ICED13
INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED13
19-22 AUGUST 2013, SUNGKYUNKWAN UNIVERSITY, SEOUL, KOREA

KNOWLEDGE BASE FOR SUPPORTING THE HANDLING OF PRODUCT MODELS IN ENGINEERING DESIGN

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ABSTRACT

Product models are the medium of capturing and transporting information about the product in engineering design. The correct handling of product models is important for efficient and effective product development processes. Currently, existing best practices or support measures for handling product models are often not available for the product developer. This leads to an inadequate use of product models and consequently to inefficient and ineffective product development processes. In this paper, we propose a knowledge base that supports the application of best practices and existing support measures to support the handling of product models. Requirements for developing the knowledge model are identified in industry study in form of model-related situations and tasks that need to be supported. The knowledge base is described in the paper and initially evaluated by implementing a support tool for the task of developing a product model. The insights from this work can not only be used in supporting the handling of product models in engineering design, but in principle in all fields of applications where models are used in order to enable a more efficient way of handling information.

Keywords: product modelling, good modelling practice, design process support, information management, knowledge management

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1 INTRODUCTION

The efficient provision and distribution of information about the product is one of the core success factors in engineering design. The exchange of information can be seen as the "lifeblood of product development" (Eppinger, 2001). Product models – as formal representation of the product – are the essential medium of capturing and transporting information about the product. Many different product representations are used in product development processes (Chandrasegaran et al., 2013). In a product development project, the stakeholders work with product models for different purposes: for example to represent, analyse, communicate and store information. An incorrect handling of product models can lead to errors in the product development process and can have a severe impact on product quality and product development process efficiency. For example, decisions that are made on the basis on insufficiently validated simulation models can lead to product failure in later process phases. Therefore, knowledge about how to handle models within product development should be available for product developers. Currently, no support for providing this needed knowledge and methodological support exist. We claim that this support can be provided by a knowledge base that contains the relevant knowledge supporting the handling of product models in product development processes (see Figure 1). The knowledge base can be used to support and assist the product developer in handling product models by providing adequate methods, guidelines and rules.

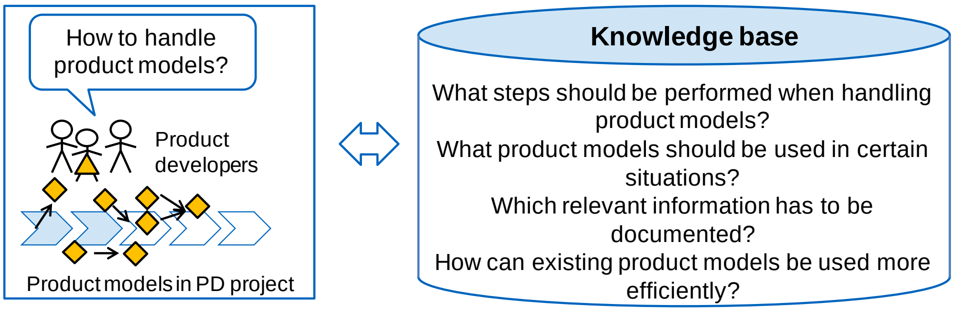

Figure 1. Initial situation and aspects of the needed support by the knowledge base

In this paper, we present the development and initial applicability evaluation of the knowledge base. First, we describe briefly our research method. We provide the necessary state of the art by defining the most relevant terms and a short introduction in information management in engineering design and knowledge representation. In the next section we present the results of and industrial observation that was performed in order to analyse the different modelling situations in the product development process and to deduce requirements for the indented support. Then, the structure of the proposed knowledge base is described in detail. Finally, we evaluate the knowledge base by instantiating it with knowledge necessary for supporting product modelling and provide an outlook on further work.

2 RESEARCH METHOD

As research method to achieve the above stated goal we used Design Research Methodology (DRM) as proposed by Blessing and Chakrabarti (2009). Our overall objective is to provide a possibility to support the product developer in handling product models in order to improve the information management in product development. For research clarification we did a literature review about models in general, product models in engineering design, information management and existing best practices in modelling. Our central research question can be stated as follows:
How can knowledge about handling product models be captured within a knowledge base and used for supporting the product developer in using product models in the product development process?
In the Descriptive Study I, we investigated the use of product models within an industry observation. It delivers the practical background and requirements for the specification of the problem-solving expertise and the required specification of the communication between user and the intended knowledge-based system. Our solution approach (the knowledge base and the steps to be supported with the knowledge base) is developed within the Prescriptive Study. The focus of this paper lies on the prescriptive study. In the Descriptive Study II we evaluated the applicability of the developed knowledge base by implementing a workflow-based software prototype that supports the developers of a case study in the automotive industry.

3 DEFINITIONS AND STATE OF THE ART

For better understanding in the following sections we want to clarify most relevant terms and present the existing research gap.

3.1 Product models and their role in engineering design

Information plays an important role in product development processes. We define information as described by Aamodt and Nygard (1995) in comparison to data and knowledge: data are syntactic entities, information is interpreted data and knowledge is learned information. In product development processes, information concerning the product is captured within product models. Models, in general, can be seen as “representations of something” (Hannah et al., 2012). Models are used in manifold applications in engineering design: for example, process models are used to support process planning and monitoring (Browning et al., 2006); structural models are use for complexity management (Eppinger and Browning, 2012); simulations models are used for exploring dynamic system behaviour (Birta and Arbez, 2007) and knowledge models for knowledge management or information retrieval (Schreiber et al., 1999). Based on the general definition of model by Stachowiak (1973), a product model can be defined as *“a representation of the product. It reflects some of the products properties or characteristics that are relevant for the creation or use of the product. It is used in place of the product with respect to certain users, within a certain time and for a certain purpose.”* (Kohn et al., 2012). Different types of product models exist – for a classification of product model types please see (Kohn et al., 2012). Table 2 gives an exemplary overview on product models in engineering design.

Table 1. Product model types adapted from (Chandrasegaran et al. 2013)

Pictorial	Symbolic	Linguistic	Virtual	Algorithmic
Concept sketches	Product architecture	Customer Requirements	CAD Models	Mathematic Equations
Structural analysis	Bill of material	Solution principles	CAE Simulations	Parametrization
Charts	Flow charts	Customer feedback	Virtual prototypes	Computer Algorithms
CAD model views	FMEA diagram	Service records	Animations	Material selection

In engineering design, a large variety of PDM and PLM systems support the information management by capturing and disseminating data and information about the product during product development and the subsequent tasks (Ameri and Dutta, 2005). Within PDM or PLM systems, product models and the contained information about the product can be structured, versioned and stored. For example, CAD-files (parts and assemblies) are versioned and structured within PDM systems. Some approaches aim at integrating knowledge engineering within PLM-systems in order to capture human intent in addition to bare information about the product (Horvath and Rudas, 2008). Also the capture of design rationale is an interesting field of research that aims at improving the reuse of existing information in the engineering process (Bracewell et al., 2008).

3.2 Knowledge representation and knowledge management

To perform a task successfully, knowledge about how to perform this task is needed. Knowledge can be captured in knowledge-based systems (KBS) that enable a situation-specific access to the needed knowledge (Schreiber et al., 1999). KBS constitute the interface between a knowledge base and the user (Shapiro, 2003). Several Knowledge representation techniques exist that allow the capturing of knowledge among others rules, frames, tagging or semantic networks such as ontologies (Davis et al., 1993). Especially standardized knowledge representation languages such as RDF and OWL become increasingly important for capturing knowledge in recent years. Knowledge-based workflow management systems can be seen as special kind of knowledge-based systems that enable the navigation through a pre-defined workflow (van der Aalst and van Hee, 2002). In Workflow management systems, the respective processes are part of the knowledge base and the single process steps can be enhanced with knowledge also captured in the knowledge base.

Several methodologies give structured guidelines for developing KBS and the acquisition of the needed knowledge for the knowledge base – for example, the Knowledge Acquisition and Documentation Structuring (KADS) methodology (Hickman et al., 1998; Wielinga, 1999) or the very detailed 46-step procedure from Milton (2007). Most of the methodologies contain the following main steps as depicted in Figure 2: First, the scope, the supported activity and the boundary condition have to be clarified. The interaction between the user and the KBS has to be considered carefully in this step. Then, the meta-model of the knowledge base has to be developed and main elements and relations have to be defined. The knowledge base is implemented within a certain representation technique that has to be chosen according to the boundary conditions. Finally, the developed knowledge model has to be implemented in a software system (the KBS) and filled with the needed knowledge.

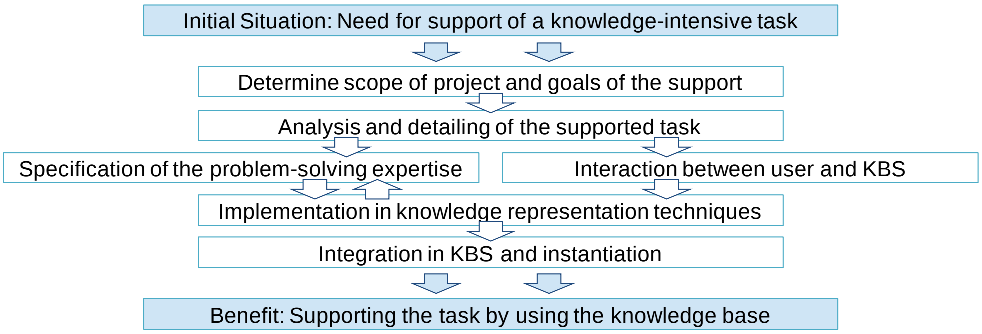

Figure 2. Main steps of the development of a KBS

3.3 Existing approaches to good modelling practice and research gap

Some approaches to achieve “good modelling” already exist in different disciplines focusing each on individual aspects that contribute to good modelling and good models. For example, Crout et al. (2008) identify key aspects of good modelling practice: the definition of a clear purpose, model evaluation and transparency of the model and its outputs. Pidd (1999) provides six principles of good modelling in the field of operations research. For simulation modelling, Sanchez (2007) provides a four-step approach and claims that with this approach it is more likely to achieve functioning models. Several more existing approaches to good modelling practices could be added here. To the knowledge of the authors of this paper, they are all paper-based. Principally, the information and knowledge within these paper-based approaches could help the engineer in handling product models. However, the knowledge in these papers is not available for the engineer during the product development process. We claim that the effort for using this knowledge and applying it for specific problems with product models in the product development process would be too high. This is where we see the research gap: by providing a knowledge based system that provides the necessary knowledge about how to handle product models on the basis of existing problem-solving expertise, the existing knowledge would be more easily available for engineers and the handling of product models can be improved.

4 DESIGN OF THE KNOWLEDGE BASE

The focus of the knowledge base is to support the product developer in handling product models. This chapter describes main results of the design of the knowledge base. By detailing the handling of product models, the supported tasks are identified. The necessary problem-solving expertise is generated on the basis of a literature review and the structure of the knowledge base is presented.

4.1 Determine scope of the knowledge base and goals for the support

The knowledge base is intended to provide needed guidelines and support measures in handling product models. The following Figure 3 describes the steps that have to be executed when using the knowledge base and the results of each step. First, the needed support has to be specified – the knowledge base provides the necessary background for specifying the needed support by adequate checklists or exemplary needs for support. On the basis of the description of the need for support, the knowledge base helps to identify existing support measures as best practices, guidelines or methods for providing this support. The found support measures have to be adapted to the specific needs. The knowledge base provides possibilities the identify differences between the actual need and the existing support measures within the knowledge base. Then, the adapted measures are applied, controlled and – if needed – readjusted during application. Finally, gained insights have to be stored to the knowledge base in order to provide similar, subsequent support need with adequate help.

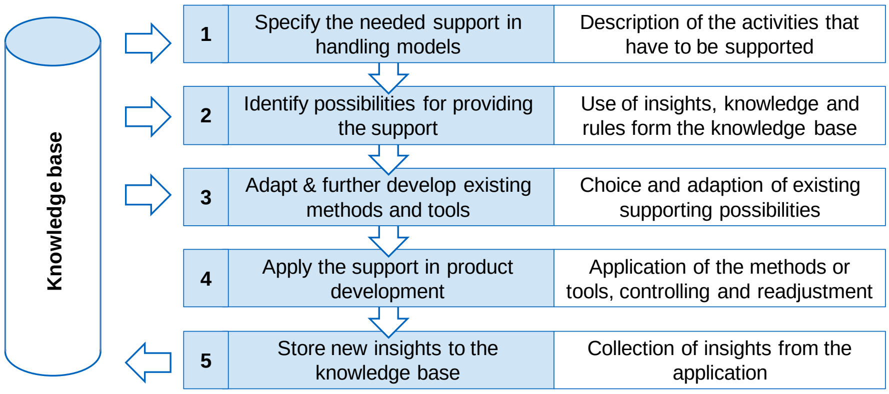

Figure 3. Application of the knowledge base – main steps and benefit

In order to provide the intended support, four main requirements for the further development of the knowledge base are identified:

1. The engineer has to understand what a product model is, what a product model contains and which product models exist (requirement 1)
2. The engineer has to know what task can be performed with product models and where possible support exists (requirement 2)
3. Relevant knowledge how to perform the task and adequate support measures have to be captured and provided to the engineer (requirement 3)
4. Emerging product models have to be captured and needed model-relevant information has to be documented (requirement 4)

4.2 Tasks to be supported when handling product models

In order to identifying the tasks that have to be supported, it has to be analysed what an engineer does with product models in product development. An observation of the handling of product models within industrial applications was performed in order to complement and justify statements about what can be done with product models that can be found in literature. The industrial observations took place within four different departments of the same automotive engineering company. The following main topics were addressed within the industrial observation in order to answer the respective questions (Table 2).

Table 2. Aspects of the observation in order to analyse the supported task

Topic	Aspects / Questions
Steps in the handling of the product models	When are product models used in the product development process? Which steps are performed in the handling of product models? What works very well/very bad?
Used tools	What tools are used for the handling of product models?
Involved persons and teams	Which persons are involved and what experience do they have? What roles to the people have and how do they cooperate?
Information flow	What tools are used for capturing information? How were models communicated?

As result, four main situations when product models are used in product development projects were identified (see left side of Figure 4): existing product models from other departments or previous projects are used for information extraction when information is needed. New product models are to be developed or existing product models are further developed within the department. Also, existing product models can be linked or combined. Finally, product models are used to transfer information to other departments (e.g. milestone documents that have to be delivered). On the basis of these situations, eight tasks performed with the product models were inferred (see right side of Figure 4). Models can be newly developed. Two or more models can be coupled or integrated into each other. Models can be further developed or transformed. Finally, information can be extracted from existing models, and models can be deleted or discarded.

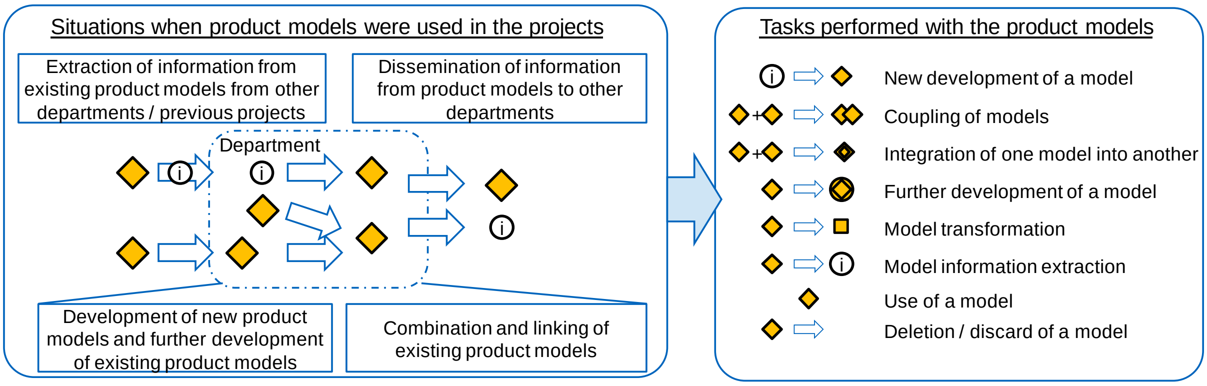

Figure 4. Situation when product models are used and tasks performed with the models

4.3 Detailing the supported tasks and specification of the problem-solving expertise

In order to support the identified eight tasks they are detailed in process steps and support measures for each process step are identified. To identify the necessary steps and the support measures, problem-solving expertise is needed and has to be captured and modelled within the knowledge base. Principally, two different possibilities for providing the needed problem-solving expertise exist (see Figure 5). The first possibility can be applied if problem-solving expertise for the handling of product models already exists and is available. Then, existing insights and best practices in the field of product modelling should be directly used. The second possibility can be applied, if no expertise about the handling of product models within the different tasks exists. Then, insights and best practices from other model types (e.g. process modelling) should be used and transferred in order to support the handling of product models. Although, there will be a transformation effort for adapting problem-solving expertise from one model application to the field of product modelling, this option is better than having no support for the handling of product models.

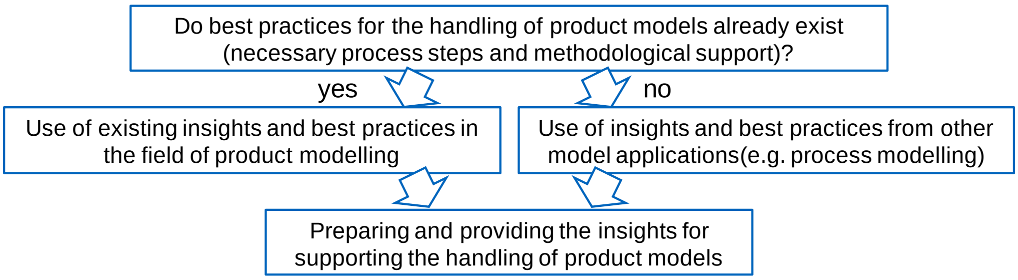

Figure 5. Possibilities for capturing the needed knowledge expertise

Problem-solving expertise can be generated via expert interviews or literature reviews. In our case, a literature review was conducted in order to identify existing problem-solving expertise both in the field of product modelling as well as within other model applications. Exemplary search terms within the literature review are “good modelling”, “best practices in modelling”, “modelling knowledge” and known synonyms of these terms and varying combinations. Some of the retrieved papers were already presented in chapter 3.3. The retrieved papers were scanned for contained knowledge about how to handle models within the eight tasks. At all, 33 international papers were in the final selection – 8 journal papers and 25 conference papers. With the help of the papers, the tasks were detailed into process steps and possibly helpful support in terms of methodologies, rules or checklists were added. The following Figure 6 exemplary shows the detailing of the task “new development of a model”. In this task, four steps were identified as most important for new development of the model. For each step, relevant knowledge elements for supporting the execution of the step were identified from the literature. These knowledge elements can be influencing factors on the respective step (e.g. number of people involved, needed tools, etc.) and guidelines how to handle these influencing factors and rules how to execute a certain step – as exemplarily shown on the right side of Figure 6.

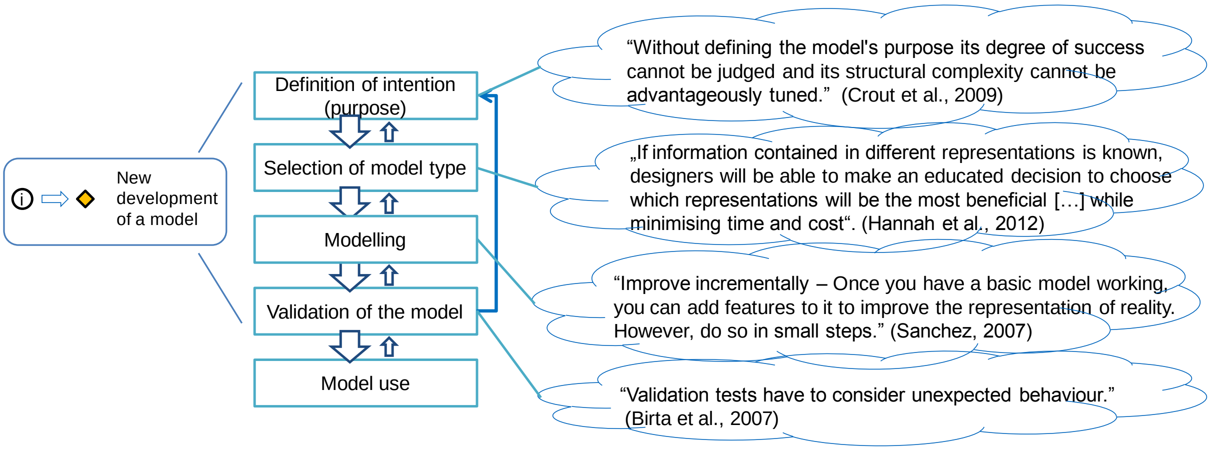

Figure 6. Detailing of the task “new product development” and exemplary knowledge elements for the steps

The mapping of the knowledge elements to the respective process steps will be captured within the knowledge base.

4.4 Structure of the knowledge base and instantiation

This chapter describes the structure of the designed knowledge base and its instantiation. It was developed on the basis of the above described detailing of the supported tasks and filled with the necessary knowledge expertise from literature. It is intended to provide support for the identification of necessary support measures for the eight tasks performed with the product models. The structure of the knowledge base defines the most relevant knowledge elements and the relations between them (see Figure 7). This structure can be instantiated with necessary knowledge about the respective aspects. The knowledge base is composed of three abstraction layers and three groups. On each abstraction layer, the aspects are divided in the three groups “model description”, “steps and situations” and “guidelines and help”. The layers below inherit the attributes described in the layers above.

The top layer (general model layer) contains application-independent aspects of handling models in general. It serves as abstraction layer for the second layer and is needed to transfer insights from other modelling application to product modelling. It provides the general knowledge necessary to understand, what a model is, what can be done with models and which models exist (as requested in requirement 1). The second layer (application layer) contains application-dependent aspects of the handling of models. The aspects described in the first layer are concretised according to the particular application in the second layer. As many parallel second layers exist as there are insights from different model applications available. The second layer provides knowledge aspects needed for realising the support in product development projects (as requested in requirement 3). For example, product model description templates are provided in the second layer that can be used to describe emerging product models in the third layer. By abstraction between the applications layers and the general model layer and the following concretisation in the other direction, a transfer of application-independent aspects from one application to another application is possible. Rules, best practices, processes and insights between the different model applications can be transferred. In the third layer (project-specific layer) the aspects described in the application layers are instantiated in the particular project. The formulation of a need for support and the subsequent realisation of the support can be realised between project specific layer and the application layer. For example, product models generated in a particular project can be saved in the third layer as instantiation of the masters for describing product models contained in the second layer. They can be reused during the project or in subsequent projects (as requested in requirement 4). Here, workflow-based assistance can support the product developer with the necessary guidelines, checklists and suggestions.

The aspects of the three layers are divided into three groups. The first group (model description) contains the needed definitions and distinctions between models. Knowledge about what models are, how models can be distinguished, what different types of model exist and what elements belong to a model is described here. In the second group (steps and situations) the relevant steps and situation for handling models are described. Knowledge about what can be done with models, which situations require models and what steps need to be taken when handling models is captured in this group (as requested in requirement 2). The third group (guidelines and help) describes the needed information, best practices and hints for handling the aspects described in the first two groups. It contains knowledge about what enables good modelling, what boundary conditions have to be considered when handling models and the role people play in modelling. The first and the third group provide the necessary background for performing the tasks and coping with the situations described in the second group.

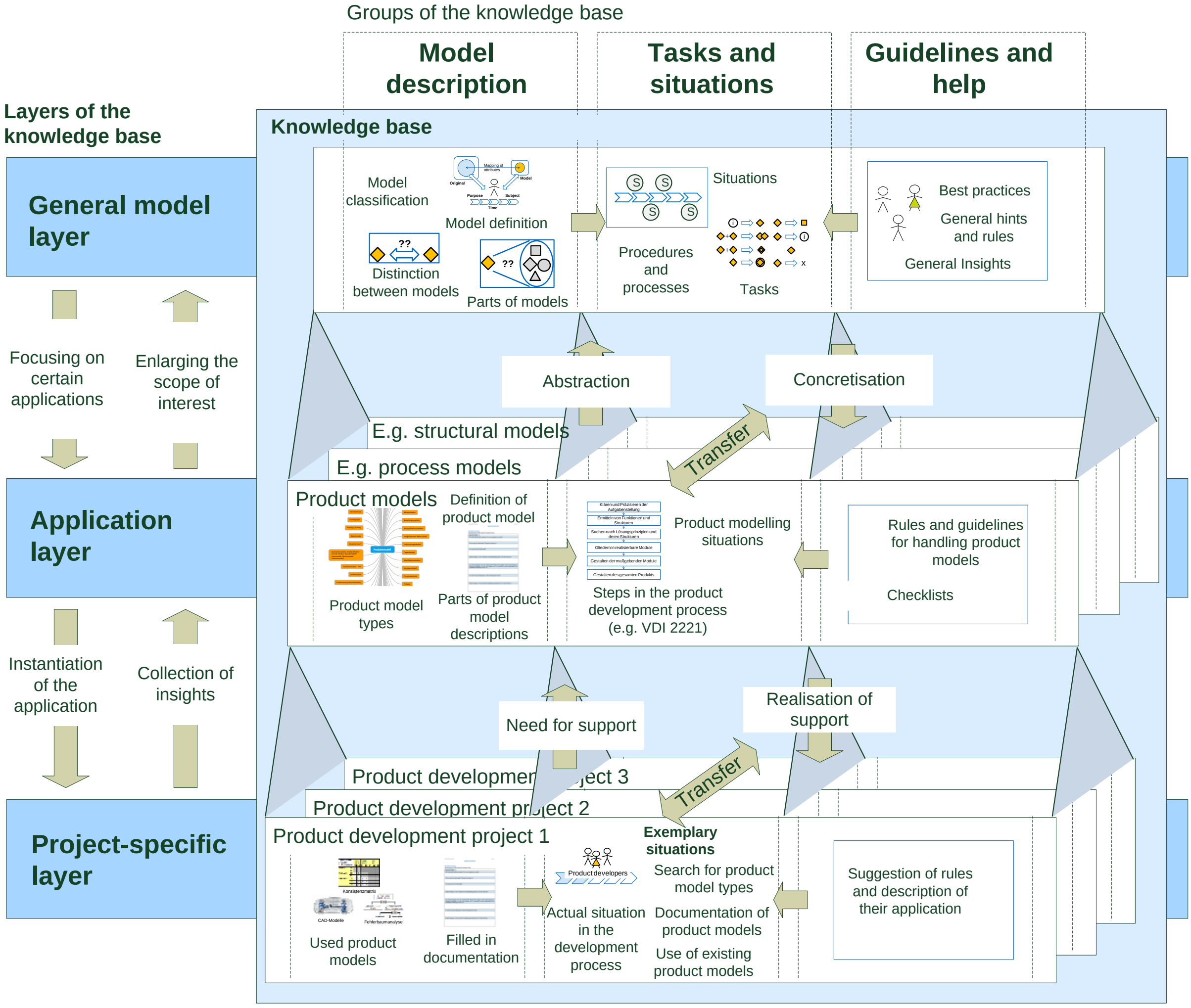

Figure 7. Structure of the knowledge base with exemplary instantiation

Figure 7 shows an instantiation of the layers and groups of the knowledge base. The situation and tasks that were identified within the industrial application were detailed into process steps and added to the general model layer. In the above described literature review, 116 aspects of guidelines and help were identified and linked to the relevant process steps. A collection of product models is integrated in the knowledge base that classifies product models according to general model attributes (original, purpose, representation technique, etc.) on the basis of work done by (Kohn et al., 2012). Templates for describing product models in the second layer were derived from the general model layer.

5 EVALUATION OF THE APPROACH

The applicability of the described knowledge base for supporting the five steps as described in chapter 4.1 was evaluated within a case study in a department in an automotive company. During a product development project for an electro-mechanic component in the drive train of a motorcycle a product developer collected possible activities that have to be supported (step 1). A checklist for reflecting the handling of product models was developed on the basis of the information contained in the knowledge base. The task “new development of a model” was identified as most important to support, as this was the main task performed within the development project. Needed support was derived from the knowledge base (step 2) and adapted according to identified needs (step 3). In order to support this task, a software prototype was implemented in Visual Basic with the main workflow functionalities for giving guidance in the process steps. A detailed description of the prototype, its functionalities and initial evaluation can be seen in (Kohn et al., 2013). Within each step, rules and guidance is provided for the handling of product models that were derived from the knowledge base. The software serves as interface between the support measures and the user. The software prototype was applied within the use-case and evaluated according to the intended support and gained insights were collected within the knowledge base (steps 4 and 5). The developers tested the prototype and confirmed that helpful knowledge is provided that they weren't aware of before. This knowledge can help them in handling product models.

This initially applicability evaluation in the case study shows that it is possible to store existing knowledge about good modelling within the designed knowledge base, identify needed support in product development processes and adapt existing support measures in order to support product modelling. A transfer from good modelling practice and support measures from diverse modelling application to product modelling is possible with the help of the proposed knowledge base. However, the necessary adaptation effort for providing support on the basis of existing best practices may not be underestimated. The knowledge base enables the access to existing support measures identified from literature – but to make them applicable within product development projects, they have to be adapted. The adaptation effort depends on the amount of needed support in term of tasks that have to be supported and the level of detail of the support – which depends on the respective case study. In the case study for our evaluation, the task "new development of a model" was focused and support measures identified and provided mainly for this task. This makes the application of the knowledge base easier. If only little support measures are needed (e.g. checklists for documenting the purpose of a model) the adaptation effort is lower than if full support is needed. If more sophisticated support (e.g. a software assistant) is needed and more tasks have to be supported, the adaptation effort is higher.

6 CONCLUSION, DISCUSSION AND OUTLOOK

Information plays an increasingly important role in product development. The amount of generated and existing information is steadily increasing. Appropriate ways of handling information in product development are therefore very important. Product models are one key aspect for handling information in product development. Mostly computer-based, they are used for generating, capturing and disseminating product information. This paper shows a possibility to improve the handling of product models. We proposed and designed a knowledge base that contains the relevant knowledge about how to handle product models. The knowledge base enables the capturing of insights from arbitrary modelling applications and model types to support the product developer in handling product models. We provide this by a three-layered knowledge base in which best practices, procedures, definitions and guidelines for good modelling are related to the steps necessary in product model-related situations. The applicability of the knowledge base was initially evaluated by instantiating it for supporting the task of "new development of a model" within the case study.

Some drawbacks of the presented work call for further work. For the implementation of the knowledge base, a rather simple ACCESS database was used. In more complex applications the relations and constraints in the knowledge base would demand for a more sophisticated knowledge representation technique. Also, the specification between user and system needs further development and investigation. User-centred studies with the developed prototype will be performed in future work and gained insights from its application will be stored in the knowledge base. The source used for the initial instantiation of the knowledge base was a selection of identified references from literature. This serves well for a first application, but of course, further development and filling of the knowledge base with insights and best practices from whatever resources is possible. The results described in this work can also be also used for supporting modelling in other applications than the proposed product modelling. The structure of the proposed knowledge base allows transfer of insights in every direction between the application layers. Therefore, arbitrary modelling applications in different fields such as systems engineering, biology or marketing could be supported by the knowledge base.

ACKNOWLEDGMENTS

We thank the German Research Foundation (Deutsche Forschungsgemeinschaft – DFG) for funding this project as part of the collaborative research centre 'Sonderforschungsbereich 768 – Managing

cycles in innovation processes – Integrated development of product-service-systems based on technical products'.

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