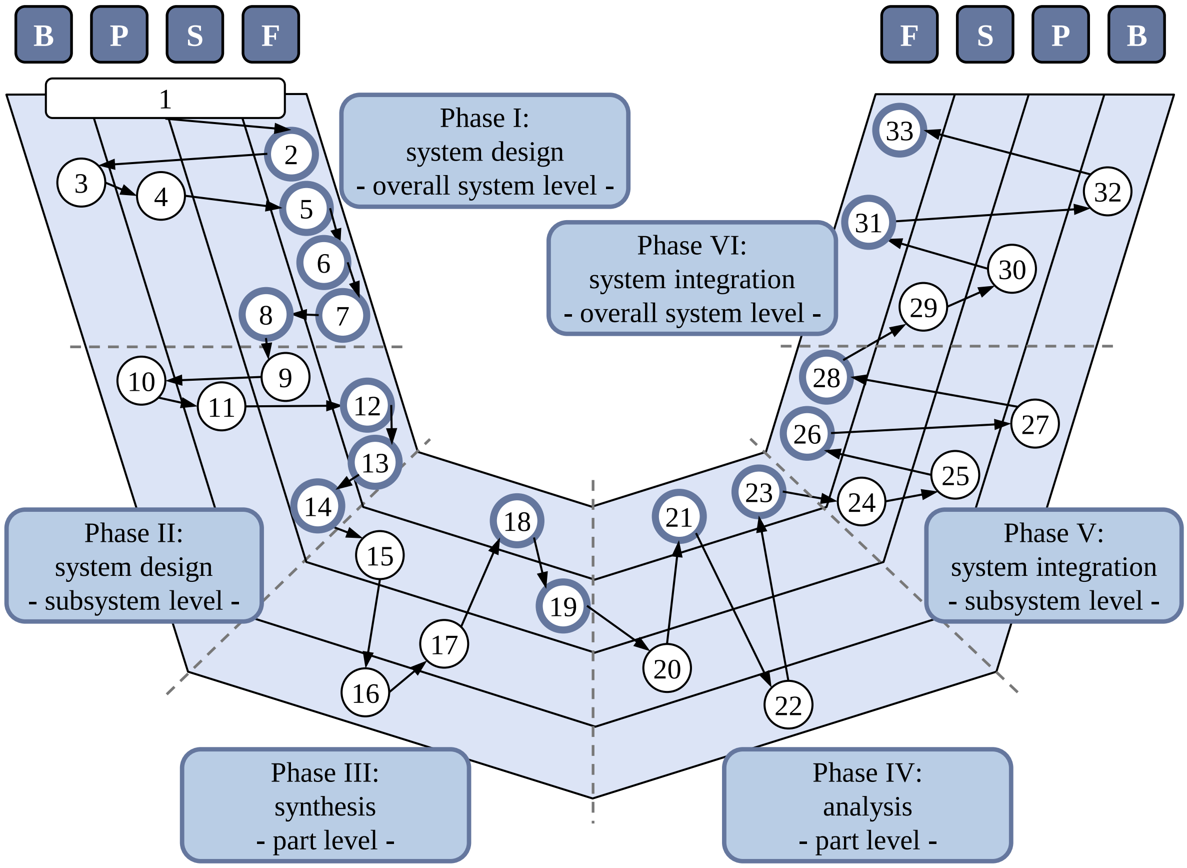

Figure 1. The advanced procedure model for property-based product development

Another feature of the procedure model for property-based product development is the comprehensive integration of the four views behavior, properties, structure and function. These views are abbreviated in Figure 1 and in the following text by the letters B (behavior), P (properties), S (structure) and F (function). These views run through the entire development process since each of the 33 steps is associated with its corresponding view (e.g. step three is associated with the view behavior). Thereby, those steps, whose execution is successful completion of a milestone, are highlighted by a dark border.

3.3 Synthesis: From requirements to the definition of characteristics

In the following, the three phases of synthesis are explained (steps 1-19). Steps 1-8, which are outlined briefly below, are assigned to the system design at overall system level (phase I), steps 9-14 to the system design at subsystem level (phase II) and steps 15-19 to the synthesis at part level (phase III).

The first step, the requirement elicitation, constitutes the starting point of the entire product development process. Even if the requirements include not only information about the desired product function, but also information about required properties or the desired behavior or the required structure of the product, this step is in particular assigned to the view function in order to indicate that requirements usually relate to functional aspects. The requirements are weighted already in this step to facilitate a subsequent prioritization. The first step is extremely important because it sets the course for the further development and provides the basis for monitoring the product's degree of maturity because it gives information about whether the product meets the required properties with its current configuration of characteristics.

The second step includes the preparation of requirements as well as definition of the overall system. Therefore, the aim is to prepare the gathered requirements and to define as precisely as possible the required overall system. In addition, it is important to identify existing degrees of freedom, persisting information needs and remaining contradictions. Moreover, also other, internal company information is taken into account. Moreover, responsibilities are defined and important milestones are terminated.

The deduction of the required overall system behavior is the aim of the third step. Therefore the required behavior of the overall system is deduced. Thereby, it is essential that the required product behavior meets the specified requirements as completely as possible. Besides, the behavioral aspects are weighted according to the achieved requirements.

In the fourth step, which is assigned to the view properties, the required properties of the overall system are determined. These are intended as target properties and have to be defined so that the required behavior (cf. step 3) results from the definition of this property profile under the given usage and environmental conditions. The product developer is supported and guided in this task by a so-called requirements matrix. This indicates which requirements are covered by which behavioral aspects and what behavioral aspects are resulting from which properties.

The objective of the fifth step, which is assigned to the view function, is the definition of the customer requirement specification. In order to do this, all currently available information of the product to be developed regarding the required range of functions, the performance as well as the product contents are gathered. These are supplemented by the boundary conditions from the perspective of the customer or the user and subsequently written down in the customer requirement specification. This also presupposes the active involvement of customers. The customer requirement specification represents a largely solvent-neutral description of the target product and describes the customer's requested condition of the product at the time of delivery (Schäppi et al., 2005) and (VDI and VDE, 2008).

The sixth step is part of the view function and in that the function structure at the overall system level is determined. For this task all the required functions of the product to be developed are identified. Afterwards the function structure is built up. This function structure describes the main functional aspects of the product and interlinks the main-, sub and secondary functions to each other solution-neutral. Finally, the function structure is reflected critically and checked for completeness because this has now become the basis for the subsequent search for a solution and hence of the further procedure.

The aim of the seventh step is to create the active structure at the overall system level. Therefore existing solution possibilities are searched for the various functions of the function structure. Wherever it is possible, existing and appropriate solutions from previous development projects are to be identified. If no appropriate solutions can be found, it is searched for suitable solution principles. When there are neither suitable solutions nor solution principles, possible physical, chemical or other effects to solve the existing task must be found. Thereafter, it is checked whether the existing partial solutions, the found solution principles or selected active principles cover all the requirements. Subsequently, these active principles can be combined to the active structure according to (VDI, 1993) (cf. Ponn and Lindemann, 2008). By selecting certain principle solutions for covering the required functions, the active structure is obtained as a possible solution concept.

Creating the product structure at the overall system level is the task of the eighth step. In this step, the whole system is broken down into its key subsystems and is therefore also known as modularization step. In doing so, there are more and stronger interactions within the modules as between the modules. Since these dependencies can be mapped between individual product components using the matrix-based product description (a kind of modified Multiple-Domain-Matrix), this supports the developer significantly in the identification and definition of reasonable subsystems and modules. Following the identification of the subsystems, the available construction space is allocated and the geometrical arrangement of the subsystems including their positions is clarified. Furthermore, the interfaces between the subsystems are defined. With the partition into subsystems, the definition of its construction space, the mutual arrangement and position, as well as with the definition of the interfaces, the product structure at the overall system level is determined as a possible implementation of the active structure. This is to be checked finally. In case of an unsatisfactory fulfillment of this step, the developer has to return to the previous milestone (step 7).

To sum up, the essential result of the first phase is the partition of the overall system into its subsystems. Moreover, the results of this phase such as the prepared and added requirements, the required overall system behavior, the required properties as well as the customer requirement specification are the basis for the further development.

The steps 9 to 14 of phase two are analogous to phase I. The required behaviors as well as the properties derived from these are determined for all subsystems in phase two. In addition, all subsystems are further subdivided into their components so that it is possible to start in phase three with the development of the individual components.

While the overall system is subdivided into its subsystems and then further into single parts in the first two phases, the third phase supports with the steps from 15 to 19 the developer in the definition of the characteristics of the parts. Thereby the steps from 15 to 17 are similar to steps from 2 to 4.

In the 18th step (view function), the functional specifications document is compiled. According to (VDI, 2001) and (VDI and VDE, 2008) describes this functional specifications document the realization of the task from the perspective of product development and represents hence in contrast to the customer requirement specification no longer a solution neutral description of product to be developed. The customer describes in the customer requirement specification, what he wants, while the developer describes in the functional specifications document what the customer gets. The check for consistency and ensuring the technical feasibility of all the requirements contained lies within the sole responsibility of the contractor.

The characteristics are to be defined by determining geometry and material of each individual part in step 19 so that this part is having the properties which were required in step 17. In each case, the interactions between the chosen material and planned manufacturing process are to be considered. Furthermore, the part is dimensioned in accordance to the material parameters of the chosen material. Hence, this step includes not only the design of the part itself, but usually also rough calculations in the context of dimensioning.

The main results of this third phase are fully configured parts, of which not only the required behavior and the required properties, but also the specified characteristics are fully known. Consequently, the developers are guided and supported in the synthesis, starting from the required overall system behavior step by step to the definition of all the characteristics.

3.4 Analysis: From the characteristics to the validation of the total system behavior

In contrast to the synthesis, the procedure has not to be adjusted to the function or active structure during the analysis. Instead, the procedure model has to concentrate on the interaction between the individual part properties within the product. That implies that a suitable procedure model for the property-based product development features appropriate steps at the part, the subsystem and the overall system level. With these steps, the realized properties and thus the expected behavior is deduced due to the respective determinations of characteristics during the synthesis. The developer is guided on the analysis side from the characteristics via the parts properties and the parts behavior to the level of the subsystems. At this level – again starting from the structural determinations – the achieved properties and the expected behavior can be deduced. Finally, the analysis of the realized properties at the overall system level is conducted and the validation of the achieved overall system behavior is done.

In the following, the right side the procedure model, which is subdivided into three phases and includes the steps from 20 to 33, is explained briefly. Phase IV "analysis at the part level" includes steps from 20 to 23. Steps 14 to 28 are assigned to phase VI "system integration at subsystem level" and phase VI "system integration at overall system level" includes the steps from 29 to 33. These almost identically designed phases differ substantially only in the considered level of product structure. Their basic procedure is explained in detail using the part level (phase IV).

The 20th step that belongs to the view property is used to analyze the realized part properties resulting from the definition of characteristics in step 19. The entire product cycle is always included at this step. The properties, which are to be analyzed precisely in this step, result in detail from the required part properties that are defined in step 17. Hereinafter, the relevant properties of a part are to be investigated thoroughly using appropriate analysis methods. As a result, the respective property profile for each part is obtained in this step.

The purpose of step 21 (view function) is the comparison of actual and required part properties. In this step a capturing of the degree of product maturity based on the achieved properties is taking place for the first time in the development. As already indicated, such a safeguarding of the comparison of the actual state achieved with the required target state can be performed. The required part properties that were defined in step 17 represent the target state. The actual state, however, is formed by the part properties analyzed in step 20 and which have been achieved by the characteristics defined in step 19.

The deduction of the realized part behavior is the goal in step 22 which is part of the view behavior. Therefore, the behavior is analyzed, which the considered part will show due to the achieved properties under the influence of the usage and environmental conditions. The realized behavior can be determined by analysis in virtual, real or in a combined environment.

In the 23rd step (view function) the comparison of the realized with the required part behavior takes place. In this step, it is for the first time that a content-based capturing of the degree of maturity through the comparison of the part behavior is conducted. Different maturity indicators are used to monitor this step. If it is proven that the part not only fulfills the required properties but also shows the appropriate behavior under the usage and environmental conditions, the goal of step 23 is reached.

To sum up, one of the key outcomes of phase IV are detailed results of the analysis for all parts. Further outcomes are information about the achieved properties as well as knowledge on the expected part behavior under conditions of use. Moreover, the degree of target achievement is determined regarding the behavior as well as regarding the properties (due to the specified characteristics in step 19).

The essential findings of the following phase V are subsystems which are checked strictly. For each subsystem, the achieved properties as well as the behavior that results from the interaction of the parts involved were analyzed. Furthermore, in each case the present degree of target achievement is determined and monitored.

The result of phase VI, the final phase of the procedure model, is the completed and fully checked overall system. Therefore, the subsystems, which have been checked in the previous phases, are integrated into the overall system. Subsequently, their properties and the resulting behavior are analyzed and the respective existing degree of target achievement is measured.

4 CONCLUSION, EVALUATION AND OUTLOOK

This contribution outlined an advanced procedure model for the property-based product development. As mentioned above, a novel procedure model was required since none of the existing approaches meet the three dimensions, which were described in section 2.3, sufficiently. The focus of this paper was the dimension “behavioral and property-based product development”. This dimension ensures that the product developer is guided step by step through the entire property-based product development process. The main focus of the developers is the required profile of properties of the product and consequently a consistent orientation towards the relevant customer requirements is achieved.

Since the behavioral and property-based product development enables an interdisciplinary comprehensible product description, the interdisciplinary collaboration is enhanced. Additionally, by comparing the required with the realized properties of the product, the product’s degree of maturity can be determined. So, the monitoring and reliable evaluation of the development process is another advantage of this approach. Furthermore, it allows estimating the consideration of existing dependencies and impacts of characteristic modifications. Unnecessary iterations are avoided by the one-step procedure as well as by supporting the product developer. As a consequence, this procedure model also helps to realize extensive time and cost savings. However, it has to be expected that the implementation of such a procedure model entails a high effort because it has to be adapted to the given boundary conditions at the beginning. It is also essential that employees are trained in dealing with the process model. Overall, this work provides an important contribution to a purposeful procedure in property-based product development, which ensures via the property-based product description that products will meet their needs as fully as possible after the shortest possible time.

The validation of the developed procedure model in real or productive use and the subsequent improvement are the next steps to improve this procedure model. This is why the objective of further research activities is – in addition to the improvement of the other two dimensions (monitoring the product’s degree of maturity and support in dealing with iterations) – in particular the validation of the procedure model using a real product in order to prove that this approach enables to meet the requirements in less time and better than current procedure models. By using this approach in two case studies, the authors validate currently also the applicability, usefulness and effort of this procedure model. The results and findings from these two case studies will be published on the upcoming conferences.

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REFERENCES

Daenzer, W.F. and Huber, F. (1994) *Systems Engineering – Methoden und Praxis*, Zürich: Verlag Industrielle Organisation.

Daniel, J., Medland, T., Newnes, L. (2007) Graphical representation of key iterations during the design process. In Bocquet, J.-C. (ed) *International Conference on Engineering Design - ICED'07*, Paris, France.

Danner, S. (1996) *Ganzheitliches Anforderungsmanagement für marktorientierte Entwicklungs-prozesse*, dissertation, Aachen, RWTH Aachen.

Gero, J.S. and Kannengiesser, U. (2006) A function-behaviour-structure ontology of processes. In: Gero, J.S. (ed) *Design Computing and Cognition'06*, Dordrecht: Springer, pp. 407-422.

Gero, J.S. and Kannengiesser, U. (2004) The situated function–behaviour–structure framework. *Design Studies*, Vol. 25, No. 4, pp. 373-391.

Gero, J.S. and Kannengiesser, U. (2000) Towards a situated Function-Behaviour-Structure Framework as the basis of a theory of designing. In Smithers, T. (ed), *Artificial Intelligence in Design'00*, Worcester, USA, pp. gk:1-5.

Jänsch, J. and Birkhofer, R. (2006) The development of the guideline VDI 2221 – the change of direction. In Marjanovic D., Storga M., Pavkovic N. and Bojcetic N. (eds) *International Design Conference - DESIGN 2006*, Dubrovnik, University of Zagreb, pp.45-52.

Krehmer, H., Eckstein, R., Lauer, W., Roelofsen, J., Stöber, C., Troll, A., Zapf, J., Weber, N., Meerkamm, H., Henrich, A., Lindemann, U., Rieg, F., Wartzack, S. (2010). The FORFLOW Process Model for Multidisciplinay Design Tasks. *Konstruktion*, Vol. 10, pp. 59-68.

Krehmer, H., Meerkamm, H., Wartzack, S. (2011) Monitoring a property based product development – From requirements to a mature product. In Howard, T. J., Mougaard, K., McAloone, T., Hansen, C. T. (eds) International Conference on Engineering Design - ICED´11, Copenhagen, Denmark.

Krehmer, H. (2012) *Vorgehensmodell zum Iterations- und Reifegradmanagement in der eigenschaftsbasierten Produktentwicklung*, dissertation, Erlangen, FAU Erlangen-Nuremberg.

Lindemann, U. (2009) *Methodische Entwicklung technischer Produkte - Methoden flexibel und situationsgerecht anwenden*. Berlin: Springer.

Pahl, G. and Beitz, W. (2003) *Engineering Design*. Berlin: Springer.

Ponn, J. and Lindemann, U. (2008) *Konzeptentwicklung und Gestaltung technischer Produkte*. Berlin: Springer.

Schäppi, B., Andreasen, M. M., Kirchgeorg, M., Radermacher, F.-J. (2005) *Handbuch Produktentwicklung*. Munich: Carl Hanser Verlag.

Suh, N. P. (2001) *Axiomatic Design: Advances and Applications*. Oxford: Oxford University Press.

The Association of German Engineers (VDI) (2004) *VDI 2206 - Design methodology for mechatronic systems*. Berlin: Beuth Verlag.

The Association of German Engineers (VDI) (1993) *VDI 2221 - Systematic approach to the development and design of technical systems and products*. Berlin: Beuth Verlag.

The Association of German Engineers (VDI) (1997) *VDI 2222 Part 1 - Methodic development of solution principles*. Berlin: Beuth Verlag.

The Association of German Engineers (VDI) (1982) *VDI 2222 Part 2 - Design engineering methodics; setting up and use of design catalogues*. Berlin: Beuth Verlag.

The Association of German Engineers (VDI) (2004) *VDI 2223 - Systematic embodiment design of technical products*. Berlin: Beuth Verlag.

The Association of German Engineers (VDI) (2001) *VDI 2519 Part 1 - Procedures for the compilation of tender and performance specifications*. Berlin: Beuth Verlag.

The Association of German Engineers (VDI) the Association for Electrical, Electronic & Information Technologies (VDE) (2008) *VDI/VDE 3694 - System requirement/specification for planning and design of automation systems*. Berlin: Beuth Verlag.

Weber, C. (2005) CPM/PDD - An extended theoretical approach to modelling products and product development processes. In Bley, H., Jansen, H., Krause, F.-L., Shpitalni, M. (eds) *German-Israeli Symposium on Advances in Methods and Systems for Development of Products and Processes.* Stuttgart: Fraunhofer IRB.

Weber, C. (2009) Theory of Technical Systems (TTS) - Existing approaches and challenges. In Bergendahl, M., Grimhelden, M., Leifer, L., Skogstad, P., Clarkson, P.-J. (eds) *International Conference on Engineering Design - ICED'09*, Palo Alto, USA, pp.2–65-2–76.