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ENHANCEMENT OF COLLABORATION AND COMMUNICATION BETWEEN DESIGN AND SIMULATION DEPARTMENTS BY METHODS OF REQUIREMENTS ENGINEERING

S. Schweigert, H. d'Albert and U. Lindemann

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1. Introduction

Simulation techniques like FEM and CFD have become a standard part of the engineering design process with an increasingly important role [Maier et al. 2009]. According to Herfeld et al. [2006], five aspects have to be considered when dealing with the integration of Computer Aided Engineering (CAE) tools into Computer Aided Design (CAD): product, people, tools, data, and processes. While a lot of research has been conducted on technical aspects in this context (e.g. [Forsen and Hoffmann 2002], [Schumacher et al. 2002], [Assouroko et al. 2010], [Park and Dang 2010], [Gujarathi and Ma 2011], etc.), there is little knowledge about the implications of this development on the communication and collaboration of the people involved (cf. Figure 1), as the focus of previous research thus far has been on tools, data and processes [Kreimeyer et al. 2005].

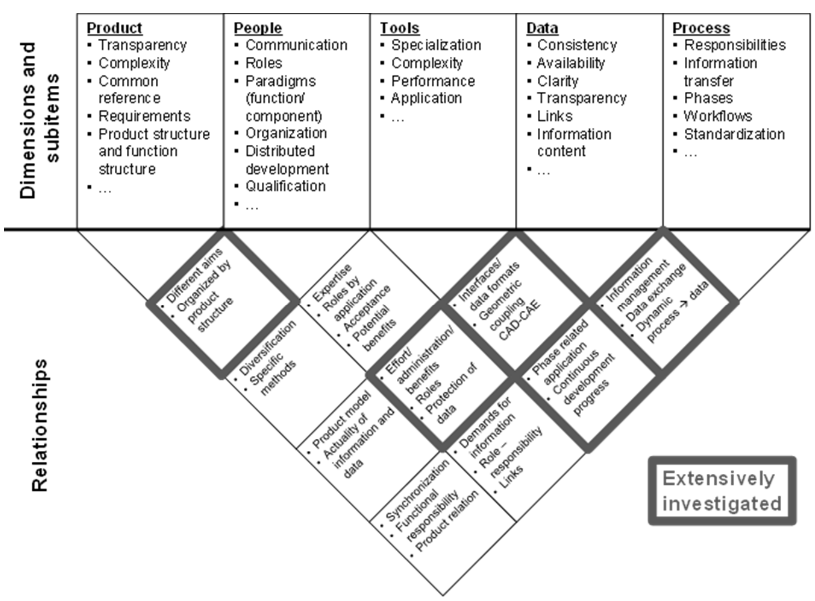

Figure 1. Matrix displaying the connections between the five dimensions of CAD-CAE integration (edited from [Herfeld et al. 2006])

To deal with dispersed and non-standardized product development and simulation data within engineering companies and in order to include already generated knowledge into future simulation processes, a clear simulation management that takes human interaction into account is necessary. A special emphasis has to be laid on the structuring of requirements to avoid misunderstandings between designers and simulation experts. A survey by Kreimeyer et al. [2006a] has shown that simulation departments feel a great deficit in the supply of proper information and data by design departments. Especially with the growing complexity of products, proper communication between design and simulation is necessary to reach products that fulfil all requirements [Kreimeyer et al. 2006b].
The ultimate goal of the approach presented in the next chapter is to integrate simulation smoothly into the product development process instead of a selective use of simulations with isolated applications only. One measure to achieve this is the improvement of communication between design and simulation departments. Of the four sets of factors that affect communication between teams in product development identified by Maier et al. [2011] the resulting simulation assignment belongs to information (rather than individual, team, and organisation). It aims at improving the availability of information about the organisation by putting into practice the recommendation of Lin et al. [2004] and Lin et al. [2007] via establishing a standardised terminology for intra-company communication and using only terminology accepted by all participating parties.

2. Approach and methods

This paper proposes a requirements-oriented simulation management concept that is based on a three level approach with special regard to human collaboration and communication. Methods from requirements engineering are transferred to simulation management to handle internal simulation requirements.
The general approach is described in the following before the next chapter elaborates an example of the tools and methods layer of Figure 2.

2.1 Expansion of the half matrix proposed by Herfeld et al. [2006]

In order to examine the aspects influencing CAD-CAE integration more thoroughly, the half matrix proposed by Herfeld et al. [2006] was expanded to a full matrix (cf. Table 1). Especially the diagonal elements of this Multiple Domain Matrix (MDM) are important as one of them covers the field of human interaction in product development. As before, the areas that are well explored are marked. The focus of this paper is human interaction (shaded with white font in Table 1) and methods that can support it. The abbreviation "SYMM" indicates that the matrix is symmetric.

Table 1. Expansion of the half matrix proposed by Herfeld et al. [2006] to a full matrix

Model of the five dimensions of CAD-CAE-integration	Product	People	Tools	Data	Process
Product		• Different aims • Organized by product structure	• Diversification • Specific methods	• Product model • Actuality of information and data	• Synchronization • Functional responsibility • Product relatedness
People	SYMM	Collaboration and communication	• Expertise • Roles by application • Acceptance • Potential benefits	• Effort/ administration/ benefits • Roles • Protection of data	• Demands for information • Role - responsability • Links
Tools	SYMM	SYMM		• Interfaces/data formats • Geometric coupling CAD-CAE	• Phase related application • Continuous development progress
Data	SYMM	SYMM	SYMM		• Information management • Data exchange • Dynamic process → data
Process	SYMM	SYMM	SYMM	SYMM	

2.2 Three layers of communication and collaboration in CAE-CAD integration

The approach suggested in this paper for dealing with human interaction consists of three layers that differ in the level of abstraction (cf. Figure 2). The combination of measures on all three levels adds up to a support for successful communication and collaboration in CAE-CAD integration.

On a very high level, there are questions of team composition and organisational aspects. These include concepts like function-oriented teams proposed by Herfeld et al. [2006], Kreimeyer et al. [2006b] and Herfeld [2007] and many approaches to enable designers to use CAE-Tools instead of assigning a simulation expert to do the job (e.g. [Peak et al. 1998], [Spruegel and Wartzack 2015] and many more).

On a second level, rules and guidelines regulating practical aspects of collaboration and communication are defined. This is important, as human communication is a crucial - if not the key factor for efficient collaboration between design and simulation departments [Kreimeyer et al. 2006a]. Exchange of knowledge is necessary because there are two different paradigms: the topological view of design and the function-oriented perspective of simulation [Hales 2000], [Maier et al. 2009].

On the third and lowest level of abstraction, concrete tools and methods are described to enhance communication and collaboration between design and simulation departments.

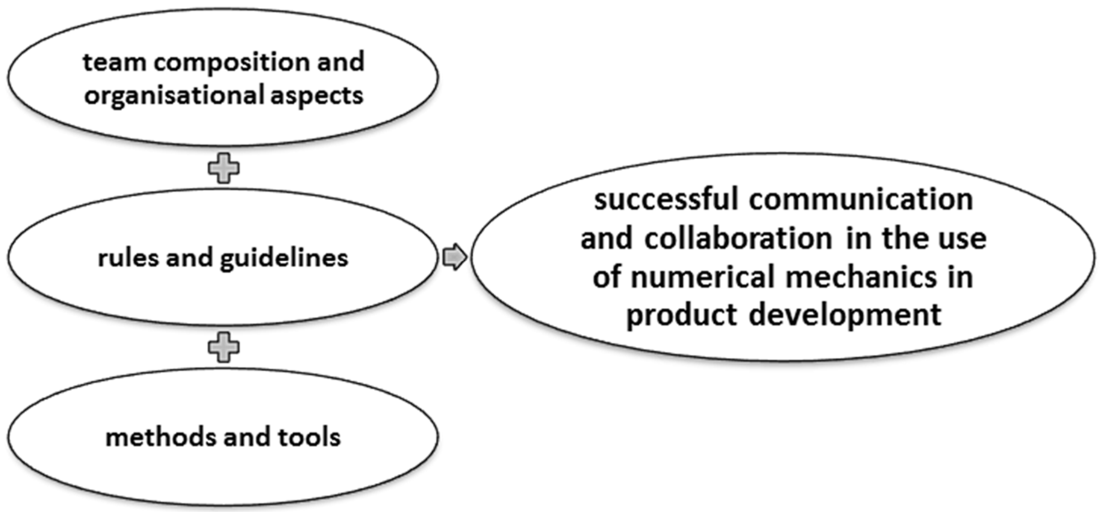

Figure 2. Three level approach for communication and collaboration between design and simulation departments

The basic idea is that measures on all three levels shall be identified to improve communication and collaboration between designs and simulation departments. This is done in three steps (cf. Figure 3). In a first step, the current situation of the examined company is analysed by interviews. This results in a system graph that is the basis for methods of structural complexity management. From this graph matrices are derived, which are used to calculate characteristic numbers. These characteristic numbers indicate for example the degree of interconnectedness, the relevance of simulations in the product development process and the number of involved employees. Thereby, the situation can be categorized in a 9-cell-cube. Each cell consists of checklists and measures to improve the current situation on the three levels in Figure 2.

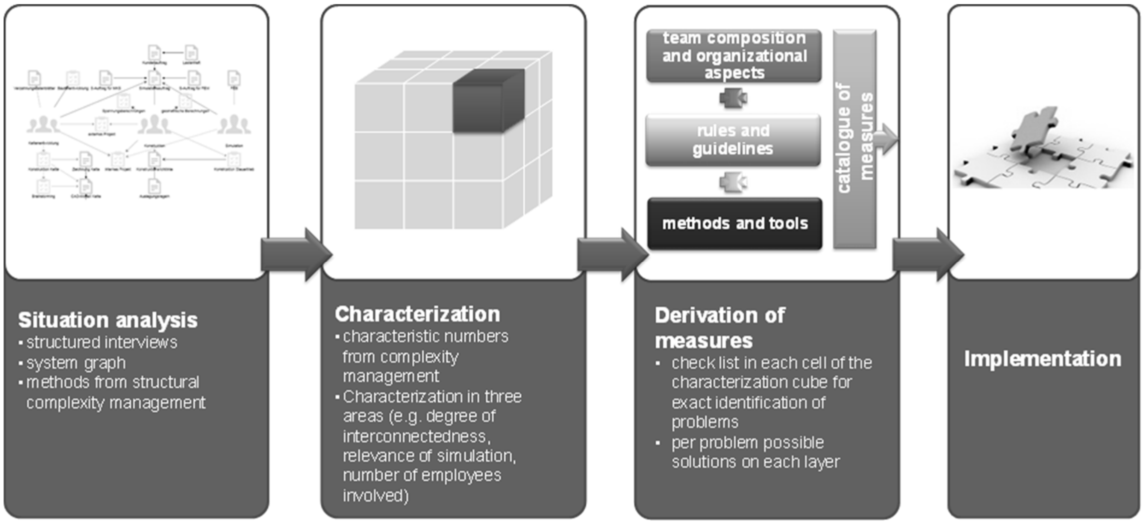

Figure 3. Approach for a catalogue of measures

In this paper, two aspects on the last layer (methods and tools) are described: the proposal of a simulation assignment and the generic form of a simulation requirement template that is part of the simulation assignment.

3. Results

The results presented in the next chapter are based on two series of interviews conducted with an industry partner from the German automobile supplier industry in a research project on knowledge-based product and process simulation. A clear conclusion from these interviews was that a central data storage system that links the departments and includes defined user roles and access rights is needed. The major aspect of such a system regarding collaboration and communication between design and simulation departments was the elaboration of a template for simulation requirements based on relevant knowledge. The identification of relevant knowledge resulted from the interviews on the one hand and a literature review on the other.
The following describes the structure and content of the simulation assignment. It is based on simulation requirement templates that are shown before the embedment into a simulation management concept is discussed.

3.1 Simulation assignment

There are well established formats for many crucial interfaces in the product development process like requirement lists (between sales or marketing and research and development) or bills of material and drawings (between development and manufacturing) (cf. for example [Pahl et al. 2005]). For the interface between simulation and design, however, there is no standard format in literature.
Therefore, we propose a template that helps to formalize the language and form of requirements for simulations in the design process. Thus, a common understanding of simulation processes including quality criteria and semantic and syntactic rules is ensured.
This template is called a simulation assignment in the further text. It is based on requirement templates (cf. section 3.2) for all relevant aspects of the simulation. Requirement templates address each of the following aspects in Table 2.

Table 2. Aspects of the simulation assignment

TOPIC	SPECIFICATION
Material properties	elastic modulus
	shear modulus
	density

	heat capacity	
	thermal conductivity	
Boundary conditions: drop-down list and defined symbols for	bearing	rigid clamping
		fixed bearing
		loose bearing
		contact faces
	loads	point loads
		surface loads
		volumetric loads
	type of loads	force
		moment
		pressure
		heat flux
	ambient conditions	temperature
		barometric pressure
	contact	point
		line
		surface
	frictional coefficient	slide friction
		static friction
		dry
		lubricated
threshold values	stress	maximum/minimum
	strain	
	displacement	

Furthermore, the simulation assignment contains a title page that serves as a header for the document. The title page comprises of general data on the simulation that is to be carried out, including the information in Table 3.

These elements form the basic structure of the simulation assignment (cf. Figure 4). The final document has the function of a checklist: By filling all requirement templates in the simulation assignment, the design engineer can be sure that all relevant data is transmitted to the simulation department and redundant iterations are avoided.

Table 3. Content of the title page of the simulation assignment

TOPIC	SPECIFICATION
general metadata	ID
	date
	author
	recipient
	project
	module
desired output document	informal
	presentation
	report (internal/external)
CAD file(s)	including preview
deadline	-
type of simulation	part
	assembly

	multibody
	fluid dynamics
short description	installation situation (sketch, screenshot and/or drawing)
	comments
planned verification and validation	-
knowledge management: link to database or summary of	comparable former projects
	comparable current projects
	best practices

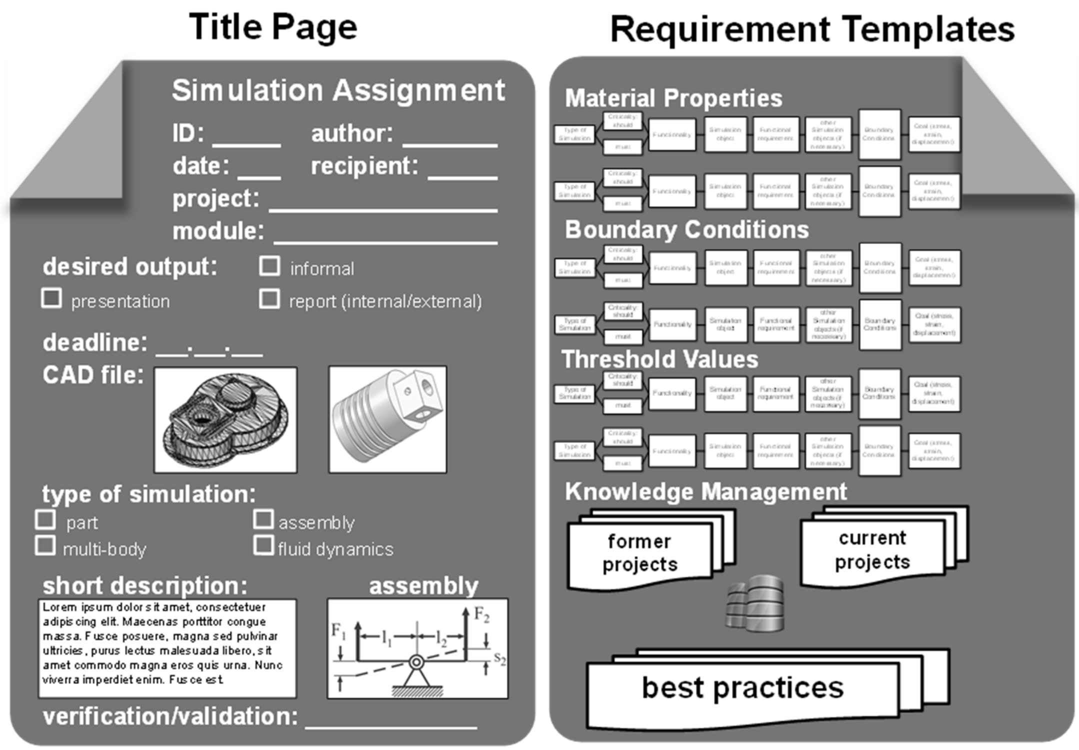

Figure 4. Schematic simulation assignment comprising of requirement templates (graphics from [Ponn and Lindemann 2011])

It is important to note that a crucial element of this concept is the link to a central database that includes former projects, material properties of certified materials within the company and the like.

Features like the automatic creation of a document ID containing author, type of document, and date as well as the extraction of keywords make a knowledge management component possible. In the central database, the simulation assignments are categorized according to this information. This makes searching for assignments and subsequent reuse in future projects possible (cf. section 3.3).

3.2 Requirement templates

Templates that make up the second part of the simulation assignment are derived from a proposal by Rupp et al. [2009] that was adapted to simulation requirements within this approach. Figure 5 shows the generic form of the simulation requirement template. By filling one requirement template per required information in the assignment, the design engineer is guided towards a complete contribution of all necessary values.

With the requirement templates, natural language can be inserted that is automatically sorted according to semantic and syntactic rules. The structure of the template is as follows: type of simulation, criticality, functionality, object, conditions, further objects, and output. This syntactic frame makes it possible to extract relevant information from the natural language of the design engineer. On a semantic level, drop-down list make sure that only acceptable values are inserted and/or proven data from former projects is used. It is also possible to double-check the input, as the result is a text in natural language that can easily by read and understood.

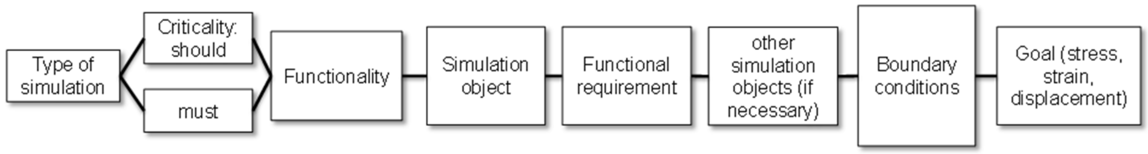

Figure 5. Generic form of a requirement template for process-oriented simulation requirements (edited from [Rupp et al. 2009])

The first box of the template is filled automatically from the header of the simulation assignment. The second box defines the criticality of the requirement, which is necessary when the simulation engineer has to choose an optimal solution for his change proposal after the simulation. In the third element, the design engineer can choose whether he or she wants the simulation to make a statement about a specific parameter or prove an already existing hypothesis. The simulation object is chosen from a drop-down list that includes all CAD parts of the title page. As described in the section above, there are also drop-down lists of applicable boundary conditions. Displaying according symbols helps inexperienced designers to pick for example the proper bearing for the load case in question. After possible further parts are selected from a list, the parameter in question (stress, strain, displacement) is stated. The application to an example from the industry partner is depicted in Figure 6.

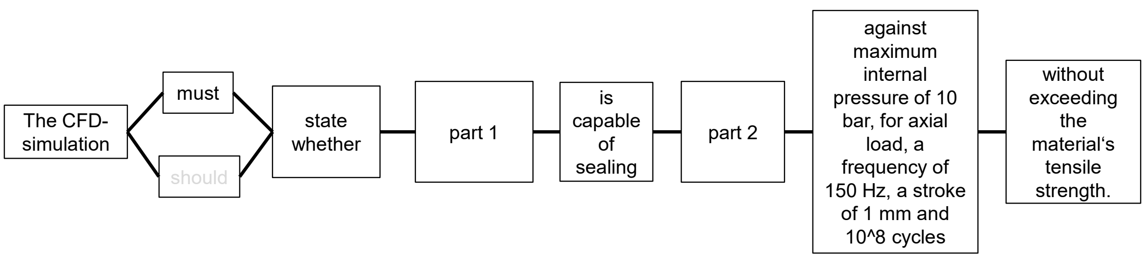

Figure 6. Example of a requirement template from the industry partner

Due to the confidentiality agreement with the industry partner, only exemplary values are displayed. From this template, several pieces of information can be extracted. It contains the simulation object, boundary conditions, further parts and the output values in question. All further data is received in the same way by templates that are adapted to the information still required.

3.3 Simulation management concept

The requirements in the simulation assignments are cross-checked with a requirement database to use requirements for transferring knowledge from the simulation department back to the design department. Thereby, already formulated requirements of former assignments can be used and best practices from similar projects are transferred. Figure 7 shows the concept of the requirements-oriented simulation management concept already published by the same authors in Schweigert et al. [2015]. In combination with functionalized CAD files, a transfer of knowledge between simulation and design departments in both directions is possible.

In the beginning, the database has to be filled manually either by the direct insertion of values, keywords and data or by extracting information from sample assignments for example with data or text mining [Kestel and Wartzack 2015]. In the process, the database is expanded with every new simulation assignment. At a certain point, an expert committee with participants from both design and simulation department has to analyse the content of the database. After adding further inputs if necessary the access rights are changed so that only members of the expert committee or administrators can add further values into the database. Thereby, the content of future simulation assignments is controlled and it can be ensured that in the future proper values are inserted in certain fields.

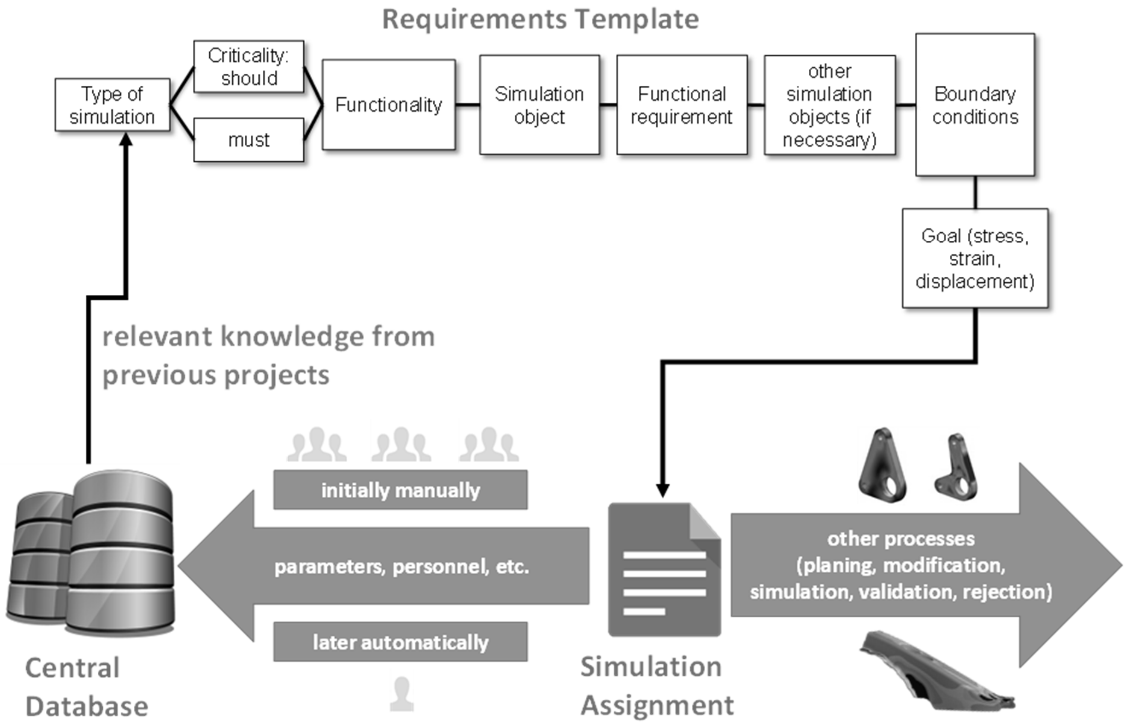

Figure 7. Simulation management concept as of [Schweigert et al. 2015]

3.4 Implementation of a prototype

In order to implement the presented concept successfully, great changes in the IT infrastructure of a company are necessary. Therefore, the results of this research were merely implemented in a spreadsheet program with the use of basic VBA programming to ensure the described functionality. The industry partner judged the concept as beneficial mainly for inexperienced employees.

To prepare the implementation in simulation data management software, a link to the list of possible simulation types that includes an approximate effort in days and a mapping to the steps in the development process is necessary. First steps into this direction have been taken together with the industry partners.

4. Conclusion and outlook

Despite the fact that simulations are an everyday tool in product development these days, there is still room for improvement when it comes to the communication between design engineers and simulation experts. The consequent use of structured simulation assignments can help in the enhancement of collaboration and communication between design and simulation departments. Simulation assignments that include requirement templates for all relevant aspects help the design engineer in transforming natural language into the parameters required by the simulation expert. Thereby, the completeness of the information is checked, leading to an efficiency increase in comparison to the currently used templates as redundant iterations are minimized. This also makes it possible to transfer knowledge from the simulation department to the design department.

While it may be argued that this approach only addresses the needs of one of these groups, it tackles one of the major issues between these two departments, the often limited transfer of proper information and data from the engineering departments to the simulations departments. As simulation departments often act as an internal service supplier, this can significantly hinder the development process.

Future work will include the application of the template-based simulation assignment on industry examples from various companies to generate a document that is both generic and applicable in a broad range of industrial sectors.

Another aspect that might be interesting for future research is the question whether the matrix in Figure 2 is truly symmetric. In other words: is it possible not only to display connections between the five aspects of CAD-CAE integration product, people, tools, data, and processes, but also to include directed influences.

Further research is also necessary to evaluate and the fill the upper two layers of the three level approach for successful communication and collaboration between design and simulation departments as the tools presented herein are only some mosaic stones in the attempt to enhance communication and collaboration between design and simulation departments.

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Sebastian Schweigert, Research Assistant
Technical University of Munich, Institute of Product Development
Boltzmannstrasse 15, 85748 Garching, Germany
Email: schweigert@pe.mw.tum.de