Development of a Toolkit of Methods for Simulations in Product Development

C. Carro Saavedra[1], N.-J. Marahrens[1], S. Schweigert[1], P. Kestel[2], S. Kremer[1], S. Wartzack[2], U. Lindemann[1]
[1]Department of Product Development, Technical University of Munich, Germany
[2]Department of Mechanical Engineering, Friedrich-Alexander University Erlangen, Germany
(carrosaavedra@pe.mw.tum.de)

Abstract – **Simulations contribute to the efficiency of the product development process and the quality of the developed products. However, their integration in the development process can be improved. We propose a knowledge-based framework, containing a toolkit of simulation methods as its central element to integrate simulations in the product development process. Within this paper, we briefly introduce the knowledge-based framework and we present the toolkit structure and the methodology for its development.**

Keywords – **toolkit, methods, simulation**

I. INTRODUCTION

Product and manufacturing process simulations offer the potential to improve the efficiency of the product development process and the quality of the developed products [1]. Although their application in industry is continuously rising, their potentials are still not fully exploited [2,3]. Simulations are especially helpful if they are applied along the entire product development process rather than only being executed in specialized departments [4]. A lack of overview and improper knowledge are hereby critical factors that may lead to simulation errors causing unnecessary iterations in the product development process or costly product call-backs.

Current knowledge-based engineering solutions support the implementation of simulations in the development process in a computer-aided fashion [5]. However, none of these solutions have yet included a general procedure to perform knowledge-based simulation along the entire product development process [6]. They rather represent a gathering of methods, each designed for specific applications, like the ones found in [7].

In order to come up with a holistic solution, we propose a knowledge-based framework with a toolkit of simulation methods as its central element. Within this paper, we present the toolkit and the procedure for its development.

II. CONTEXT AND APPROACH OF THE TOOLKIT OF METHODS

A. *The FORPRO² project*

The FORPRO² project aims at increasing the efficiency of product and manufacturing process development through the creation of a knowledge-based framework comprising of simulation methods and expert knowledge. The project is organized as a multi-partner research collaboration of ten subprojects addressing three main areas: knowledge management, product simulation, and manufacturing process simulation. The subprojects focused on knowledge management, develop methods for the systematic documentation and analysis of general aspects of simulations, like the requirements, the quality, or the application phase during the development process. The projects working on product and process simulation develop innovative knowledge-based tools for simulation, like software assistants for unexperienced developers.

The knowledge-based framework is ideated to provide structure, transparency, and integration of various simulation techniques to be employed along the entire product development process chain. The proposed framework consists of three elements (see Fig. 1).

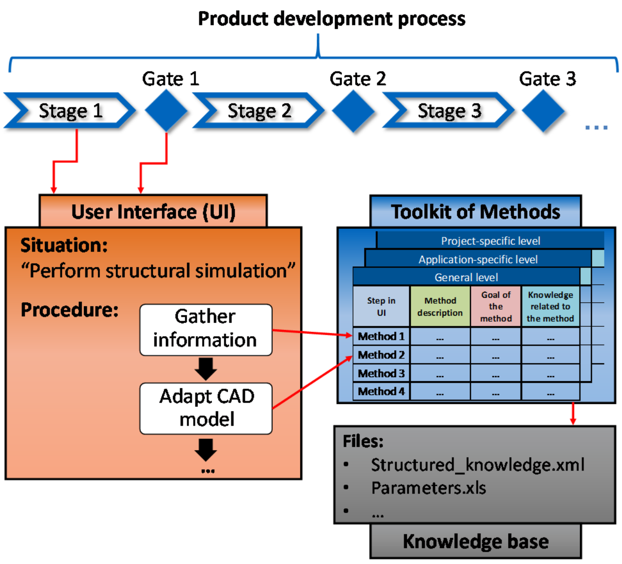

Fig. 1: Overview of the FORPRO² knowledge-based framework (the depicted situation, procedure, and files are exemplary).

- *User interface:* representation of the workflows that the developer should follow to achieve several goals regarding validation and simulation, and considering his situation.
- *Toolkit of methods:* structured table containing explanations of the methods to conduct each step of the workflows in the user interface.

- *Knowledge base:* collection of files to support the systematic application of the methods described in the toolkit.

The integration of the knowledge-based framework in the company's development process is done by applying a methodology developed during the project. The methodology proposes a new definition of the development process, which is divided in stages and gates that are linked to the possible simulation methods for them [8].

B. *Toolkit of methods: the concept*

The toolkit of methods is the central element of the framework and at the same time its most complex one. The structure of the toolkit is based on [9] and consists of three levels: the general level, the application-specific level and the project-specific level (see Fig. 2). The general level presents a generic description of the method (e.g. geometry adaption). The application-specific level presents how the general method must be adapted for different cases of application (e.g. geometry adaption for a deep drawing geometry). The project-specific level shows concrete examples of the application of the methods, including the context and the outputs obtained (e.g. geometry adaption for a deep drawing geometry of a car's side rail).

Each level is divided into three categories of content (see Fig. 2): method description (containing aspects like name or procedure), goal of the method, and knowledge related to the method (containing aspects like advantages/disadvantages or the files contained in the knowledge base to be used when applying the method).

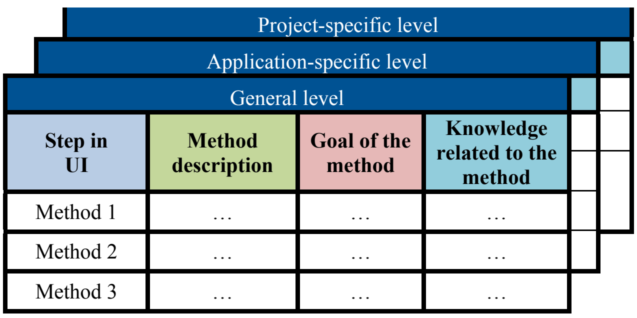

Fig. 2: Levels of the toolkit and their categories of content.

The objective of the different levels is enabling the application of the toolkit for as many cases as possible. If the current case of the user is described in the application-specific level (e.g. geometry adaption for a deep drawing geometry), the explanations of the method and additional files from the knowledge base can be directly applied without modification. If the current case of the user is not specifically described (e.g. geometry adaption for a forming geometry), the user can always refer to the general level, where he or she will find information to understand the method and to be able to adapt the necessary steps and files to his or her own case. The examples of application collected in the project-specific level contribute to the better understanding of the method application and results. The specific knowledge of a particular component in the project-specific level can be also reused for similar or standardized components.

We collected all innovative methods developed within FORPRO² in the toolkit of methods. In order to implement the proposed knowledge-based framework in a company, the toolkit should not only contain our simulation methods, but should be extended with the specific simulation and validation methods used in the company. The development of the toolkit within the company can be done using the methodology explained in section III.

III. METHODOLOGY FOR THE DEVELOPMENT OF THE TOOLKIT OF METHODS

The methodology to develop the toolkit of methods is divided into four phases: understanding, analysing, filling, and verifying (see Fig. 3). A person or team acts as moderator (MOD) for the whole development. The rest of the participants provide the inputs (methods, knowledge, etc.) to fill the toolkit and are summarized under the term input providers (IP). A prerequisite for the development is the identification of all participants (moderators and input providers). In the case of FORPRO², the IP are the ten subprojects involved and one subproject performed the role of MOD. The development starts based on the main structure of the toolkit (described in section II.B).

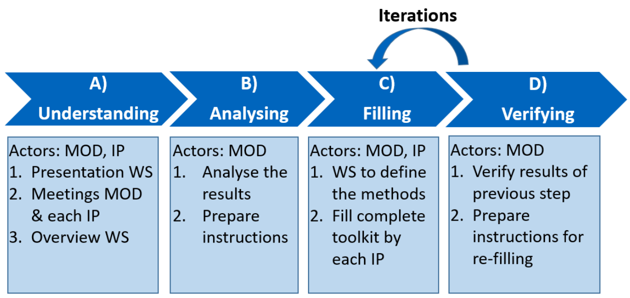

Fig. 3: Four steps for the development of the toolkit of methods. Abbreviations: MOD – Moderator; IP – Input Provider; WS - Workshop

Each phase of the toolkit development is explained in detail in the following sections.

A. *Understanding*

The first phase consists of understanding the overall methods that the IP propose for the toolkit. In order to achieve that, we propose a three-step methodology combining group work and meetings with the MOD. First, a workshop with all the IP must take place, in which each IP explains key aspects of the overall methods that he or she proposes for the toolkit. For each method, it will be explained: which development problem/case the user of the method is facing, who the user of the method is, the method's output and what the user does with the output. The individual explanations are followed by a group discussion, in which the IP discuss the exposed content and the differences and similarities between their methods.

This first explanation of methods is usually very general. The IP use similar terminology, making it difficult to differentiate the numerous methods. Therefore, the MOD is supposed to analyze the workshop results and clarify the details afterwards in bilateral meetings with each IP in a second step. The differences between the methods of all IP must be clear after those meetings. Furthermore, these meetings are used to collect the methods' procedures (input for the user interface) for the method user.

In the third step, a second workshop with all IP takes place. This time, the MOD presents the procedures extracted from the bilateral meetings (user interface) to the group and asks the IP to go through the steps to allocate the correspondent methods to be conducted in each step of the procedure in the toolkit (see Fig. 4). The toolkit of methods shows only the overview of the three levels (general, application-specific, and project-specific level). Only the name of the correspondent method should be introduced in the toolkit at this stage. The content related to the method is not considered at this point of the toolkit development because the goal is to obtain a consistent overview of the methods to add to the toolkit before starting to fill it with further details.

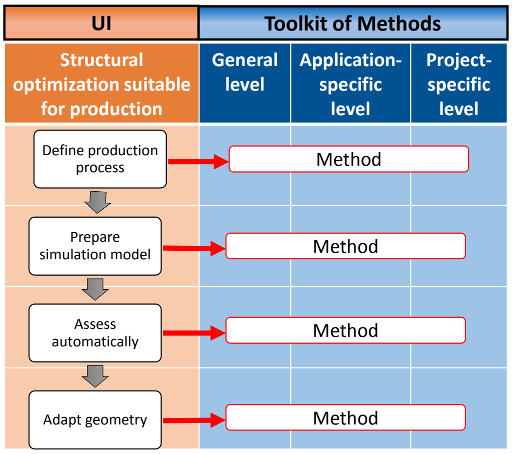

Fig. 4: Template used in the workshop to fill the methods for the toolkit. The user interface shows as example the "structural optimization suitable for production".

B. Analysing

The second phase of the development is the analysis of the results obtained from the understanding phase. The analysis is carried out exclusively by the MOD based on the overview of the methods collected from the workshop (step three in section III.A). Fig. 5 shows an overview over some of the methods suggested by the IP in case of the FORPRO² project toolkit development.

General level	Application-specific level	Project-specific level
Shortest-path analysis	Shortest-path analysis for filling simulation	
Introduction of production-related deviations in a simulation model		
	3D-Surface capture	3D-Surface capture of a motor carrier
	Parametric correction in the CAD system	
	Extension of parametric correction by scanning inserts	
	Morphing the simulation model	
Guideline interview	Guideline interview	Guideline interview *(project-specific)*
…	…	…

Fig. 5: Some of the methods the input providers (IP) of the FORPRO² project suggested to be included in the toolkit at the end of phase A.

Based on our experience, common mistakes at this point of the toolkit development are:

- *Location of methods in the levels of the toolkit:* The understanding of the purpose of the different levels may be unclear. Despite the emphasis on the meaning of the different levels during the understanding phase, the IP tend to think that the application-specific level constitutes a breakdown of the method from the general level. However, this is not the idea, since the application-specific level constitutes a specification of the method from the general level for an application case.
- *Relations between methods in different levels:* Each method is only defined in one level and not in the three levels as it should be.
- *Few specifications in the application-specific level:* Usually only one application case is named.
- *Unfilled sections:* Numerous fields are not filled, especially on the project-specific level.

After the analysis of the current mistakes, the MOD will prepare some instructions focusing on clarifying points unclear to the IP.

C. Filling

The final filling of the toolkit is performed in two steps: deciding on the final methods to be introduced in the toolkit and filling the complete toolkit with the content associated to each method.

In order to decide on the final methods for the toolkit, the instructions prepared by the MOD after the analysis phase are given to the IP. Based on these instructions, they are supposed to fill the overview of the methods again (Fig. 4). Subsequently the MOD has to analyze the new overview of methods and bring up the remaining aspects that were misunderstood in a group discussion. During this discussion, concrete examples of the misunderstandings found are elaborated. Subsequently the MOD proposes adaptions in order to make the entries fit the concept of the toolkit.

The result of the discussion is a common understanding of what is required and a final agreement on the methods that each IP will contribute.

The overview of the selected methods for the toolkit in each level is documented in tables like those that exposed in Fig. 6. Once this is final, the complete filling of the toolkit begins. For each method, the three content categories (method description, goal of the method, and knowledge related to the method) are documented, as it is presented in Fig. 7. The IP will individually fill the content and send it to the MOD for verification.

User Interface	Toolkit of Methods		
	General level	Application-specific level	Project-specific level
Define prod. process			
Prepare simulation model	Model preparation (MP)	MP - Pressure casting (PC) simulation	MP – PC Simulation - Firm A: side member
		MP - Deep drawing (DD) simulation with OneStep	MP – DD simulation with OneStep - Firm B: demonstrator
Assess automatically	Manufacturability analysis (MA)	MA - Pressure casting (PC) component analysis for experienced users	MA - PC component analysis for the experienced users - Firm A: side member
		MA -Pressure casting (PC) component analysis for other users	MA - PC component analysis for other users - Firm A: side member
		MA - Patch generation deep drawing (DD)	MA - Patch generation DD - Firm B: demonstrator
Adapt geometry	Geometry Adaption (GA)	GA - Ingate placement pressure casting (PC)	GA - Ingate placement PC - Firm A: side member
		GA - Deep drawing (DD) geometry	GA - DD geometry - Firm B: demonstrator

Fig. 6: Final overview of the methods in the toolkit for the simulation procedure "structural optimization suitable for production".

D. *Verifying*

The MOD assure the consistency and completeness of the toolkit. Therefore, they verify the input of each IP and communicate the aspects to be changed in order to achieve the required consistency and degree of completeness. Several iterations between filling and verifying may occur until the toolkit is finally completed.

Based on our experience, common mistakes to be checked by the MOD are:

- *Few/no difference between the explanations* in the different levels: The different levels are filled with the same content or with a reference referring to the information stated in another level. This should not be the case. If two methods have exactly the same goal or procedure, they should be the same method.
- *Lack of connection* between procedural steps to conduct the method and the knowledge files (templates, rules, guidelines, etc.) to be used during those steps: IP forget to associate the files of the knowledge base with the steps of the method procedure, or the associations are unclear.
- *Too long explanations:* Writing running text rather than bulletin points reduces the readability of the contents.
- *Unfilled sections:* Fields are left entirely blank and it is not clear this was intentionally or unintentionally.

Corresponding step in the User Interface			Gather simulation knowledge
Method description	Name		Knowledge discovery in databases
	Definition		Employment of data- and text-mining methods for the analysis of simulation models and reports
	Steps		1. Selection of information relevant to the simulation (text-mining) 2. Preparation and transformation (text-mining) 3. Derivation of superior connection through classification and regression (data-mining) 4. Interpretation and evaluation of the analysis results 5. Preparation and representation of the acquired simulation knowledge in a central knowledge base
	Documents		2 - A,B,E; 3 - A,C,F; 5 - D
Goal of the method			Efficient capturing of expert knowledge and its digital representation in a structured knowledge base
Knowledge related to the method	Advantages		Efficient method to provide less experienced users with expert knowledge
	Dis-advantages		Large database and processing of a great amount of simulation reports necessary
	Limits		Limitation to acquisition processes for structural mechanical analysis
	Hints for application		-
	Know-ledge base content	I	A Simulation_Report.pdf B Perform_textMining. xml C Perform_dataMining. xml D Preprocessing.m
		O	E text_mining_result.xls F data_mining_result.res

Fig. 7: Exemplary documentation of one method for one level (here: general level for the method knowledge discovery in databases) according to [10]. Connection between the steps (numbers 1-5) and the contents from the knowledge base (letters A-F). Abbreviations: I – input, O - output.

IV. FINAL TOOLKIT OF SIMULATION METHODS

The final toolkit of methods contains all the collected methods and their correspondent explanations as well as associated knowledge divided in the three content categories (see Fig. 7).

Within the FORPRO² project, we filled the toolkit with methods contributing to the following activities in the context of simulation:

- Structural optimization suitable for production
- Assisted simulation for non-experience users
- Communication via the CAD model
- Comparison of ideal simulation model with real manufactured model
- Die casting simulation
- Assessment quality of simulations
- Strategic simulation planning and documentation
- Communication between design and simulation departments

V. CONCLUSIONS AND EVALUATION

We presented the methodology to develop a toolkit of simulation methods, which constitutes a central element in the proposed knowledge-based framework of FORPRO² to integrate simulations during the product development process. The methodology is based on our own experience of developing the toolkit to collect the innovative simulation methods developed by the participants in the project. In order to use the proposed knowledge-based framework, every company must extend the FORPRO² toolkit of methods with its own specific methods, using the methodology exposed in this paper.

This paper contributes to research, presenting a new approach to structure and document the simulations to be applied during the product development process in a transparent, flexible and applicable way. Transparent because all methods as well as their characteristics are documented. Flexible because thanks to the different levels, the information regarding the method application can be as specific or as broad as necessary for the users' case. And applicable because the toolkit is not only a way of documenting the simulation methods, but one element in a holistic concept to improve the integration of simulations within the product development process.

The contribution of the knowledge-based framework and toolkit to industry was evaluated in workshops with two industry partners (four employees of the development departments per workshop). They consider the framework beneficial but only if it is implemented in a software tool. The situations of the user interface can be generalized to facilitate a top-down search. The toolkit structure is understandable. The framework was feasible for application on company's processes and the company's own methods could be documented in the toolkit.

VI. FURTHER WORK

Our next step is implementing the knowledge-based framework with its toolkit of methods in an Engineering Knowledge Management (EKM) software, as proposed in [10, 11]. We will also conduct a case study to integrate the software-implemented framework and toolkit of methods in a company's development process using the methodology for stage-gate process design presented in [8]. The costs and time for the implementation of the methodology in an industrial context will be derived from the case study.

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