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# KNOWLEDGE BASED SUPPORT FOR THE DESIGNER AT THE INTERFACE OF CAD/CAE

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## Abstract

The extensive possibilities of modern CAD-software turn the classic approach into a more dynamic one. This opens up the possibility to take into consideration influences from the production and computation at an early stage of the design process. The content of this paper is a three-stage approach for the developing of support systems for a knowledge-based safeguarding in the design process. This method has been developed as part of researches of supporting methods for simulations during the design phase. Accordingly, the focus is still on the interface of CAD-CAE. The method is divided into three parts: the knowledge acquisition, the system design and the knowledge implementation into the CAD System. The approach will be applied in a case study, which focuses on an integrated simulation strategy for injection moulded parts.

**Keywords**: Computer Aided Design (CAD), Integrated product development, Systems Engineering (SE), Knowledge-Based Engineering (KBE), Injection-moulded part design

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## 1 INTRODUCTION

The extensive possibilities of modern CAD-software turn the classic approach into a more dynamic one. This opens up the possibility to take into consideration influences from the production and computation at an early stage of the design process, which leads to a higher complexity in this process. A consequence is the requirement of a higher share of expert knowledge. This leads to a less reproducible process and a higher risk of human failure. As a prevention, the standardization of processing steps and the integration of relevant knowledge into the CAD-environment could be used. Therefore, an even closer integration of relevant influences is needed to further accurate the product development. All this requires practical methods, which specify how complex support systems can be developed for a CAD-environment. Due to the high level of complexity, for the creation a full formalization of a system model before the implementation is necessary.

The content of this paper is a three-stage approach for the development of support systems for a knowledge-based safeguarding in the design process. This method has been developed as part of researches of supporting methods for simulations during the design. Accordingly, the focus is still on the interface of CAD-CAE. An ability to transfer the approach for other process chains is given.

The entire process is managed by a systems engineer. Further roles are the designer, the simulation expert, the manufacturing expert and a programmer. In the first stage, methods for knowledge acquisition and transformation will be shown. The seconds presents the knowledge formalization. Techniques of model-based systems engineering (MBSE) are used. This ensures a neutral discussion basis for all persons involved in the development process. Techniques for the Implementation in CAD are part of the third stage. These include for example the application of user-defined features and the usage of a webservice combined with a database. The approach will be applied in a case study, which focuses on an integrated simulation strategy for injection moulded parts.

## 2 RESEARCH CONTEXT

A large number of institutes are researching methods to streamline the design process. In the area of CAD-CAE a first step for an optimization of the CAD-CAE process chain is the usage of master models, which contain a geometrical model for CAD and an idealized model for CAE. (Lee, 2005; Danjou et al., 2008; Boussuge et al, 2014) Current contributions regarding simulation during the design process mainly cover the development of knowledge based FEA-support systems (Kestel and Wartzack, 2016; Arabshahi et al. 1993) and methods for a knowledge based development of simulation oriented product models (Klemme, 2015). The objective is to support the designer in conducting and comprehensive simulations. Regarding the optimization of the process chain CAD-CAM Humpa and Köhler (2015) present a practicable CAD-based geometry design approach for spiral milled parts. They are using KBE methods such as UDFs, in combination with hybrid modelling techniques and rule based model design, which leads to an improved process (Humpa and Köhler, 2015): “By the use of methods and tools of knowledge-based engineering (KBE), manufacturing process information and manufacturing knowledge can be integrated into the 3D product model”.

The selected publications demonstrate the need of methods for the development of integrated process chains. In most cases KBE methods are used. An important condition for KBE is the acquisition and transformation of knowledge. A first approach was the "Ripple Down Rules"-method (RDR) (Gaines and Compton, 1995). RDR describes a method to collect knowledge from human experts, where rules are created while the system is working. If the system does not work correctly, a human expert sets up a notification describing the faults. For every error the user adds a rule to the knowledge base (Gaines and Compton, 1995). Another approach is named CommonKADS (Schreiber et al., 2000). This method can be used for the development of knowledge-based systems. The main part is divided into three groups (context, concept and artifact), which are divided into different models. For knowledge implementation, the knowledge model is utilized, which is also divided into three categories (Schreiber et al., 2000). For the development of knowledge-based systems (KBS) and the formalization of knowledge another method called MOKA (Stokes, 2001) exists. The main part of the method consists of the MOKA lifecycle, which is divided into six steps for knowledge acquisition.

The state of the art shows that the development of support systems for the design process is still a current research topic. These are used to support and ensure the designer in his work at the center of the interdisciplinary product development. This increases the quality of the entire design process. The required product development time is reduced by removing unnecessary iterations, which also saves costs. On the other hand, there are the costs and the effort for the development of such support systems. The knowledge acquisition and knowledge formalization form the basis of every KBE method. The personal knowledge of the involved experts must be extracted. The presented methods involve relevant expert groups at the beginning and then carry out a knowledge transformation. This creates the basis for the formalization and implementation. Later changes to the system, during the formalization and implementation, can only be realized with increased effort. This can be optimized if experts and users are integrated into the formalization stage and in the development of the overall system. This also leads to increased acceptance of the support system by the designer.

## 3 KNOWLEDGE BASED SUPPORT OF THE DESIGN PROCESS

The classical milestones in the development of KBSs are the creation of a knowledge base and the implementation in the CAD environment. The system design is assigned to these two as a third milestone, see Figure 1. Changes to the system in this milestone can be realized more cost-effectively and less time-consuming than the following milestone, the implementation in the CAD environment.

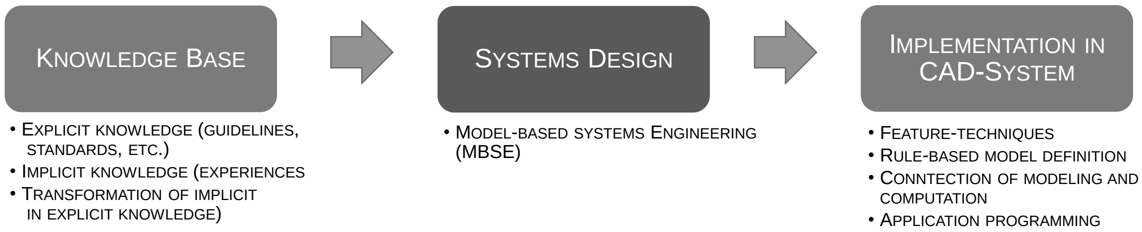


*Figure 1. Systems design as a new milestone for the developing of KBSs*

Starting from this, a three-stage approach for the developing of support systems for a knowledge-based safeguarding in the design process is developed, see Figure 2. The approach provides that in stage 1, already existing explicit knowledge is collected in form of standards or norms, regarding the problem situation. Additional implicit knowledge is transformed in the form of expert knowledge. The second stage starts with the systems engineering based on stage 1.

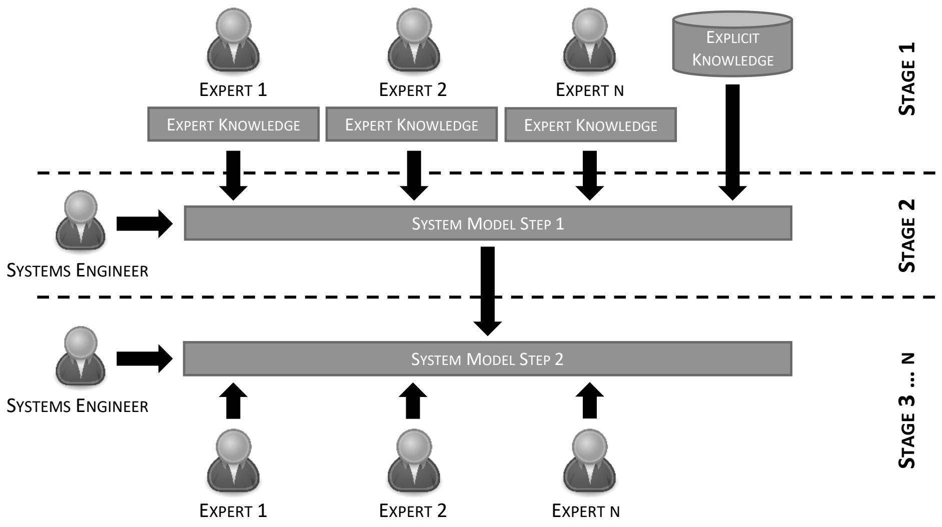


*Figure 2. Three stage approach*

This is the developing of a basic system model (system model step 1) on the given input. One advantage is that the system model allows different views on information at any time. This ensures the required discussion base to include the designer and other experts in the development of the system, marked as stage 3. All involved participants contribute to the formalization and creation of the system (system model step 2). In the following, tools and methods for implementing the above approach as well as methods for implementation in the CAD environment are presented.

## 3.1 Knowledge Base

The first stage of the approach is the definition of a knowledge base. The knowledge acquisition is an important precondition for the qualification of the modeling process. Problem specific characteristics must be considered as well. In general knowledge is given in two different types. The explicit knowledge, which can be understood as written knowledge and is available in guidelines, standards, technical code, etc. If a guideline contains relevant knowledge it could be summarized into a knowledge base in a formalized form. The second type of knowledge is implicit knowledge. This could be understood as knowledge which concludes from experiences, in this case the experience of the simulation expert and the designer. To collect this knowledge into a knowledge base it has to be transformed into explicit knowledge first. One possible approach is the conduction of a "Failure Mode and Effects Analysis" (FMEA), which can detect potential sources of errors during the modeling process (Dittmann, 2012). This can result in a rule set for error prevention that can be processed in FMEA-forms. These forms need to be answered by the experts regarding a specific problem. The recommended actions of the FMEA provide a first declaration of implicit knowledge. This will be implemented into the knowledge base in addition to previously given design rules.

## 3.2 Systems Design

Within this second milestone approaches of MBSE are transmitted. However, the usage requires a transformation of the document-based to model-based system development. This essentially means that documents are no longer seen as the original source, but describe a view of the defined model and are derived from it. For formalization of the explicit knowledge MBSE methods will be utilized. In this case the modelling language SysML is used. This is a graphical modeling language which is based on UML and is mainly used for the modelling of complex systems. The formalization with SysML gives a neutral discussion basis for the systems engineer and the involved experts, while an efficient implementation into the CAD environment can be ensured. The main diagram types are divided in structure-, requirement- and behaviour-diagrams. A subtype of the behaviour diagrams is the activity diagram, which is used for the representation of processes in a defined use case. Furthermore, it is an object oriented adaption of a flowchart. This is an advantage regarding the implementation into the CAD environment by an API, because the programmer can translate this into a program flow chart. Requirement diagrams contain all requirements of the system, subsystem and their relations. Structure diagrams can be divided into package-, block definition- and internal block definition diagrams. The package diagram can be utilized to define the main division of a system.

## 3.3 Implementation in CAD/CAE

The implementation in a CAD system is done by using different KBE techniques. The usage of these is application-specific and requires a further classification according to certain criteria, like the level of integration or a desired/required knowledge representation form. Depending on the system developed in the chapter before, it would be selected the appropriate techniques for the knowledge-based safeguarding. A selection of possible techniques is feature-techniques, a rule-based model structure, a linkage of design and computation and the application programming.

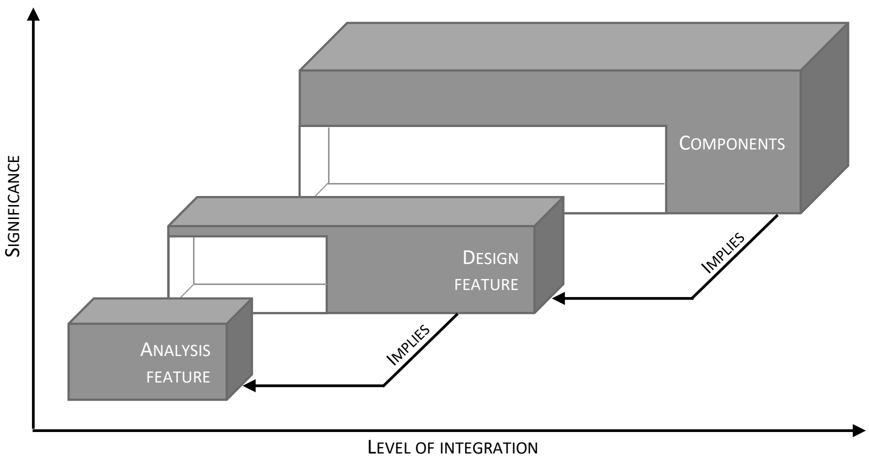


*Figure 3. Significance of the safeguarding*

The significance of the safeguarding is dependent on the extent of the integration level of the chosen technology. This can also be defined as an indicator of the level of information. The techniques are applied on three different levels. Level 1 describes an analysis feature. By definition only semantic and no geometry is included. If a feature contains both geometry and semantics, this is defined as a design feature corresponding to level 2. The third level contains components as already fully developed CAD models. In general, a classification as in Figure 3 is permitted. It is important to note that a technique with a higher valence can be based on the knowledge of a technique with a lower value. This ensures, for example, the usage of knowledge, which is necessary to define an analysis feature, also for the definition of a design feature. Thus, in the prevailing design mode, the usage can be optimally weighted against the expense of a knowledge-based safeguarding. Which technique is used is derived from the created system. If the safeguarding is defined in a block definition diagram it is the first indicator of the development of components. Conversely, when the safeguarding is a result of the activity diagram, this points to a feature.

# 4 KNOWLEDGE-BASED PRODUCT PLANNING AND ENGINEERING OF INJECTION-MOLDED PARTS

In the following, the presented approach will be applied in a case study. In the first part the system design is shown. Participants are a systems engineer, a designer and a simulation expert. Upon completion of the systems design, the implementation of the system in the CAD environment is represented in the second part. The implementation is done by a programmer. The content of this project is the development of a method for an integrated product simulation. It reasons in the missing support of the designer in the CAD-system regarding the injection moulded part design during the entire design process. The project is carried out in cooperation with the department of Engineering Design and Plastics Machinery.

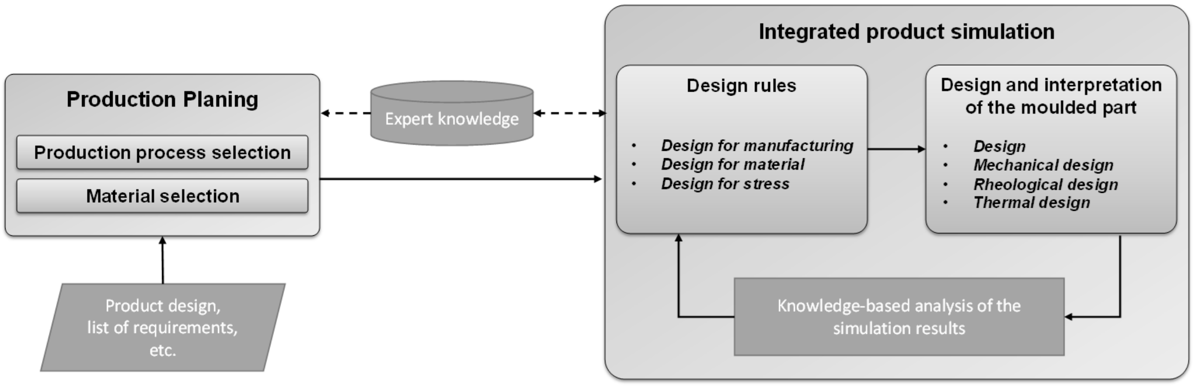


*Figure 4. Project setup*

An essential objective is the realization of a knowledge based assessment of manufacturing possibilities and the preselection of materials for a safe and objective product planning. Furthermore, the project aims for the acceleration of the design of moulded parts through the reduction of unnecessary optimization steps according to the usage of knowledge based systems, as shown in Figure 4.

Relevant guidelines, standards and expert knowledge for the development of the knowledge base are provided by the cooperating project partner. For the systems engineering the software Visual Paradigm (Visual Paradigm International) is used. A requirement on the later implementation is the realization with a software cluster consisting of Siemens NX 10 (Siemens), Sigmasoft (Sigma Engineering GmbH) and Matlab (MathWorks).

## 4.1 Systems Design of the Project

The entire project was developed first theoretically in a specific number of feedback loops using SysML, as described in the approach. The developed methods are presented in this chapter. The practical implementation in the CAD system is described in the next chapter. A rough allocation of the structure of the project is seen in Figure 5. The structure is divided in three modules. Module 1 includes the selection of material and production processes. Module 2 describes the support of mould design in the CAD environment. In module 3 techniques for rheological simulation are presented. In the following selection of the generated diagrams by SysML, including explanations, are presented. In this paper the focus lies on module 2 and the linkage of the modules.

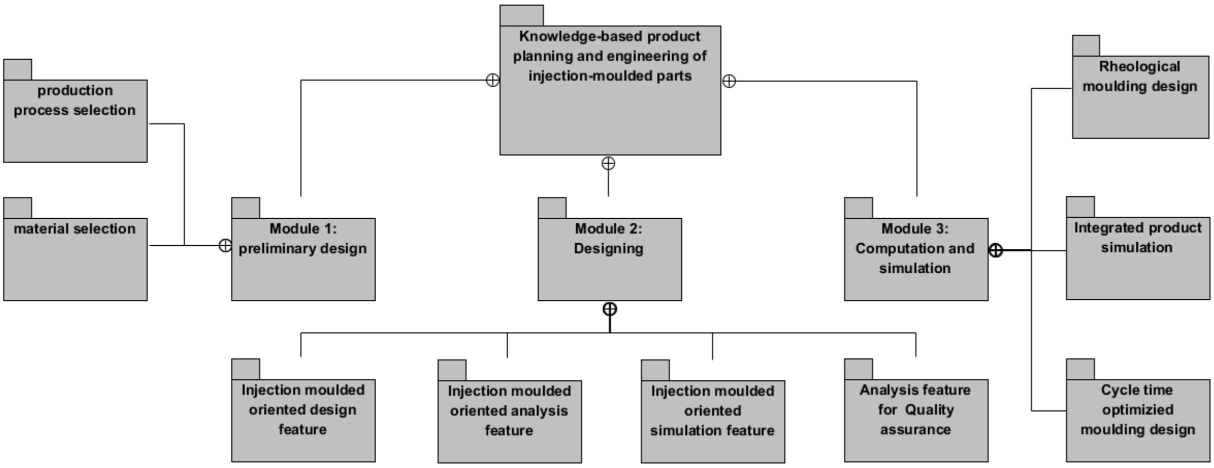


*Figure 5. Project structure as a package diagram*

As described before a requirement is a neutral knowledge representation. This is ensured by using a webservice and a database. All relevant data are stored in a database, which is placed on a server. This approach also ensures a lower maintenance effort for the system, since only the webservice and the database need to be updated when it is integrated into more than one workstation. The queried data is then loaded into the CAD system via a neutral data exchange format and saved as expressions. These data can then be used by corresponding features. A regeneration control is to be ensured at this point in order to be able to record the influence on relevant features in the event of a change to the material or process.

The module 1 is divided in two sub modules. One contains the selection of production processes while the other deals with the material selection, which is limited to thermoplastics. This selection is performed by the designer in the CAD-Environment. The related workflow is shown in Figure 6. The requirements are separated in general and specific requirements.

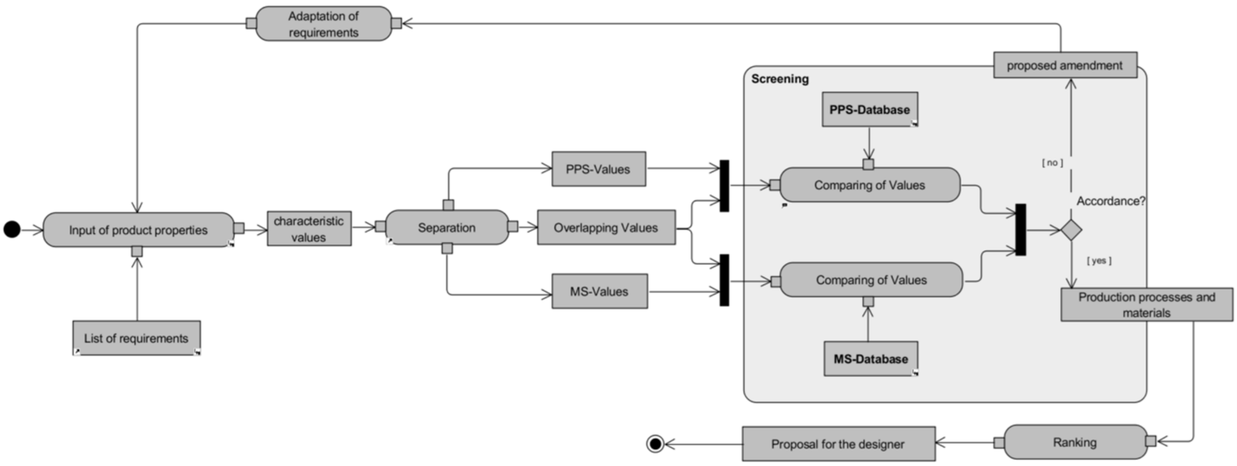


*Figure 6. Activity diagram production process and material selection*

A requirement for the entire system is the consideration of product properties derived from standards and guidelines already in the material and procedure selection. These properties are taken into account in the specific requirement list. For this purpose, a digital preparation of standards and guidelines was necessary.

Some materials and procedures can be excluded from the product type. This qualification of product properties can also be integrated into the further course of the geometric modeling. Geometric restrictions of guidelines and standards can thus be integrated at an earlier stage. For this purpose, the product must be defined in advance and respective standards must be taken in account. The designer can view a requirement list directly in his CAD system via the internal web browser. The conditions must then be defined in the CAD model. By linking standard dimensions with dimension parameters in the CAD model, these can be used as design conditions or as an optimization goal in a subsequent optimization study. A further implemented scenario is the definition of function surfaces specified in the standard. Thus a surface can be locked for a sprue definition or it could require a certain surface quality.

If a relevant CAD-model is already available, requirements for the material and production process selection can be derived from it. The aim of this screening is a ranking of the most suitable production processes and materials, which will then be proposed to the designer.

The next step is the usage of the saved knowledge for the design phase. This is the context of the module 2 "Designing". This module is divided into four sub modules. The developed modeling methodology allows an individual and standardized modeling. Individually means as long as the required injection moulding suitability is to be checked. This is ensured by developed test methods and analysis features. In the case of a standardization of a production-oriented feature, the injection-suitable is ensured directly. Requirements for an injection-moulding-oriented feature are largely defined in the literature.

When developing the feature, it is important to note that many of the rules in the literature are interrelated. Accordingly, these links are analyzed and then implemented. Furthermore, the relationships between the material selection, the production process selection and the feature have to be analyzed as well, because they determine some geometry parameters. The material defines e.g. a limitation with respect to the minimum and maximum wall thickness as well as the permissible (material-dependent) draft angle. The production process provides boundary conditions, such as the maximum installation space. All boundary conditions are able to be manually inserted and scaled by the designer.

In the theoretical feature development with SysML the workflow is defined in activity diagrams. The workflow for a design feature for inserting draft angles is shown in Figure 7. The geometry of the component has a great influence on the demouldability. No surface of the component should lie perpendicular to the separation plane. By inserting a certain incline on the relevant surfaces, the frictional force during demoulding is reduced. The draft angle material-dependent is ensured by linking the feature to the expressions that were stored in the system during the material and production process selection. Due to the regenerability, the correct angle is also defined during a subsequent material exchange. Additional design features in an implemented form are shown in the following chapter.

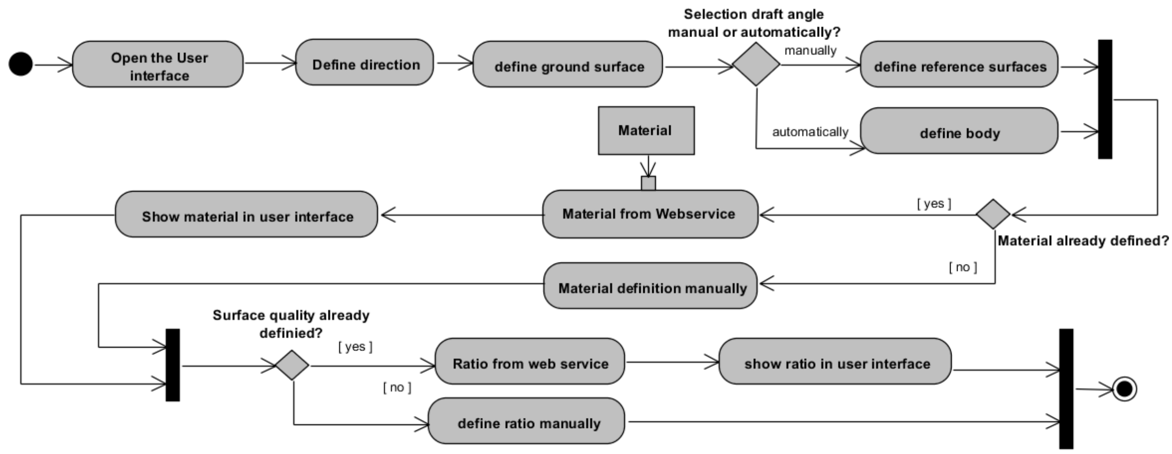


*Figure 7. Activity diagram feature draft angle*

In the CAD system the simulation preparation is divided on the one hand into geometry-preparatory methods and on the other hand into methods for interface definition. For the transformation of the geometry model of the CAD model into that of the simulation model, model-preparatory steps are necessary. Depending on a rheological simulation, the focus is on a real representation of the later cavity. Factors are e. g. the inclusion of the shrinkage and the tolerances. The shrinkage is controlled by a material-specific parameter. This is also result from the expressions defined in the material selection. The tolerance model must also be considered. All dimensional tolerances must be defined before the rheological simulation to the respective minimum. For this purpose, the respective tolerance fields are defined from all geometric-determining dimensions and then adapted.

The filling simulation is handled by the software Sigmasoft. Due to non-existent interfaces regarding the optimization, the post processing has to be carried out in Matlab. The first step is the export of a step-file to Sigmasoft, where the simulation is processed. Based on the mesh creation in Sigmasoft, derived mesh creation parameters are provided for NX. This results in a second mesh which is created in NX and transferred to Matlab together with some simulation meta data subsequently. In Matlab the Sigmasoft results are mapped onto the imported NX mesh, which enables Matlab to analyse all relevant values. The process was defined in an activity diagram, see Figure 8.

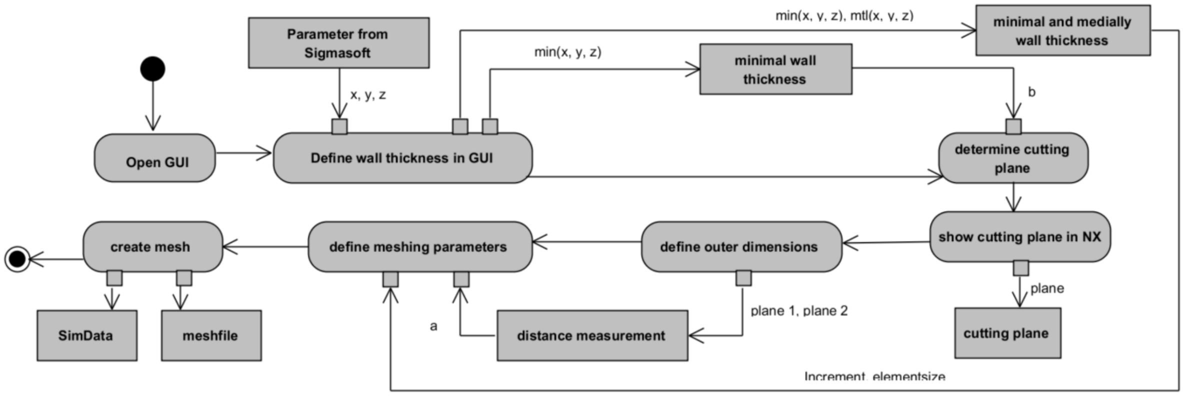


*Figure 8. Activity diagram 3D-export feature*

Once the simulation is finished, which is mainly part of the cooperation partner (Porsch et al. 2016), the results have to be transferred back into the CAD-environment: Assuming a fixed gate location and an uneven filling of the part, the system determines coordinates for possible flow aids or barriers. Those coordinates are transferred to NX for a semi-automated creation of these geometries. For this purpose, a transfer feature is introduced which requires the user to declare the path to the respective neutral data-file and thereby automatically generating the geometry. The geometry parameters are monitored by the simulation software and if the rectangular geometry does not result in the desired improvements the system will suggest up to two alternative cross-sections. In the end this will lead to a design proposal for a consistently filled part.

## 4.2 Implementation in CAD-Environment

After the systems design in the chapter before, the project was implemented in the CAD-Environment. A state of the implementation in NX 10 is shown in Figure 9. The GUI is divided into four clusters of features.

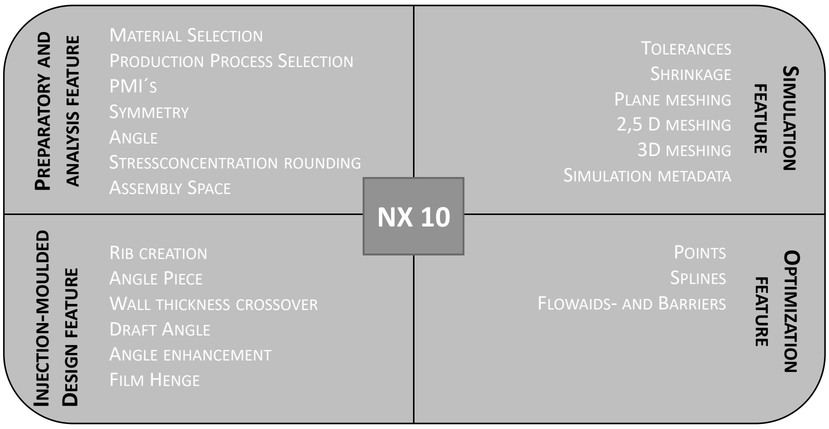


*Figure 9. Implemented features in NX 10*

The data transfer between the webservice and the CAD-System is achieved by the usage of HTTP-requests and separate JSON-files. For the material or production process selection the user gets access about the respective features, which are connected with the internal web browser of NX. The access via an external web browser is also possible. When the designer is not sure about the selection, he can arrange the selection by an expert. The release of the selection take occurs via a feature. Another feature serves the linkage of geometry parameters (wall thicknesses, volume, etc.) with those of the material and process selection. If the selection is made before the model creation, the relevant data is displayed to the designer as table. Thus, individual geometry parameters are easier to assign during modeling. The assembly space is indicated by bounding surfaces, which can be shown and hidden by a feature. The opening direction can also be displayed. If the modeling is made before the material and method selection, the relevant geometric parameters will be analyzed by different feature. Then they are predefined as fixed parameters in the selection. The standard analysis feature of the CAD system can be used to determine most geometry parameters. In Figure 10 implemented design features are shown. On the left side a feature for a contra angle and on the right side a rib creation feature is shown, while the draft angle feature is included in both of them. To simplify the usage of those features a two-dimensional schematic illustration, which gives a clear idea about the varying parameters, is embedded into the interface. For the rib feature three different placement types are implemented. The user can use the sketch based feature if guide curves are present. If not, he can use the perpendicularity- or variability-feature. In both cases the user has to provide the placement surface while the system automatically identifies the boundary surfaces.

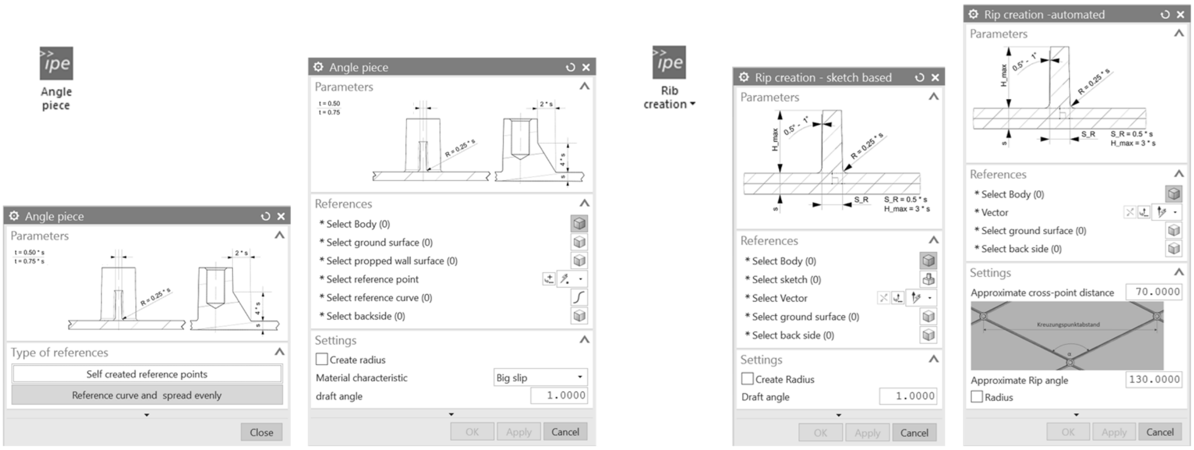


*Figure 10. Angle piece and rib creation feature*

In Figure 11 the 3D-Export feature is shown. Sigmasoft provides the minimum wall thicknesses in every single coordinate direction. The lowest of those three values defines a cutting plane normal to this direction. Parallel to this plane the system requires the maximum dimensions of the part.

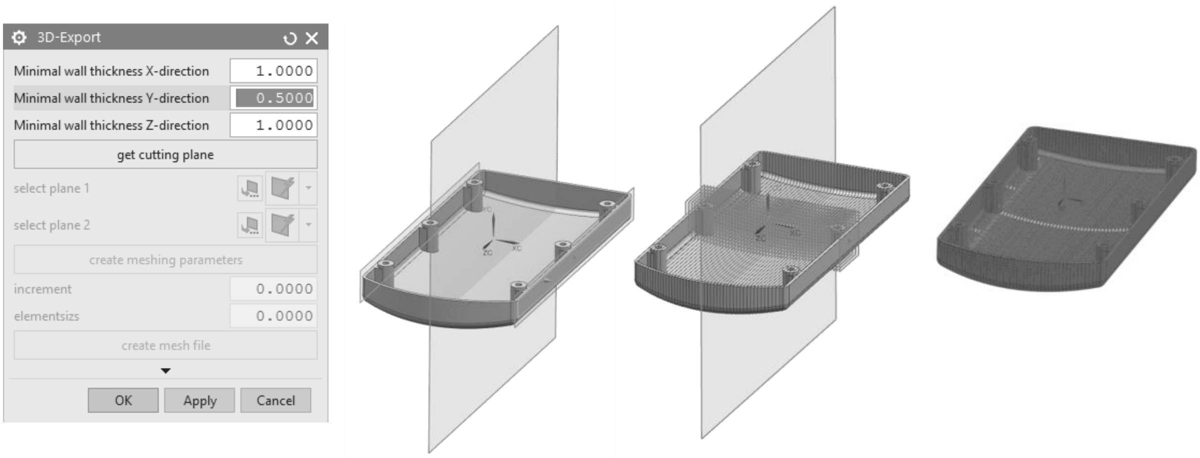


*Figure 11. Angle piece and rib creation feature*

This procedure allows the automatic generation of the mesh file and guarantees the transferability of the Sigmasoft simulation results into the post processing performed in Matlab.

## 5 CONCLUSION

The state of art shows that methods for developing KBE systems are present, but the later user is just involved at a very early stage. The approach shown in this paper adds a new one, the system development, to the two classical milestones of the KBE (creation of the knowledge base, implementation). The system developer and the involved experts use this milestone as a basis for discussions in several feedback loops. The system is implemented in the CAD system after a complete system development using SysML is done. Especially when developing more complex support systems, the integration of experts and / or later users can lead to different advantages. The neutral system definition avoids expensive changes if errors occur during the implementation. The graphical modeling of the system enhances the quality of the development process, since the structure of the support system can also be recognized and integrated without programmers people, which also increases the level of acceptance of the later user. In the case of acceptance, the safeguarding of the designer through knowledge-enhanced design techniques increases the quality of the design process. A further advantage is a positive influence on the development time of support systems since the system engineer, in addition to the actual knowledge base, profits from the knowledge of the experts in the feedback loops. The approach is used in a current research project´s case study, which is based on the integrated product simulation in regards to injection moulded part design. A support system has been developed, which supports the designer from material and process selection to rheological optimization.

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