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Simulation-oriented Transformation of CAD Models

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ABSTRACT

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.

1. Introduction

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. This paper presents an approach for applying and developing simulation-oriented features and components in a CAD-system with integrated simulation environment. By using an integrated environment, a transfer of geometry with neutral interface formats is not necessary. The benefits are on one hand a reduction of time during the preprocessing and solving phase and on the other hand the prevention of errors.

The following chapter describes the state-of-the-art concerning methods and approaches of the integration of design and simulation as a central topic and introduces the approach mentioned above for the simulation–oriented features and components. The focus in

this paper lies on the simulation-oriented components focused on repeat and standard parts/assemblies.

2. Research Context

Many researches form the past years contain the integration of design and simulation and the further development of the feature-based design. For a better classification of the presented approach, selected publications are introduced and discussed. The integration of enriched features and components is a key point in the interconnection of design and simulation One of the first concepts was published in 2003. At that time an integration of CAD and Computer Aided Engineering (CAE) wasńt really existing. Therefore, the authors described several requirements as well as the needs to couple the different models of design and simulation [1]. "*Their view on CAD-CAE integration is similar in many ways to the current views expressed by scholars*" [15].

One first step in the direction of simulation-oriented design is the approach of Lee [12], 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

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CAE-model are extracted immediately [12]. The main topic of this paper is the dimensional reduction using multi-abstraction NMT-modeling [12].

Among other things, Sypkens complements the approach of Lee. In his paper *Integration of Design and Analysis Models* [15] from 2009, he describes that the exchange between design and analysis models wasńt fully implemented yet. His publication covers an approach for an analysis view, which is part of the multiple-view feature-modelling paradigm [15]. "*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.*" [15]. In his paper *Computer Aided Design and Finite Element Simulation Consistency*, Hamri presents an approach that reduces the gap between CAD and CAE with a so called mixed shape representation [7]. This approach is used for the model exchange between CAD and an external FE-simulation and shows the difficulty of the connection between CAD and CAE.

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 [3]. "*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*" [3]. 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. In these papers, features and components are enriched with simulation-specific knowledge and interconnect the partial models of design and simulation in different ways. The transfer of the geometry model between CAD and an FE-simulation is the main reason for the gap between CAD and CAE. This gap can be closed more efficient by using a CAD-system with an integrated simulation environment and using one master model. The approach of Lee [12] focuses on an integrated CAD/CAE-model, which is also part of the presented approach in this paper. The paper *Template-based geometric transformations of a functionally enriched DMU into FE Assembly Models* [3] shows the use of simulation–oriented template files by a CAD-system

and an external CAE-system. The usage of template files is an efficient way of defining boundary conditions and is extended in the presented approach. The interconnection can be used more effectively by applying methodologies of Knowledge-Based Engineering in an integrated system regarding the setup of partial models [17]. Additionally, by using the same master model, an interconnection between the simulation and computational model can be integrated in a more lean way.

3. Classification of Simulation-oriented Features and Components

A design is categorized into new design, variant design and customized design. Simulation oriented features can be assigned to new designs whereas simulation oriented components are rather associated with variant and customized designs. For this assignment the application of simulation-oriented features and components has to be clearly classified. In this context, the terms feature and components have to be delimited:

- A feature is a summary of geometrical elements, which includes semantics [2].
- A component is a general term for parts and assemblies belonging to a construction [9].

The simulation-oriented feature combines a classical design feature with a simulation-feature. The simulation-feature includes geometry or semantic, which is necessary for the simulation process. In the following, two examples for both cases are given:

- The use of sheet metal features. An automated reduction of the dimension of the used features, if the simulation with shells is possible.
- The use of advanced rounding or chamfer features. An automated suppressing of these, if they are not placed in the flow of force.

The simulation-oriented component is the classical design component enhanced with an internal simulation model. The simulation component is build up from parts or assemblies, which can be designed with simulation-oriented features or the simulation knowledge is implemented subsequently. Therefore, the redefinition of an often used component such as a standard or repeat part into a simulation-oriented component can be performed after the originally design. The implementation of these components is the content of the following chapters.

4. Simulation-oriented Components

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 [9]. They support the designer to avoid inconsistency between the design and computation models. Fig 1 shows 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. [10].
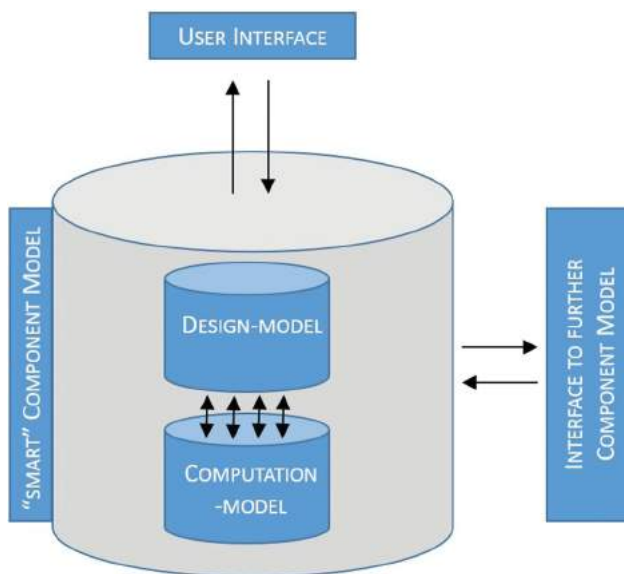

Figure 1. "Smart" Component Model (adapted from [9]).

This changes the classic way in a manner that the design calculations are executed after the component is placed in the assembly. These new component models are based on parametric CAD-master models [9]:

- they can be compare with classes of the object-oriented programming
- they have the aim to enclose the functionality and to hide the complexity
- they got a semantical closed behavior, which is characterized by the integration of design and computational model

The components own different interfaces, with which, they can interact with the designer and other components in an assembly context [9]:

- dialog interface: interactive requests of missing parameters

- placement interface: intelligent selection of placement references
- interface to other components: Interface for cross-component dependencies

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. 2.

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. 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. The following chapter describes the implementation of a Knowledge-Based System (KBS) focusing on the automated model transformation.

4.1. Developing of KBE-applications in the context of CAD-CAE integration

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. 3. The development of the KBS is oriented towards the general KBE lifecycle [14] as seen in Fig. 3. In the area of design planning and configuration, three ways of knowledge representation apply:

- constraint-based representation
- rule-based representation
- object-oriented representation

This approach uses the rule-based representation, because the formalized classification of the used component
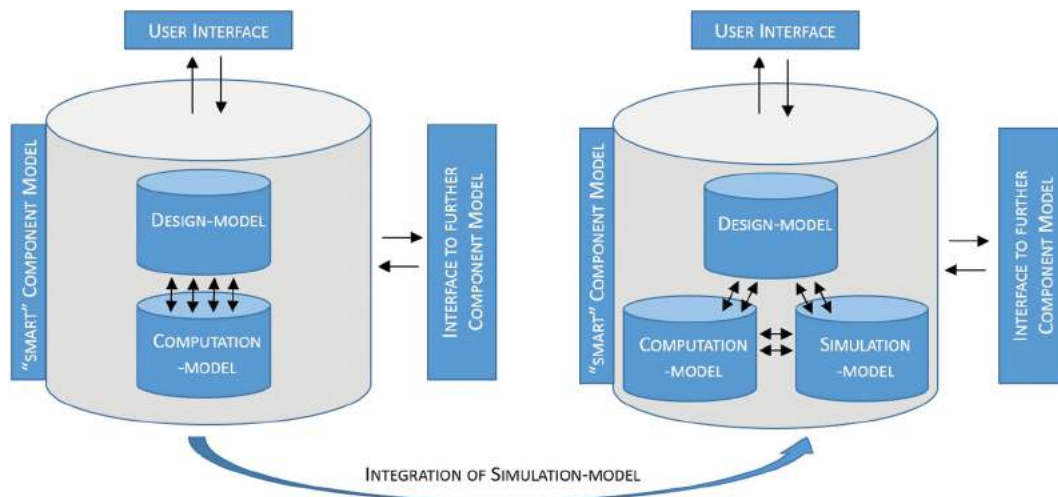
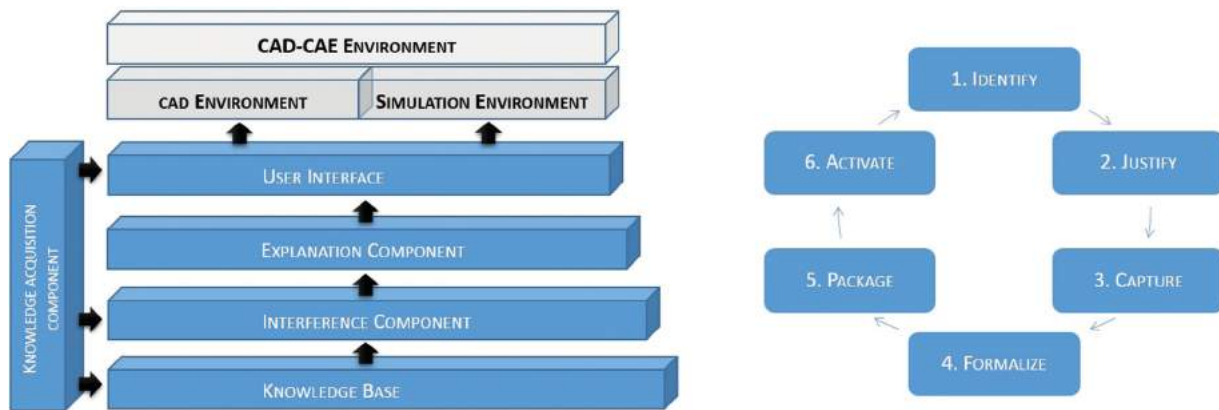**Figure 2.** Advanced component "smart" component-model.

Figure 3. Architecture of a Knowledge-Based system (left), general KBE lifecycle (right).

models is always unambiguous. This unambiguousness is an objective of various methodologies of knowledge acquisition. Accordingly, a transferability of knowledge is ensured.

4.2. Knowledge Acquisition and Representation

The acquisition, which also considers problem-specific features, is an important precondition for the qualification of the modeling process. The knowledge acquisition is an important point of any KBS [6]. It is necessary to acquire relevant knowledge to build up the knowledge base. 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 the Failure Mode and Effects Analysis (FMEA), the Quality function deployment (QFD) and the Fault Tree Analysis (FTA) can be

used. These tools can be understood as first explanation for implicit knowledge. The implicit knowledge has to be transferred into explicit knowledge. Through e. g. an FMEA two forms of knowledge representation can be analyzed: the procedure itself contains the procedural knowledge and the results contain the declarative knowledge [5].

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 [5] as shown in Fig 4. 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
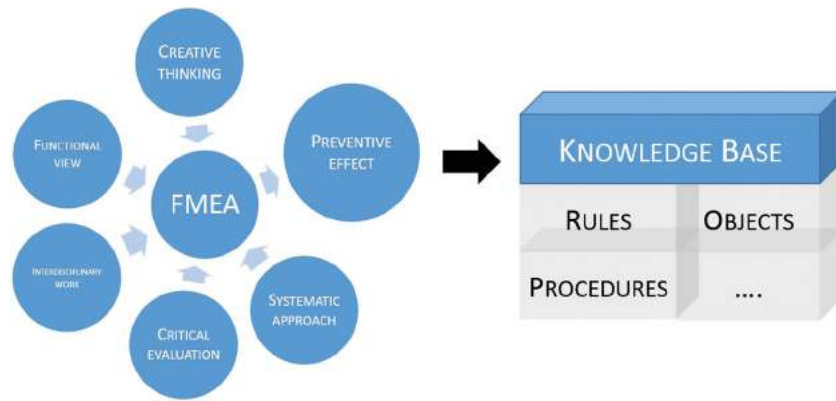
Figure 4. Using FMEA for building up the knowledge base

CAD-CAE environment. In case of feature context, the availability is realized by user defined features (UDFs).

4.3. Implementation of the approach

There are three possibilities for the implementation of a KBS. They depend on the level of integration as seen in Fig. 5. A customized KBS performs the implementation in this approach. In this case, the KBS communicates with the CAD-system over an API (Application Programming Interface). The customized system uses system specific functions to build up or to manipulate a model based on the stored knowledge in the KBS. The API provides the opportunity of a geometrical feedback to the system [11]. The transferability of the saved knowledge of the system into the CAD environment is bidirectional possible. The knowledge is separated into simulation templates and knowledge that is integrated into the source code.
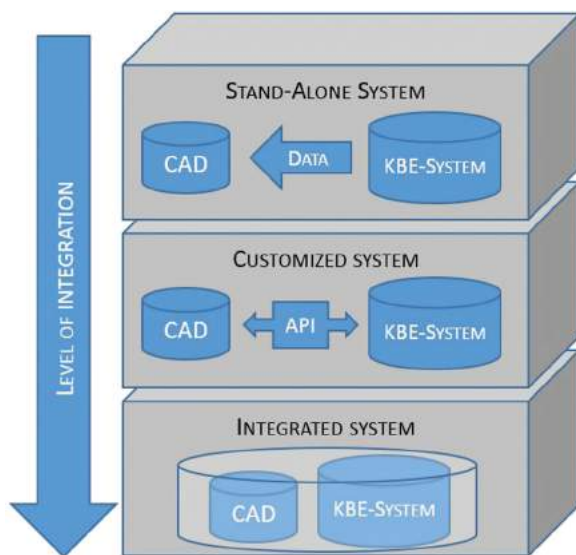

Figure 5. Possibilities of KBE system integration (adapted from [4]).

For the whole implementation, various options are given. One is the definition of simulation templates with the intention to simplify the pre-processing for the user [4, 1]. For type series and part families, the geometry model can be defined by using a family table in the CAD environment, which is linked to corresponding simulation templates. More extended component dependencies can result from the integration of further inference mechanisms; e.g. by a configurator.

4.4. Examples for model transformation

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. Afterwards a third example revolves around a tank construction. All examples were realized with Creo Parametric 2.0, Creo Simulate 2.0 and Creo Toolkit, all products of PTC.

4.4.1. Simulation templates for model transformation

Bolted joints are divided into four classes of models for the numerical calculation according to VDI 2230 Part 2 [16]. 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. The model classes of the simulation models are defined as follows [8]:

- 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
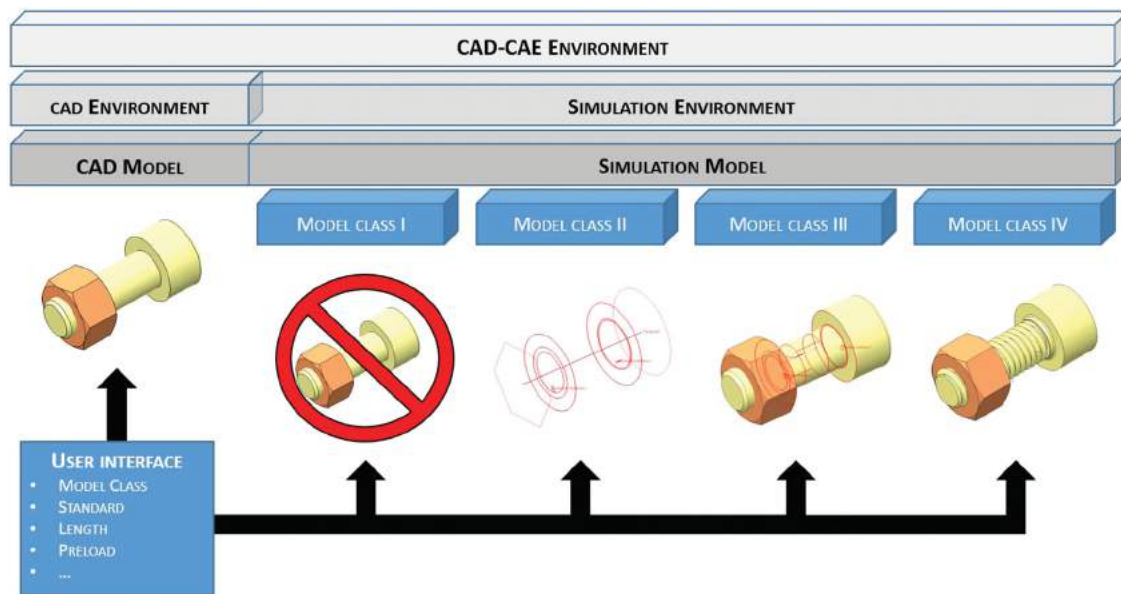
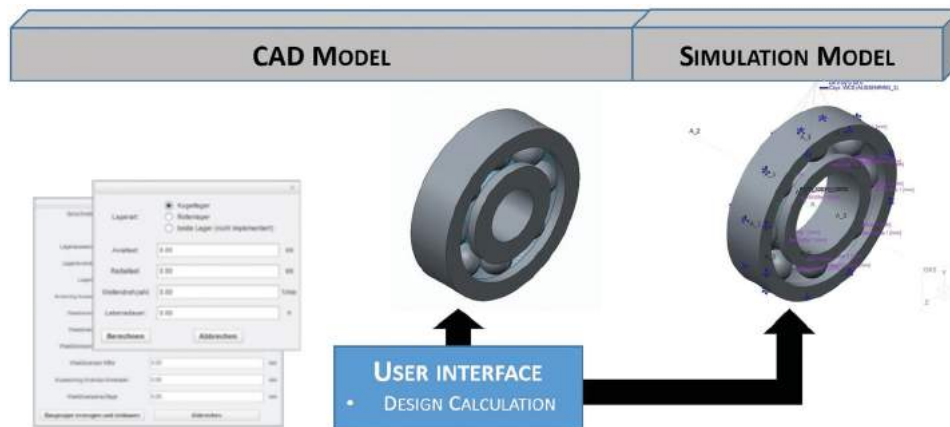**Figure 6.** Automated idealization of bolted joints.

Figure 7. Using a configurator as inference component.

- 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

Figure 6 shows the schematic overview of the model classes and the level of detail in the geometry model.

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. For defining contacts, the surface IDs, which are known through the placement of the components, are necessary.

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 [13]. 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. 7.

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
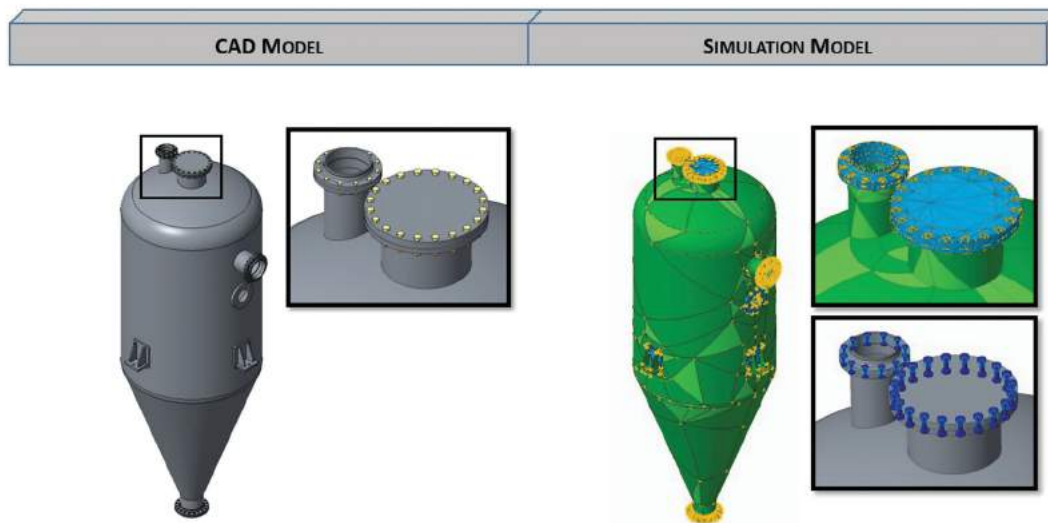
Figure 8. Pressure tank construction.

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. In both examples, the computation and simulation models can be connected. After the simulation of the assembly, design calculations start automatically and recheck the respective component. The other way around, computation and simulation models are closely interconnected in a bidirectional way. If the simulation is saved as a design element in the model tree, the simulation succeeds automatically.

In the following schematic example presents the usage of bolted joints and simulation-oriented features. In this assembly, which is shown in Fig 8, more than 80 fasteners connections are needed. By the use of the previously shown approach, e. g. the model class 2, less mesh elements were created and on the other hand the idealized bolted joints are created directly.

Many elements of the assembly can be created by using sheet metal features. This indicates towards the usage of shells during the preprocessing. By using simulation-oriented features, the dimension is reduced automatically. This requires a usage of a clear design strategy. In this example, the designer has to work consequently with sheet metal tools. The wall is designed by one sheet metal revolving feature that assumes a constant wall thickness, which is a precondition of the direct use of shells.

5. Conclusions

The presented approach for an automated model transformation turned out to be a successful validation 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 is reduced significantly. Furthermore, this approach is particularly useful for a standardization of the modelling setup. This offers potentials for the development of product adaptations and variant designs. Improved possibilities for new designs are given in order to confirm simulation- and functional-oriented product data models. Another potential is the use of the presented methods for an advanced parameter optimization approach, which adds production parameters to the already implemented design parameters. In the pressure tank example, sheet metals tools are used, that integrate specific manufacturing knowledge into the model, which can be an objective of an optimization process as well.

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