PRODUCT MODEL DRIVEN DEVELOPMENT

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ABSTRACT

Product development processes are characterised by a high division of labour to reduce time to market and to optimise cost efficiency. Concurrent engineering addresses these requirements, but at the same time increases the complexity of the product development process. To handle this complexity, appropriate process planning and support for the execution of tasks is needed which arranges product models, controls the information flow and considers the design situation and the process itself. Since product models are considered to be the driving elements of a product development process, this paper proposes an approach called Product Model Driven Development (PMDD) to support managers and engineers, who are in charge of process planning and execution of tasks. Because product models and the design situation are closely related, this approach is based on description methods for both aspects. Hence, this contribution also presents approaches for the description of product models and the analysis of the design situation.
The combination of these two factors builds the framework of Product Model Driven Development. Furthermore a permanent link between project planning and operative work shall be achieved.

INTRODUCTION

Companies need to reduce their costs and to manage their processes more efficiently. The increasing pressure for success and the rapid changes in product development result in a very complex development process. This is especially the case for concurrent engineering, because the requirements for the management of parallel tasks increase. The growing complexity makes it more and more difficult to handle development processes. Since product models are essential for the documentation of results and the execution of the process, a characterization of the process by product models is considered to be useful. Hence, this contribution outlines an approach called Product Model Driven Development (PMDD), which considers product models as driving elements. The approach also includes a description of the design situation, which cannot be neglected in a development process, since there are bidirectional interdependencies between the product models and the design situation. The latter supports the consideration of the specific boundary conditions such as complexity of the task. The consideration of the design situation for development process planning allows further improvement of the retrieval of product models. Both, product models and the design situation have great influence on the process to reach the final product faster and with better quality. To allow the PMDD approach, new description methods of product models as well as the design situation are developed.

MOTIVATION AND PROBLEM ANALYSIS

Problems in today’s product development processes are the insufficient integration of product models into the process and the disregard of the design situation in which product development takes place. This hinders the process planning. To give a more detailed explanation of the motivation for this contribution, figure 1 shows the relation between the product development process, the product models, the information flow, the information breaks and the design situation. In this contribution, product models are defined as all documents and artifacts, which describe (intermediate) results and store product information e.g. sketches or prototypes. The design situation is analysed concerning the factors that have the main influence on planning product development processes.
During the development process, several product models are generated, which are required in multiple process steps. Since many product models demand information of other product models, information has to be exchanged (information flow) between them to maintain information consistency. However, information breaks such as communication problems or different data formats interfere with the information flow. Additionally, external and internal conditions that define the design situation influence the execution of the whole product development process.

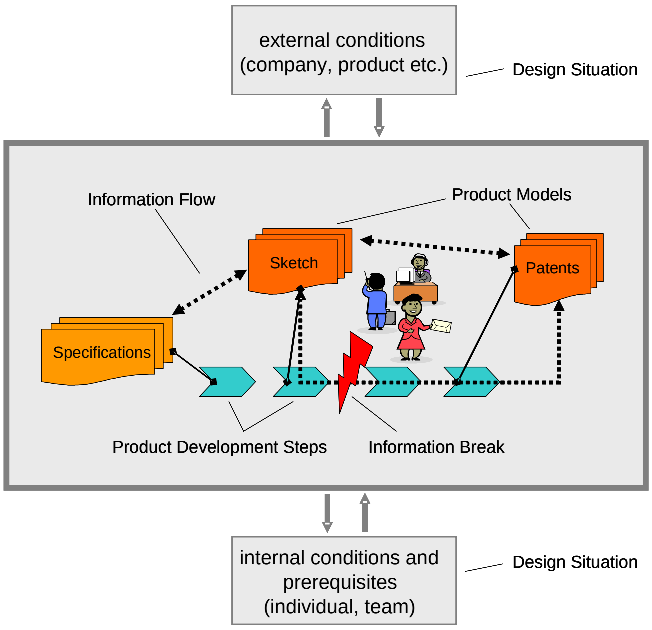

Figure 1. Key Aspects of the Product Development Process

Since product models and the design situation depend on each other closely, the isolated consideration of these two aspects by new description methods is rated not to be enough. For example, the objective of the product model description is the improvement of the retrieval of the right information at the right time. For this definition, the knowledge about the design situation of the designer is essential. Without the design situation, an evaluation of the importance of information cannot be done. Therefore, the decision, if the considered information is the right information at the right time, is impossible. Furthermore, the description method for product models allows the retrieval of relevant information dependent on the position in the process as it is described later on in this contribution. Here it has to be clarified, that the design situation itself delivers the information about the position of the task in the process, which means without the design situation, the current position in the development process is unclear. Vice versa, for the clear definition of the design situation, it is important to know, what product models are already known. This information can be provided by the product model description and design situation analysis. According to the mentioned problems and deficits the objectives of this paper are derived and explained in the following.

OBJECTIVES

The intention of this contribution is to enable a better product development workflow by analysing and connecting the development process, product models and the design situation. A workflow will be supported by this connection because it improves the situation-specific retrieval of information for the process planning as well as for the design engineer. This refers not only to geometrical data but to all data originating from the product development process. The connection will be realised by linking product information to the development process, providing a process-oriented description of product models and defining a product-oriented description of the development situation. All of this sums up in an approach towards Product Model Driven Development. This approach focuses on product models as the main result of development processes.

IMPORTANT ASPECTS OF PRODUCT DEVELOPMENT

In order to be able to describe the approach towards Product Model Driven Development, it is essential to clarify the major aspects regarded in this approach. A characterisation of product models, development processes and design situations as they are understood in this context will be given. A possibility for the integration of these three aspects will be depicted in the PMDD approach later on.

Product Models

The handling of product models is identified as a basic need for the purposeful integration of product models into the product development process. In this contribution, product models are defined as all documents and artifacts, which describe (intermediate) results and store product information e.g. sketches or prototypes. Several researchers have addressed the issue of purposeful integration and have developed different methods and approaches for the description of product models. The state of research can be divided into level based approaches, parameter based approaches and design guidance systems.
Level based approaches use different levels of concretion to classify the information included in the product models. One approach describes product models with the three parameters degree of concretion, completeness and consistency (Rude 1998), see figure 2.
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 embodiment), which can also be found in the model of (Ehrlenspiel 2003). The intermediate results of these levels are documented in partial models of an integrated product model. A similar approach has been developed by (Hartmann 1996), where the idea of a description in a single space of model is basically the same. Especially the four different levels of concretion of Rude and Ehrlenspiel are considered as classifying properties.
Parameter based approaches are expected to address bad information 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's Axiomatic Design (Suh 1998). Another approach called Property Driven Development (PDD) has been developed by (Weber 2002). He distinguishes by the number of known properties and values of the product to calculate the stage of maturity.
The approaches using design guidance systems concentrate on the support of the early design phase to reduce the 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 (Brix 2003). Brix

et al. use the three levels of function, principle and embodiment to structure the development process. Another approach of a computer supported product development is described by (Dyla 2002). His model considers aspects like system-neutral interfaces, integrated product models, optimal process management, design guidance systems and the support of early development phases.

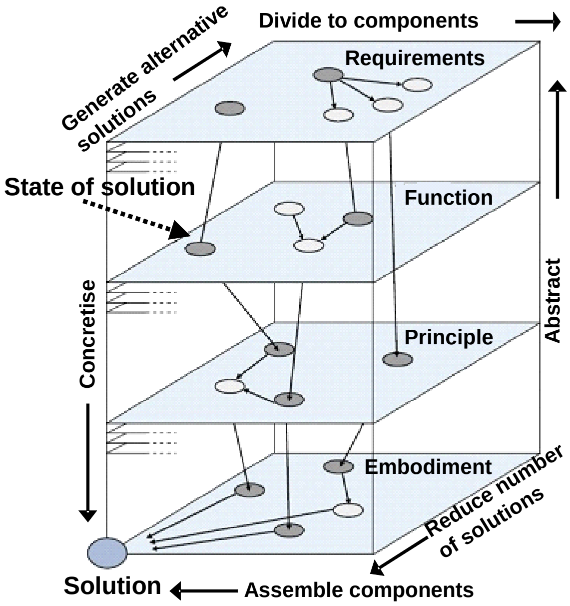

Figure 2. Level Based Three Dimensional Space of the Development Process by (Rude 1998)

The level based approaches are considered to be useful to characterize the product models in relation to the process. Especially the approach by Rude is used as basis for the development of a process oriented product model description as described further on. In particular the design guidance systems support the information flow and the maintenance of consistency, which delivers input for the selection of suitable parameters. Additionally, the approach by Weber gives hints how to measure the degree of maturity, which helps with the characterization of product models in the process.

Development Processes

According to (Harrington 1991), a process is an activity or group of activities that takes an input, adds value to it, and provides an output to an internal or external customer. Coming from a more product development oriented view (Vajna 2005) regards a process as a meaningful set of sub-processes and activities to solve a certain task. Here, activities are logically enclosed operations that contain at least one or more working steps. Activities are started by events, require a certain input, and produce certain events and results respectively. (Blessing et al. 2007) point out, that activities may have manifold interactions and that resources are required to produce an output from a given input. In summary, a process can be regarded as the transformation of a defined input into a defined output.

As many of the definitions above have shown, processes can be decomposed into nearly any number of sub-processes, activities and operations, often referred to as process modules. The utilisation of such process modules is commonly suggested for the management of product development processes (see e.g. Bichlmaier et al. 1999, Freisleben 2001, Meissner 2006). The process decomposition enables the differentiation of more defined partial processes as it is necessary for adequate planning and assignment of (design) processes.

Unfortunately, the best level of decomposition cannot be defined in general. Rather it depends on the specific objectives of the modelling and planning issue. While it might be necessary to look at a very detailed process level for example in cognitive design research, it is sufficient to stop decomposition on a very high process level with respect to multi project management. However, according to (Lindemann 2007), four main levels of design process decomposition shall be distinguished in the following (cp. Fig. 3):

- **strategic process level** (with only generic processes and roadmaps respectively)
- **project level** (with rough stages but a clear vision of outcome)
- **operational level** (with interrelated activities but vague certainty of final outcome)
- **action level** (with elementary processes)

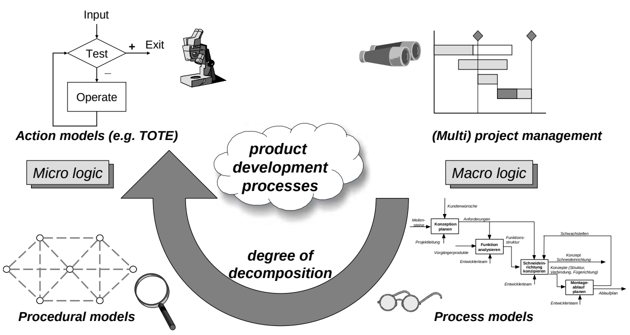

Figure 3. Design Process Models on Different Levels of Decomposition adapted from (Lindemann 2007)

For concrete planning of design processes neither the strategic nor the action level are of much interest. Rather, process planning should take place on the project and the operational level. Both levels are by far more object oriented and thus enable the necessary consideration of design problem structure, product structure, and organisational structure (Ropohl 1999, Beneke 2003). Here, it is necessary to switch continuously between project and operational level, especially with respect to ensuring target oriented navigation through the design process. While the project level suits better to keep the desired project output, the overall project conditions and constraints as well as pre-planned activities (e.g. work packages) in mind, the operational level is more adequate when considering steps/activities to be performed next as well as to allocate resources, means, and methods for process execution. The structure of design processes strongly depends on the situational conditions of the design process in question, which will be addressed in the following section.

Design Situation

In recent years some approaches towards the description of design situations have been introduced. These approaches mainly vary in granularity between a strategic and an operational level. E.g., (Hales and Gooch 2004) as well as (Meissner 2006) cover the analysis of design situations on different levels, whereas e.g. (Badke-Schaub and Frankenberger 2004) focus on the design engineer's daily work. Most approaches want to achieve a holistic picture of the design context (to be understood synonymously to design situation) and therefore establish many different parameters, some of which can only be analysed in hindsight and thus are not applicable for process planning. It is important to note here, that it is not the goal to achieve a complete characterisation of the design situation, but to consider the most important parameters that allow a situation-specific configuration of the development process.

One classification of design context is introduced by (Dylla 1990). The degree of novelty and the amount of given solution elements respectively (new design, adaptive design, variant design), the kind of design problem with respect to the main requirements to be solved, the complexity (as well applied e.g. in Meissner 2006, Hales and Gooch 2004, Badke-Schaub and Frankenberger 2004) and the type of product, the manufacturing type (one off or serial production), and finally the transparency of product characteristics are supposed to be the main characteristics of a design context here.

(Wallmeier 2001), for example, applies amongst others the factors "number of changes in requirements" and "number and duration of discussions" in his situation analysis, which can only be analysed after the task is fulfilled. As another factor he introduces "communication", which is undoubtedly an important factor in development work but which is hard to be measured. In regard to the requirements for situation analysis mentioned above these factors are not applicable in this case, because they cannot be used for process planning.

APPROACH

The intended approach towards Product Model Driven Development is expected to improve product development processes. To achieve this, a special description of product models and analysis of the design situation is needed. After the description of these methods, the approach towards Product Model Driven Development is presented, which includes the connection of product models and design situation.

Product Model Description

This section outlines a generic product model description method for the purposeful integration of product models into the product development process. Thereby product models are defined as all documents or files, which document intermediate results e.g. a list of requirements as the intermediate result of the clarification of requirements. The description method is explained in the following.

Since the quality of the retrieval of product models depends on the structured storage of them, classification and accessibility are necessary for purposeful integration of product models into the development process. This description method claims to be generic to provide the possibility to be adapted universally to different scenarios. It is based on certain parameters addressing the aspects of retrieval, process oriented integration and the design situation. The usage of parameters provides a structuring of product models, which facilitates the retrieval of product models dependent on the position of the designer in the development process. The parameters are used for classification of the product models and are divided in retrieval and process oriented integration as well as parameters addressing the design situation.

The used retrieval oriented parameters are:

- **type of product model** (paper-based, digital or physical product models, etc.)
- **purpose of use** (analysis, synthesis, verification, etc.)
- **degree of concretion** (Function, principle or embodiment, etc.)
- **Development tools** (Electronic Data Management, object modelling tools, groupware, simulation software, etc.)

Another set of parameters consists of process oriented parameters, which follow existing level oriented approaches of product concretion, see section Product Models. The levels of concretion are 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 enables the control of certain processes such as a release process, which can be controlled by the value of product parameters. Using the parameters helps to decide, if the considered product model meets the requirements of completeness and consistency. The decision is supported by the information about the reliability of the identified properties of the product model. The process oriented integration of product models facilitates the support of engineers with their decision about the completeness of the product model.

Amongst the mentioned parameters, an additional set of parameters considers the relation and interdependencies to the design situation. This set allows the linkage of product models to the designer's situation, which itself includes information about the development process. Relevant parameters 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 an efficient classification, because the content of product models of early design phases is conceptual and leaves room for further creative problem solving. 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 Quality Function Deployment (QFD) can generate new cognitions about the quality of functionality of the product. The determined quality needs to be matched to quality standards and eventually adapted to the new cognitions.

This set of parameters will be extended by considerations of information breaks, which will be part of future work.

Analysis Of The Design Situation

The situation analysis for process planning, as proposed in this contribution, will take place at two levels of decomposition that lead to two levels of planning respectively. These are the project and the operational level as mentioned above. The interaction between these levels of planning, i.e. switching between both levels of detail while planning, is essential in order to achieve a high value of information and transparency of the process plans. To achieve a context description that is feasible for process planning, we focus on factors that can be measured and at least estimated at the beginning of a process. Due to the different levels of detail in planning, these situational parameters have to be described specifically for both levels. Some of these parameters are only relevant for one of these levels of decomposition while others apply for both levels but regard different aspects. There are also parameters that have to be considered in general without taking a specific level of process detail into account.
The general parameters for the situation description chosen in this approach are:

- Design problem and requirements
- Process results (i.e. the required outputs)
- Degree of novelty
- Complexity of the task.

The situation-describing parameters that are considered on the project level are:

- Customer
- Risk
- Project constraints
- Structure of the design problem
- Number of units produced

On the operational level the influencing factors regarded are:

- Product models available/process up to the present point (Input)
- Required output/planned succeeding process steps
- Structure of partial design problem
- Operational constraints (organisational, individual, environmental prerequisites)
- Main DfX requirements
- Interdependency with other process participants (number of interfaces)

Depending on the situation analysis the overall product development process is adapted for the project on hand. Most companies nowadays use generic development processes to plan their projects. Based on this company-specific framework or based on a general approach as e.g. the (VDI 2221 1993) respectively, the situation-specific process adaptation takes place. Project processes usually just give a rough outline of the engineer's work. They involve information about the development task, the project milestones and the people that have to coordinate their work. Thus, elements of the project-specific adaptation can be for example the determination of the length of process steps, the order of the steps or the definition of a suitable project organisation.
It is a focus of this approach to provide a tool the engineer can use for planning his project work as well. After an analysis of the design context on the operational level taking into consideration the factors defined above, recommendations for potential process steps or chains will be given. At this degree of decomposition suitable process steps have to be defined in more detail than the steps applied to the project level. Even though the level of detail varies and the parameters that describe the situation on these levels differ, it is very important to establish the possibility of switching between the levels of planning in order to provide navigation through the development process.
To support this kind of development process planning, a process knowledge base has to be implemented from which process steps can be taken in order to configurate the project processes. Depending on the context specification a search for and recommendation of process steps or process chains will be initiated in the knowledge base. Based on the situation analysis process steps can be modified and finally put together as a complete product development process.
The process planning support will provide the documentation of actions taken during the design processes. This documentation is needed in order to be able to reuse best practice processes and to evaluate which order of process steps maybe did not lead to the designated target and therefore should not be recommended in the future. Moreover the possibility of defining and registering new process steps in the knowledge base will be established in case new situations arise, which cannot be met with already documented process steps. After finishing a development project its process quality is evaluated and thus further information about best practices can be gained and reused over time.

Product Model Driven Development

Based on the product model description and the design situation analysis, the approach towards a Product Model Driven Development process will be illustrated in the following (cp. Figure 4).
This kind of development process shall facilitate the implementation of a better engineering workflow, by specifically supporting the operational working level. The focus on product models, which are the objects (information,

respectively) that have to *flow* through the process, emphasizes this support.

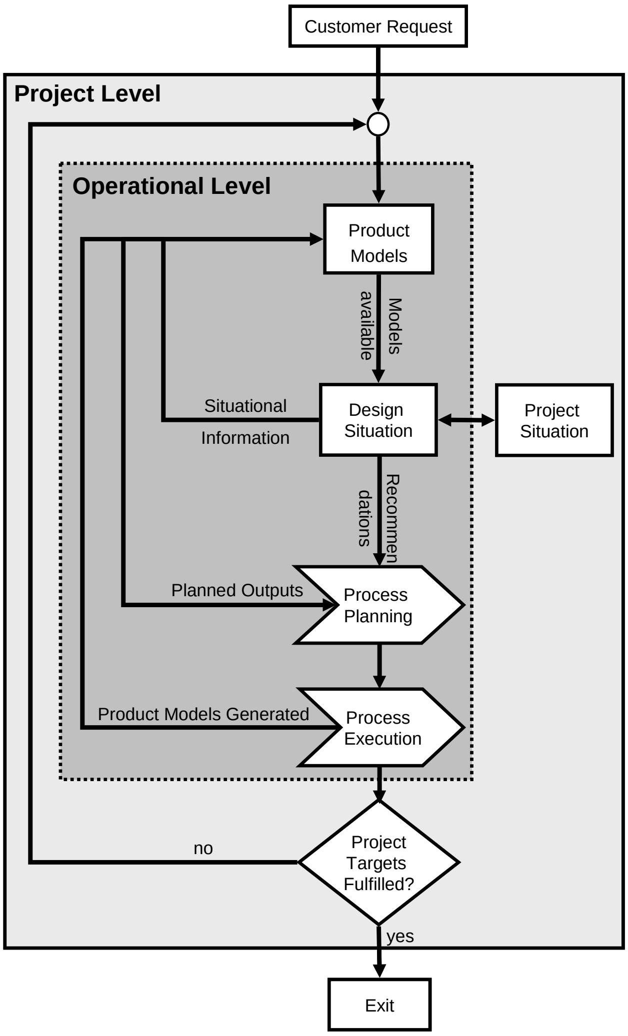

Figure 4 Product Model Driven Development Process

In this model a product development process starts with a request by an internal or external customer. This request initiates a project. On the project level the strategic decision has to be made whether the request shall be accepted or not. If this decision is positive, the project work is executed on the operational level. The first step on the operational level is analyzing, which product models are available. After the first customer request these can be documents provided by the customer or meeting protocols, in later project phases product models can be e.g. sketches, CAD-data, prototypes and so on. The information about product models available is the essential input for the situation analysis on the operational level. Here, the constraints and influencing parameters on the operational level are regarded as well as the project situation.

As described above, according to the situation analysis recommendations for further process steps are provided. At the beginning of a project this can be planning and analysis of the project goals or generating a project plan. In later project phases these recommendations might be e.g. the initiation of a simulation or building a prototype.

The planned process steps are carried out next. After finishing the current process step, the results are matched with the project goals. To achieve the product model orientation, the overall project goals are defined as product models that have to fulfill certain requirements. A project is finished, if the product models generated in the current process step correspond to the ones defined as the project goals. As long as the models do not match, new operational process steps have to be started. This loop implements the connection between the project and the operational level. Within the operational level there are circuits implemented as well, in order to support the product model focus properly. The first loop is institutionalized between the product models and the design situation. As mentioned before, the models available are the essential input for the situation analysis, but on the other hand, information about the situation has to be given to the product models. This information concerns the situation-oriented model describing parameters. These are as illustrated above the process phase, partial process steps and methods, for these are considered in the design situation. Information about the design situation is necessary to anticipate which models should be generated next or which models still have to be built in order to achieve the project goals, respectively.

Another information exchange is implemented between process planning and the product model base. Process planning consists of the selection of the next process step(s) and the assignment of resources, times and further planning details. Since every process step has the goal to develop new product models, the purpose of the model to be developed or complemented in the following step is reflected to the product model base. Taking into consideration the available models and the situational information the product model base suggests a suitable type of product model and the development tool it can be generated with as well as a degree of concretion appropriate for the current design phase. These recommendations are essential for planning an appropriate output for a certain process step.

In the process execution step the product models anticipated are developed. Since the product models developed often do not match exactly the models planned it is the actual available models that have to be considered for the determination of whether the project goals are fulfilled or not. Therefore the actual models are considered on the project level for the decision whether to start a new circuit or to exit the project. The product models generated in a process execution step are added to the product model base, so that these models can be regarded as new input for the next situation analysis.

The focus on product models as the main (intermediate) results of development processes is expected to facilitate a development workflow, because it improves process transparency. This is achieved by providing an overview of the product models available and taking into consideration the design situation for every new process step. The link between project and operational level helps to keep the overall project goals in mind as well as the resources on hand for the next process steps.

CONCLUSION

The complexity of product development processes requires an intelligent and powerful process planning. To provide sufficient support for process planning, an approach named Product Model Driven Development is proposed. On the basis of existing product models and the project situation of a certain development process, the design situation can be defined and used for planning of further process steps. Thereby, for the definition of the design situation, information exchange is required between the description methods of product models and the design situation. The used description methods of both aspects follow existing approaches (e.g. Rude 1998 and Blessing 2007), which are described in this paper. Afterwards, the adapted description methods are explained and integrated into the approach Product Model Driven Development. The connection between product models and the design situation allows the improvement of process planning. It facilitates the information flow, which reduces inconsistencies and uncertainties. Because the design situation is addressed properly in this approach, the process planning becomes more accurate and reliable, which leads to fewer iterations and shorter development processes.

FUTURE WORK

The approach proposed in this contribution is the result of project work in the research alliance ForFlow up to this point. The next step will be the further discussion and completion of the model. The applicability of PMDD has to be evaluated in collaboration with the associated companies in the following. Concepts for the implementation of the single aspects of PMDD have to be generated subsequently in such detail, that a prototypical implementation of PMDD in the associated companies is enabled. The prototypical implementation will be used to evaluate the benefit that can be generated by applying this type of process modelling. Moreover further room for improvement can be identified and integrated into Product Model Driven Development.

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