Title:
Simulation-oriented Transformation of CAD models

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Introduction:
Computations and simulations during the design process are performed with a variety of Computer-Aided Design (CAD) systems. For the integration of analytical calculation methods, KBE (Knowledge-Based Engineering) approaches have been integrated quite successfully. This is particularly true for parameter-oriented inference mechanisms. Numerical methods require further developed methods especially in the consolidation between design and simulation models. This paper presents a methodological approach that automates the model transformation from the design to simulation environment. This approach bases upon so-called “smart” component models, which are processed rule-based and are enriched with component-specific knowledge for the integration of design, computation and simulation. By using simulation-oriented features and components, the preprocessing becomes more efficient

Main Sections:
Comprehensive products, rising product variants and the flexible reaction to customer requirements increases the complexity of the developing process. To tackle these demands more integrated methods and software tools are required. CAD has become a standard tool for the development process in many companies. Due to extensive possibilities of modern CAD-software, the classic approach turns into a more integrated one. This opens up the possibility to regard influences from the production and computation at an early stage of the design process, which leads to a higher complexity in the simulation process as well. Methods are needed, that bring the design and simulation process even closer to shorten the product developing time. One first step in the direction of simulation-oriented design is the approach of Lee [8], which covers the CAD-CAE integration by using feature-based multi-resolution and multi-abstraction modelling techniques. Here a system simultaneously creates and manipulates a single master model that contains the geometric model for CAD and the idealized model for CAE. Through a selection process in the master-model, the CAD- and the CAE-model are extracted immediately [8]. The main topic of this paper is the dimensional reduction using multi-abstraction NMT-modeling [8]. Among other things, Sypkens complements the approach of Lee. In his paper *Integration of Design and Analysis Models* [10] from 2009, he describes that the exchange between design and analysis models wasn´t fully implemented yet. His publication covers an approach for an analysis view, which is part of the multiple-view feature-modelling paradigm [10]. *“Multiple-view feature modelling can do better here, by providing a separate view on a product for each development phase, and integrating all views. Each view contains a feature model of the product specific for the corresponding phase.”* [10]. For simulation-oriented design and for the presented approach the use of template files is important. The paper *“Template-based geometric transformations of a functionally enriched DMU into FE Assembly Models”* from 2014 proposes the use of an enriched digital mock-up with geometric interfaces between components and functional properties [1]. *“Using the template-based transformations, the user can robustly and efficiently define the geometric*

transformations according to his/her FEA objectives. Thus, new components shapes adapted to CAE software requirements are produced while the consistency of the assembly model is preserved" [1]. For example, the use of bolted junctions in assembly context is presented. The geometry of the CAD-models is separated and simplified in relevant sub domains, which can be exported as a STEP file into a CAE-software. The presented publications give an overview over the further development in the area of the integration design and analysis. The approach of Lee [13] focuses on an integrated CAD/CAE-model, which is also part of the presented approach in this paper. To use simulation-oriented features and components enhances the design process, particularly by using a CAD-system with integrated simulation environment. The paper *Template-based geometric transformations of a functionally enriched DMU into FE Assembly Models* [1] shows the use of simulation-oriented template files by a CAD-system and an external CAE-system. The idea of using template files for an efficient way of defining boundary conditions is extended in the presented approach. In both papers, features and components are enriched with simulation-specific knowledge and interconnect the partial models of design and simulation in different ways. The gap can be closed more effectively by using a CAD-system with an integrated simulation environment and by using methodologies of Knowledge-Based Engineering [12] regarding the setup of partial models. Hereafter, simulation-oriented features and components are classified. The term "smart" component models is introduced and extended in the context of the integration of design and simulation. For the presented approach, it is necessary to integrate further knowledge about computation and simulation into component models. "Smart"-component models are defined as an add-on to the conventional design components [5]. They support the designer to avoid inconsistency between the design and computation models. Fig 1 shows on the left the definition of a "smart" component model. Internally, the design and computation models are closely interconnected in a bidirectional way. The user has access to an interface to set and define information. Another interface for data exchange to other component models is given. [6]. For the definition of the internal behavior, it is possible to use all available functions for the specification of the design intent. For a usage of "smart" component models between the design and simulation, the components have to be extended by a simulation model. Within these component models the three partial models namely the design, computation and simulation model have to be interconnected as shown in Fig. 1.

Hence, after the simulation, the enriched components give a feedback, which is used for the additional design of all components of the assembly. Compared to a classic parameter optimization study, the objective is the optimization of a component not a single design parameter. After all components are placed an iterative process start, where the design calculations are performed and the simulations are executed. If these have a negative result, design parameters in the SCM are adjusted. It is sufficient that components, which require design calculations, are initially placed as dummy components. A further application of these components is the automated model transformation in regard to modeling processes for providing the designer with advanced simulation knowledge.

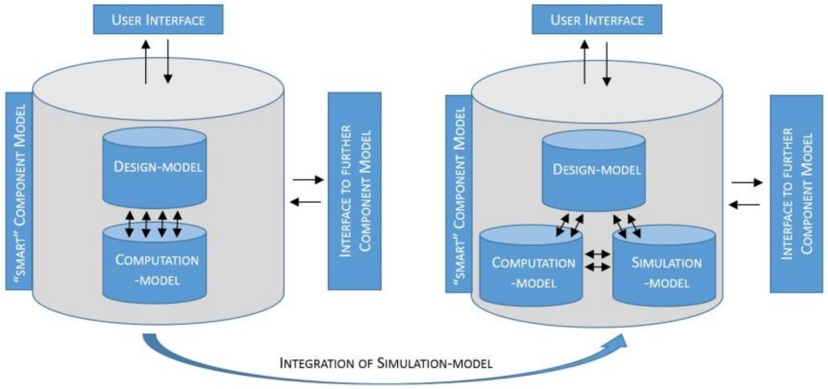

Fig. 1: Advanced component "smart" component-model.

Thereby these simulation-oriented components help the designer by defining the load- and boundary conditions. This can be an automated reduction of the dimension or a design calculation, if there is an interconnected computational model. For the realization of these simulation-oriented components, methodologies of KBE are necessary. For the integration, the definition of a KBS in the CAD-CAE-system is necessary. The architecture of such a system is shown in Fig. 2. The development of the KBS is oriented towards the general KBE lifecycle [9] as seen in Fig. 2. In the area of design planning and configuration, three ways of knowledge representation apply: the constraint-based representation, the rule-based representation and the object-oriented representation.

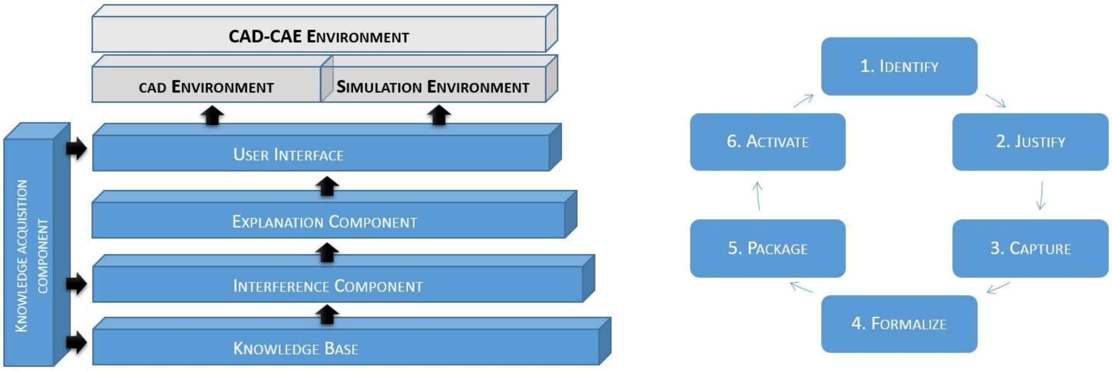

Fig. 2: Architecture of a Knowledge-Based system (left), general KBE lifecycle (right).

The knowledge acquisition is an important point of any KBS [3]. It is necessary to acquire relevant knowledge to build up the knowledge base. The acquisition, which also considers problem-specific features, is an important precondition for the qualification of the modeling process. Hence, it is a task for two expert groups. Respectively, one design and one simulation group, that extract, prepare and integrate knowledge into the knowledge base. The relevant knowledge can be gathered through different tools. For this approach, different tools of the quality management like the Failure Mode and Effects Analysis (FMEA), the Quality function deployment (QFD) and the Fault Tree Analysis (FTA) can be used. The FMEA is the most suited method for this approach. The FMEA determines the possible error sources during the modeling process from which appropriate rules derive. Thus, the application and transfer of knowledge follows the FMEA [2]. Due to the systematic procedure of revealing critical components and potential weaknesses, the transferability into the previously introduced rule-based knowledge representation is assured. Initially the distinction has to be made whether the modeling is done in component or feature context. For components, the stored knowledge is available to the user through simulation templates, family tables and control modules. The choice depends on the integration depth, complexity of the application and the used CAD-CAE environment. In case of feature context, the availability is realized by user defined features (UDFs).

The examples of bolted joints and ball bearings show implementation options for a simulation-oriented model transformation. Both use simulation templates. A configurator as additional inference mechanism extends the example of the ball bearing. Bolted joints are divided into four classes of models for the numerical calculation according to VDI 2230 Part 2 [11]. This guideline specifies how bolted connections can be defined as boundary conditions within a structural-mechanical simulation. The four model classes are differing in the level of detail of the simulation model. Thus, each geometry model can be linked to four simulation template files, which can be selected by the user [1]. The model classes of the simulation models are defined as follows [4]:

- Model class 1: No bolt in the model; clamped parts are modeled as continuum
- Model class 2: Clamped parts are modeled as a continuum or with contact at the interface; the bolt is idealized using a beam or spring element

- Model class 3: Bolt is modeled as substitute volume body without thread; preload forces are defined; contact at the interface
- Model class 4: The geometry is fully detailed

Fig. 3 shows the schematic overview of the model classes and the level of detail in the geometry model.

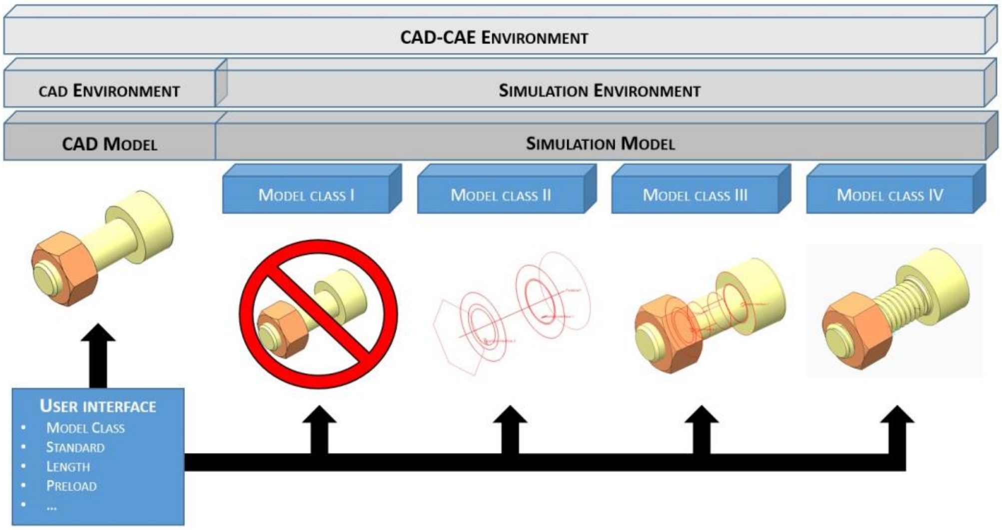

Fig. 3: Automated idealization of bolted joints.

The process is as follows: The user defines a bolted joint in the assembly. The CAD model is linked to the four simulation models and depending on the user´s choice, the model class will be defined for the simulation. In each of the four simulation models, a predefined load model is available, which is based on the respective boundary and load conditions. They must be defined in the component according to the guideline. If the implementation is insufficient only with simulation templates, additional inference mechanisms can be used. In the subsequent example, a configurator for an internal design calculation is used [7]. Regarding the structural mechanics simulation of shafts, the simulation model is so highly simplified that the ball bearing and the associated stiffness cannot be mapped. By assuming an ideal stiff bearing, a falsification of the results is expected. Through the use of simulation templates, the stiffness is realized by an idealized bearing. This is controlled by an integrated design calculation as shown in Fig. 4.

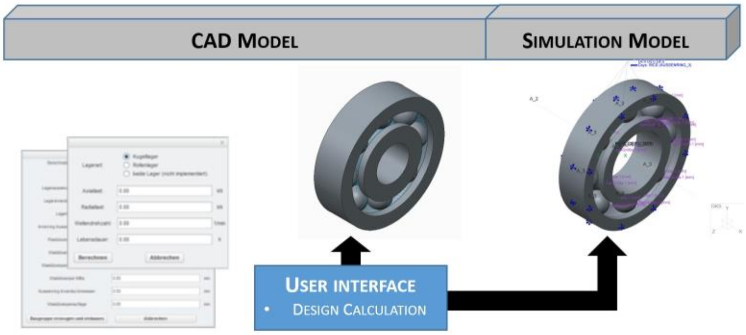

Fig. 4: Using a configurator as inference component.

The design of the bearing is the result of an integrated configurator, which includes an internal design calculation. The created CAD model is placed into the assembly. By switching to the simulation environment, the idealized ball bearing will be loaded and can be used directly as a boundary condition, because all partial models are already defined. Like previously presented, the integrated knowledge has to be separated. In this case the template files include three parts: the inner ring, the rolling elements and the outer ring. All parts are designed parametrically according to standards of ball bearings. Therefore, the complete dimensioning is controlled by six parameters. The further knowledge is integrated into the source code. Both are connected via the configurator as an inference mechanism. The placement of the subassembly can be done in two different ways. On the one hand, an existing subassembly can be exchanged and one the other hand the subassembly can be placed directly.

Conclusions:
The presented approach for an automated model transformation turned out to be a successful safeguarding of a simulation-oriented CAD model. This is essential for the integration of product and process specific knowledge into the interconnection of design and simulation processes. As a result, the complexity of the modelling process during the preprocessing can be reduced significantly. Furthermore, this approach is particularly useful for a standardization of the modelling setup, if frequently used components are available. This offers potentials for the development of product adaptations and variant constructions. Improved possibilities are also given for new constructions in order to confirm simulation- and functional-oriented product data models.

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