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PURPOSEFUL INTEGRATION OF PRODUCT MODELS INTO THE PRODUCT DEVELOPMENT PROCESS

Wolfgang Lauer[1], Josef Ponn[1] and Udo Lindemann[1]
[1]Technische Universität München

ABSTRACT
In many current product development processes, engineers spend a lot of time in the search for essential information and transformation of documents into useful data formats. This problem does not only exist in the design phase, but also in all other product lifecycle stages. Reasons are the huge amount of data and a way of structuring product models in Electronic Document Management (EDM) systems, which is independent from the designer's situation. Hence, adequate retrieval services for information are needed to improve efficiency of the engineer's every day work life and in consequence for the product development process. For a better access to product models, the engineer's design situation has to be related to product models. Hence, a linkage between the development process and the product models could provide useful support for the engineer. In this context, a systematic method is to be developed, which helps to describe product models in a process oriented way. The method aims at a dynamic and automatic integration of product models into the product development process, which is not provided with current practice in the field of product model integration. To achieve that goal, description parameters are used, which support a structured storage and retrieval of process and product information. This approach provides a dynamic and flexible integration of product models into the product development process, which leads to better access to relevant information and facilitates its introduction in the industry.

Keywords: purposeful integration, product models, process oriented product model description, EDM, product lifecycle

1 INTRODUCTION
The product development process of technical systems grows in complexity day after day. This evolution is influenced by the complexity of the products themselves and the increasing competition and pressure within a branch for shorter time to market and higher cost efficiency. Thus, special software applications have been developed to support the development process. Since the main concern of this paper is the integration of product models into the product development process, especially tools for the support of data and information management are relevant. Amongst others such tools are solutions for Product Data Management (PDM) and Electronic Document Management (EDM), which store and retrieve data for the development process. However, documents are buried within the application as long as they are not related to each other and to the development process. Since retrieval services are poorly provided with sufficient information addressing this matter, the retrieval of the relevant information is difficult and leads to time-consuming searching of engineers for the required information [1]. Nowadays, companies address this matter by planning the access to information manually. This means, they have to analyse their complete process and define the corresponding information to a process step. This procedure is time-consuming and also produces a static connection of product models with the process. Thus, this paper aims at the improvement of information retrieval by providing a new description method for product models, which allows a process oriented search and flexible integration of product models into the product development process. In the context of this work product models are defined as all product information, which is created during the development process in a company. This term is not equal to partial product models known from the integrated product model of the ISO10303 (STEP) [2], see also subsection 4.
To improve the understanding of the context and the objectives of this paper, the framework of this project is described in chapter 2. After a short overview, in chapter 3 the motivation for this project

and an analysis of the problem is presented. The needs for a better handling and consistent description of product models are also displayed. While chapter 4 deals with the objectives of this research, chapter 5 gives a summary of the state of research in this field. The approach for the improvement of the product model integration is described in chapter 6. The paper concludes with an outlook on future work in chapter 7 and a conclusion in chapter 8.

2. FRAMEWORK OF PRODUCT MODEL INTEGRATION

In the project ForFlow - a publicly funded joint project - the overall objective is to improve the support of the workflow in product development processes. It is identified that planning and controlling are hindered by bad access to the relevant information and slows down the development process [3]. Hence, additional support of information retrieval is considered to improve the development process. The considered information includes product information, methods, tools and process information, which are essential for the implementation of a product development process. The concept followed in ForFlow aims at providing the engineer with the most relevant and helpful information. To achieve this optimised retrieval of information a software tool will be developed, which supports the engineer during the development process. The software tool called Process Navigator will give recommendations and guidelines to the engineer how to navigate through the development process.
The Process Navigator is based on several research projects, which are carried out in the context of ForFlow. These include research in process oriented, product oriented or tool oriented topics. In this paper product oriented topics are emphasised, wherein the multiplicity of product information, product models and documents play a major role. The main objective of this paper is the purposeful flexible integration of product models into the product development process. Therefore, the question of how to handle this voluminous data has to be answered by a suitable and consistent description of product models and also how to connect the product models to the product development process flexibly. In addition, the optimisation of information exchange between the product models is also addressed in this research. The approach, which is described in this paper, is a process oriented description of product models, which consists of certain parameters like degree of concretion, or date of creation of the information. In the following subsection the motivation for the project is explained in greater detail.

3 MOTIVATION AND PROBLEM ANALYSIS

The motivation for the sub-project “Integration of Product Models” originates from the needs of companies to reduce their product development costs and manage their processes more efficiently. Like mentioned above, increasing pressure for success and the rapid changes in product development result in a very complex development process. The growing complexity makes it more and more difficult to handle the process. The documentation of information of the product development process and the status of the product is essential for the quality of the process to reach the final product faster and with better product quality. Figure 1 shows the relation of the product development process, product models, information flow and information breaks.

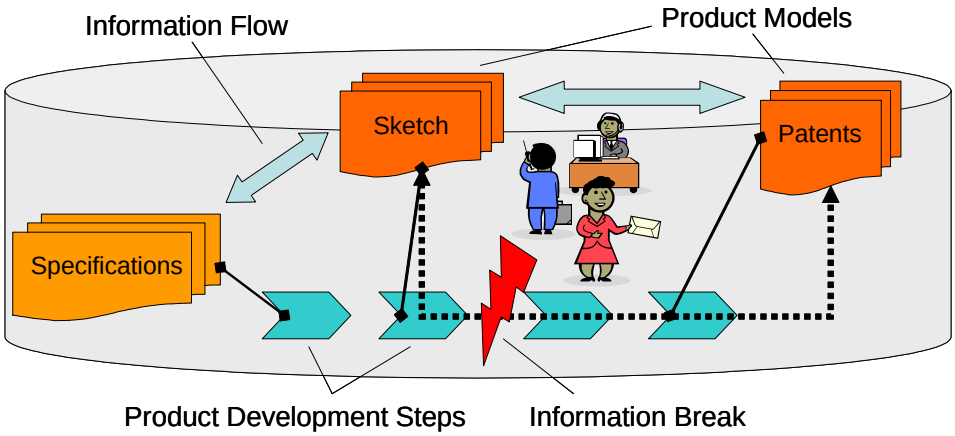

Figure 1. Product Models, Information Flow and Information Breaks in the context of the product development process

Figure 1 shows exemplary product models (sketch, patents, specifications) and their application (connection) in the corresponding product development steps (of the process). E.g. specifications are defined in early phases of the product development process and are linked to the process step "clarification of the specification". Others provide important information for other steps and additionally even influence each other. The dotted line between "Sketch" and "Patents" illustrates this bilateral influence. The indicated Information Break disturbs the information flow between the process steps and the product models. Information Breaks are caused by different file formats for data exchange or communication problems like unclear contact persons (responsible persons).

In the context of complex product development processes, the number of created documents/product models is tremendous. Product models are created in different phases of the product lifecycle as described above. Distributed over the stages, further examples for product models can be drawings, information of quality, promotion flyers, change requests or recycling protocols. This short list gives an idea of the number and diversity of product models generated over the development process. The diverse information and different data formats generated over the different stages of the process complicate the search for relevant and adequate information. Additionally, each engineer has his own special search behaviour, which makes it even more complicated [4]. Engineers spend 60% of their time to search for information and to choose the most relevant [3, 5]. Since current PDM-Systems just allow searching for the name of a document, it does not imply that the given name informs about more detailed information like e.g. the functionality of a component. New ways of structuring could reveal increasing retrieval precision and an easier obtaining of desired information [6]. The Re-use of design is another important aspect, since 75 % of design activities comprise of the usage of already existing information and knowledge [3].

In addition to the difficulties with locating product models in a database, it is also very important to consider the information flow over the development process between the product models (see Figure 1). For the consistency of product models a sufficient information flow between product models is necessary, because during the product development process product models change dynamically and iterations take place. For example the list of specifications changes dynamically and is hardly transmitted to geometry models in later phases of design. This means the transmission of information between product models over different process stages is aggravated. Other research addresses this issue in analysing the lack of common structure and a lack of precise semantics of product models [7]. To overcome this deficit, amongst others, communication between individuals and mainly the relations or linkages between product models and the development process support this information flow. Support of these two aspects can be either manual or computer supported or even a combination of them. Here, concentration on the support by computers is considered, since existing support by PDM/EDM-systems does not work properly or is even not addressed at all [8].

For a better description of this circumstance, the terms "Bad Transmission" and "Information Break" are introduced. They emphasise the interruption of the information flow between the product models, see Figure 1. Typical kinds of information breaks are caused by different media types e.g. diverse data formats, by unclear distribution of responsibility and differences in the time line. Information breaks occur, if e.g. information, which is generated in the phase of the clarification of the task, is not considered in the geometry model. Another example is, if engineers are provided with poor information about possible competent co-workers, which could be used for further information retrieval. Amongst others, reasons for this poor information can be a lack of information about the original source of product models and the diversity of communication channels [8]. For example, if someone needs additional information about a product model, it cannot be specified, who is the most experienced person familiar with the request.

Concluding, problems in today's product development processes are the retrieval of the right information at the right time on the basis of product models and the flow of information between the product models and the individuals. It is a result of a non sufficient integration of product models into the development process. The description of the situation in product development processes referring to product models and the information flow shows the deficits and gives reasons for the improvement of product model integration into the product development process. Although the integration of product models into late development phases is considered to be established well, there is only loose and inadequate integration into early design stages. From the motivation and current problems the objectives of the research in this paper are derived.

4. OBJECTIVES

As described in the previous section, amongst others, problems in product development processes are the quality of the information flow between the product models and difficult retrieval of relevant product models. Hence, research of this paper focuses on the optimisation of the quality of the information flow and the improvement of the retrieval of product models. In the context of this research, the retrieval should be supported by a context oriented integration of product models into the process, which is needed for a flexible integration. This flexibility is considered to be very useful for companies to find a quick start into workflow planning, since they do not have to connect product models to the product development process manually.

The context of the product development process is defined as the situation and boundary conditions under which the engineer works. For example, an engineer, who has deep knowledge and great experience in the functionality of a special part, does not need any further information referring to its functionality. He also knows the right people to contact for required information. On the opposite, someone, who has never worked on such a part before, considers information about functionality very useful to fulfil his task, and also has another group of persons, who he can acquire appropriate information from. Here only two different aspects of a situation are named exemplary.

For the optimised retrieval of product models, the matter of storage of the product data will also be addressed. Therein, a structured way of storage has to be developed, which facilitates the integration of product models into the development process. A handicap for proper integration of product models can be located in early design phases, where the generated product models are not as clearly structured as in late phases. Since product models of early design phases are unclear and can not be classified yet in reference to the process, the goal is to improve product model integration especially into early design stages. At the same time, the integration should help to identify information breaks and increase awareness of them. Knowledge about these breaks allows adjusting of the engineer's behaviour to improve the information retrieval even if information breaks occur. Since it is believed that information breaks cannot be eliminated during this project, the exposure to information breaks should be improved by the mentioned enhancement of awareness.

When talking about the structuring of product data it has to be clarified that it is not the goal of this research to develop an integrated product data model (iPDM) like STEP [2]. In this paper, the product models cannot be equalized with the partial models in an integrated product data model. As defined earlier in this paper product models are defined as all documents and even artefacts, which are created during the development process in a company. It is not intended to put these different documents (all in different data formats) into the iPDM and use a standardized data format. The goal is to leave the product models (documents) in the original form and to add further information, which allows the intended improvement of information flow and retrieval. Additionally, the product models should be linked semantically to guarantee consistency and to facilitate the intended process oriented product model retrieval.

5. STATE OF RESEARCH

The handling of product models is identified as a basic need for the purposeful integration of product models into the product development process. Several researchers have addressed this issue and have developed different methods and approaches for the description of product models. The state of research can be structured to level based approaches, parameter based approaches and design guiding systems, which are explained in the following subsections.

5.1 Level based approaches

Some researchers use different levels of concretion to classify the information included in the product models. One approach describes product models with the three parameters level of concretion, completeness and consistency [9], see Figure 2.

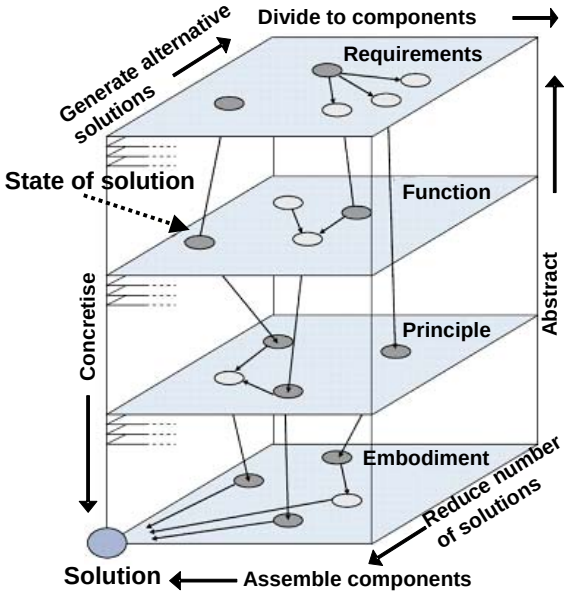

Figure 2. Level based three dimensional space of the development process by Rude [9]

They define a model space and are used to classify intermediate results in the context of the product development process. The degree of concretion itself is divided into four levels (Requirement, function, principle and form). The intermediate results of these levels are documented in partial models of an integrated product model.
A similar approach has been developed by Hartmann [10]. He uses five parameters, which differ slightly from those of Rude. However, the idea of a description in a single space of model is basically the same. The four levels of concretion can also be found in the model of Ehrlenspiel [11]. This approach is included in Integrated Product Development, which uses a hierarchical model for description and presents the different stages as levels. The three level based approaches are the basis for the new approach explained in this paper, using the mentioned parameters for classification of product models. Especially the four different levels of concretion are considered as classifying properties.

5.2. Parameter based approaches

Other researchers developed parameter based approaches. They expect to address bad transmissions between product models more effectively than the level based approaches. Some of these approaches consider the linkage of product models to improve the information flow, like Suh does in his work [12]. He sets the focus on the description of transmissions by using Axiomatic Design with mathematical formulas and matrices, which are transformed by specified rules. Another approach called Property Driven Development (PDD) has been developed by Weber [1]. It gives a new interpretation of the product development process. Here, the early and late phases are diversified by the number of known properties and values of the product to calculate the stage of maturity. The resulting new product model uses a list of properties, solution patterns as well as a list of unsolved problems. Advantages are seen in the handling of alternatives in the product development process and product data as well as the reuse of product information (Design Re-use).
Experience shows that pure parametric based approaches are not appropriate for the goals of this paper, because parameters depend strongly on the chosen solution. Since in early phases most of the parameters are unknown and still have to be defined with great effort, there is a great uncertainty about the actual demand for them in the following phases. However, parameters related to the process are of importance for this research, since product models are planned to be connected to process. The advantage of the new method is seen in the chance for flexible integration of product models into the product development process.

5.3. Design Guiding Systems

Further approaches concentrate on the support of the early design phase to reduce dependency of the designer on personal skills like creativity and experience. Therefore tools have been developed for the

support of the designer by automating the synchronisation of the product models of different development phases. The approach of Brix et al. aims on a better consistency of product models by providing a linkage and synchronisation between product models of different levels [13]. The information flow during necessary iterations is supported by the linkage of levels. Linkage is realised by special approaches e.g. constraint solver, feature-based description or constraint-based description. Brix et al. use the three levels of function, principle and embodiment to structure the development process. Furthermore a catalogue-based repository facilitates the access to predefined elements of diverse levels.
A model of a consequently computer supported product development is developed by Dyla [14]. This model considers aspects like system-neutral interfaces, integrated product models, optimal process management, design guiding systems and the support of early development phases.
The mentioned approaches follow the same objectives as the planned new approach, but do not focus on the objective of creating a flexible integration of product models.

6. SOLUTION APPROACH

This paper describes an approach to realise the purposeful integration of product models into the product development process. The concept for the integration of product models is presented in the following.
As mentioned in subsection 4., the goal is to use meta-data attached to the original product models. The intended approach includes three stages (see Figure 3). The first step consists of the development of a generic description method, which allows a classification and characterisation of product models in relation to the development process. The method should allow to consider the design situation of the engineer and to provide adequate relevant information for the engineer. This means, that product models are flexibly connected to the process and are dynamically related to the process in dependency of the design situation. The second step ordinates the classified product models in a repository similar to a kit. The product models are considered as modules defined by the description (Meta-data). Thus the modules are linked to the process and the designer's situation, which allows the selection of relevant product models. The final step arranges the development of an integration concept of this approach into the Process Navigator, which will be realised until the end of the overall project ForFlow. The product model kit, which emerges from the application of the description method, will be formalized using class diagrams of Unified Modelling Language (UML). Classes will be defined by the parameters of the description method and connected in class diagrams in the notation of UML.

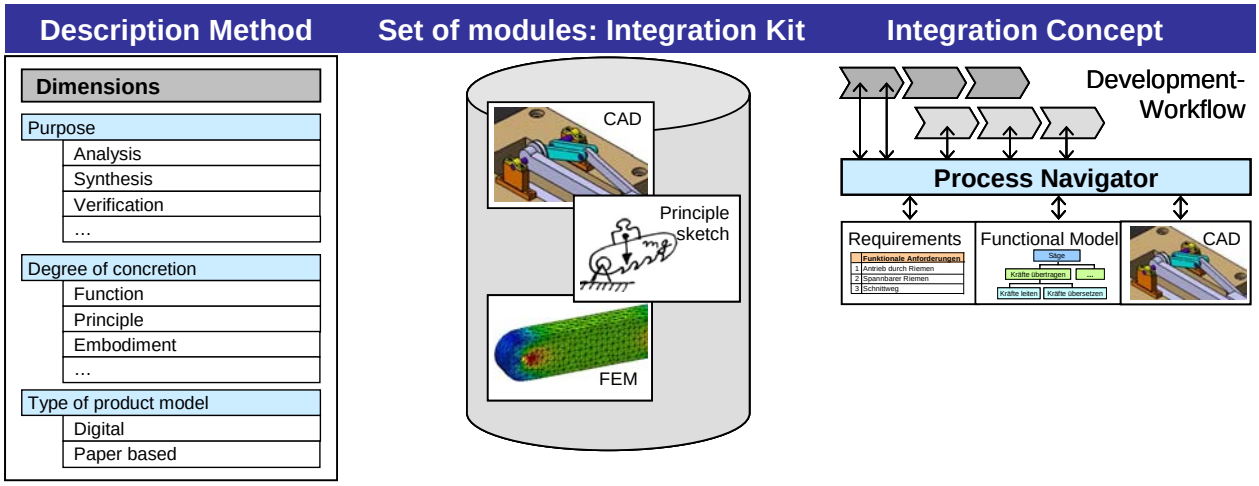

Figure 3. The three stages of the purposeful integration of product models into the product development process

6.1. Towards a generic description method

The purposeful integration of product models into the development process requires information for classification and accessibility. A generic description method will be based on certain parameters addressing the aspect of retrieval and others, which address the process oriented integration. Thereby product models are considered, which document intermediate results. Amongst others, they include

information about requirements of the product and about the given task in the form of e.g. a functional model or black box. Further information can be about direct product properties like geometry models or principle sketches. Indirect properties can be a prototype or a Finite-Element-Method-Model (FEM-Model), which are needed to evaluate the product properties. The description method allows a structuring of product models, which results in a product model kit (see section 6.2.) from which retrieval services can obtain the needed product models. For the achievement of this flexibility suitable parameters have to be chosen. Analysis of existing approaches and case studies in industries will examine current structuring of product models and makes derivation of further useful parameters possible [15].

6.1.1. Retrieval oriented integration

The mentioned product models can be classified by a first set of parameters. So far, following parameters for the description method are chosen in accordance to mentioned existing approaches:

- Type of product model
  This parameter allows differentiation between paper-based, digital or physical product models.
- Purpose of use
  It indicates, if the product model can be used for analysis, synthesis, verification, documentation, evaluation and communication.
- Degree of concretion
  Function, principle or embodiment of a product model is considered by the classification of the degree of concretion.

The next set of parameters addresses the role of product models in relation to the designer's situation. Since the designer's situation includes information about the development process, these parameters allow the context oriented linkage of product models to the development process. In correspondence to another project, which defines the designer's situation, relevant parameters for the connection of product models to the designer's situation are identified as follows:

- Phase of the process
  Classification by this parameter is essential for purposeful integration of product models, since dependent on the *phase of the process* different product models are most appropriate. Especially the distinction between early and late design phases allows a first efficient classification, because the content of product models of early design phases is conceptual and leaves room for further creative problem solving. In contrary product models of late design phases are more concrete and provide information relevant for the embodiment or realisation of the product.
- Partial process steps
  The parameter *partial process step* is independent from the design phase. Re-occurring process steps are e.g. goal analysis or finding a solution. This parameter uses a further dimension to classify the product model and thus allows a more accurate classification.
- Methods
  Methods of systematic product development can cause changes of the content of product models. To maintain the consistency of product models, it is helpful to know the influence and relation of methods to product models. For instance the application of the method brainstorming can generate sketches, which relates the product model "sketch" to the method "brainstorming".
- Development tools
  Both, methods and development tools are considered important for the documentation of product models. Especially in early design phases, they can support the capturing of product models to make them available for others as well as to complete partial product models into applicable product models. Corresponding methods and tools still have to be examined. Thereby, the relation between benefit and effort has to be considered, because on the one hand more documentation increases the chances for Design Re-use, but on the other hand additional effort is needed for documentation.

These parameters have not been evaluated yet and still have to be adjusted to further analyses, which are planned with industrial partners in the near future. The set of parameters will be extended by considerations about information breaks, which will be part of future work, see section 7.

6.1.2. Process oriented integration

These first sets of parameters are part of the basis for the synthesis of the description method. Because the above mentioned parameters mainly address aspects of retrieval, the following section deals with the process oriented integration of product models into the development process.

The description method will partly follow existing level oriented approaches of product concretion (see section 5.1.). The levels of concretion will be extended by further dimensions and parameters like degree of detail, consistency, completeness and reliability. The introduction of these further parameters helps to describe product models more detailed. This makes it possible to identify their position in the overall process for example in a release process. The values of the parameters indicate the status of the release process. It can be accepted if the software tool can decide based on the values of parameters, that the considered product model is complete and consistent. At the same time, the degree of reliability gives information about the quality of the product model which the calculation or decision is based on..

Since the parameters define the position of the product model in the model space (see Figure 2), this integration into the development process is not static but flexible. With every change of the parameters, a new version of a product model arises and is automatically linked to the process as well as the designer's situation (Dynamic Integration of Product Models). The used retrieval services consider the designer's situation in the process and search for closely located product models. The positive effect of the intended parameters is the possibility to support engineers in their decision dependent on their actual task and situation dictated by the process and the environment.

6.2. Product model kit

The description method allows the definition of product models as modules (UML-classes). The modules consist of the common overhead (retrieval and process oriented parameters) and the specific content of the product model. The definition of formalized modules and the storage in a repository or product model kit allows retrieving relevant data. The set up of a product model kit and the consideration of the designer's situation facilitate the derivation of concrete recommendations for action. This includes proposals for accessible product models, which can be most relevant for information retrieval. Furthermore the storage of the defined product models in a repository and the previously considered semantic relations between product models and the used description parameters make it possible for the Process Navigator to retrieve potentially relevant product models. For example, if the designer's situation includes the search for solution, the system can provide possibilities for the reuse of previous solutions contained in product models. This means the designer is provided with relevant information, which helps to find a suitable solution faster than without a situational retrieval of information.

6.3 Concept of Integration of product models

So far, only the description method and the product model kit are described. For the actual use of the description method, the product model kit with its description elements has to be integrated into the Process Navigator. The concept of integration is explained in this section.

In the context of future integration, the product model kit represents only one part of the Process Navigator's functionalities. Therefore, interfaces to other modules of the Process Navigator have to be defined for proper integration. In coordination with other subprojects, possibilities for the technical realisation of the functionalities have to be discussed. This includes information about the saving of the product model kit in a database and corresponding search and retrieval services. Furthermore, the Process Navigator should guide through the development process by proposing certain steps. This is required for the purposeful creation and reuse of product models. Additionally, the user interface has to be realised intuitive and ergonomic to prevent the disturbance of the every day work life of an engineer. The quality of the interface related to this aspect is very important, because it enhances the acceptance of the product model kit in industrial practice.

7. FUTURE WORK

Future work will include further analysis of product models and information breaks in companies. The acquisition of data for the analysis will take place at industrial partners. Thereby, existing repositories of product models will be analysed with the focus on the identification of further parameters. The aspect of the linkage between product models will be emphasised. The identification of information breaks is inevitable to assess the information flow. The influence of the information breaks on product models will also be analysed during the research in this project. Basis for the analysis will be the large scale development process of an automotive manufacturer. Additionally, it is necessary to examine existing methods and tools, which have potential to be useful for the enhancement of documentation especially in early phases of design. This includes the search for such tools as well as an evaluation in relation to the relevance for the purposes of this research.

After the mentioned detailed analysis of product models and information breaks, requirements of the description method have to be derived and existing parts of the method have to be evaluated. The set of requirements helps to assess the introduction of new parameters and allows further evolution of the approach.

Afterwards, the developed approach has to be integrated into the software tool called Process Navigator. Close cooperation and coordination with other partners in the project is needed to specify interfaces between the approach and the Process Navigator. The examination of the feasibility of the integration has also to be considered.

Finally, it is planned to deliver a proof of concept and a concept for possible optimisation steps of the developed approach. In cooperation with industrial partners different scenarios will be used to evaluate the process.

8. CONCLUSION

This paper explains a new approach, which supports purposeful integration of product models into the development process. The described approach represents a concept, how to encounter the mentioned problems in product development processes. The objectives of this research can be summed up to the optimisation of the quality of information flow between product models, the improvement of the retrieval and the support of context oriented integration of product models into the product development process. The objectives are derived from the analysis of the current situation in product development processes. Therefore the motivation for this research is explained. It is identified, that a current problem in today's product development processes is the insufficient integration of product models, which expresses in bad information retrieval and disturbed information flow between product models. It is stated, that information breaks can be responsible for the lack of consistent product models. Furthermore it is explained, that use a static integration of product models, since they connect product models with process manually. Because of these problems and the time-consuming current integration of product models into the product development process, a new approach for integration is considered to be useful. In chapter 3, a short introduction to the state of research gives an idea of existing approaches. The mentioned approaches are distinguished between level-based and parameter-based approaches as well as design guiding systems. Some aspects of theses approaches are adopted to the new approach. Especially the approach by Rude [5] provides input about the description of the model space by using dimensions like degree of concretion, of completeness and consistency. The described new approach includes the development of a description method, a product model kit and a concept for the integration into the Process Navigator of the overall project ForFlow. The description method is used for the classification and characterisation of product models in relation to the development process. The consistent description defines product models as modules, which can be stored in a repository in form of a product model kit. This takes care of the storage and retrieval of product models. The kit facilitates the improvement of integration, since it helps providing the right product model at the right time to the designer. This reduces the time for finding this information and increases the quality of the retrieved information. Additionally, the considered requirements of the concept for the integration of the new approach into the Process Navigator are mentioned. Finally, future work will include further analysis of product models and information breaks, their influence on product models and the extension of the description method. Furthermore, the product model kit still has to be defined using UML and the integration concept into the Process Navigator has to be realised.

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Contact: Wolfgang Lauer
Technische Universität München
Institute for Product Development
Boltzmannstraße 15
85748, Garching
Germany
+49(0)89/289-15136
+49(0)89/289-15144
WolfgangLauer@pe.mw.tum.de
http://www.pe.mw.tum.de