# Virtual engineering and planning process in sheet metal forming

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**Summary:**

Nowadays the engineering and planning process in sheet metal forming is fundamentally supported by CAD and CAE systems. Beside the full 3D design process of parts and tools the simulation of sheet metal forming processes has established itself in the last 15 years within standard industrial practises. Nevertheless the virtual engineering and planning consists of more than just CAD and CAE tools. For a coordinated and effective process it is recommended to make use of the so-called process chain model. Therewith the interactions between different technologies or single processes can be taken into account. The process chain “Painted Car Body” consists of geometry and functionality development as well as forming, joining and coating processes. The backbone of a process chain is generally called “Synchroplan” where the main technical and business milestones for the different technologies and development processes are fixed.

The challenges for the virtual planning process are response time and accuracy with respect to the Synchroplan milestones. In the early phase of product development it is helpful to make use of standards. These standards give guidelines for the product design process with respect to feasibility and robustness without restricting “engineering freedom” which will enable new styling and technical innovations. These standards are sometimes much more than just single numbers. For repeatable geometry details (door entrance, rear lights etc.) one can define so called meta models if these details can be represented by few parameters. The benefit of these meta models is the quick assessment of parameter combinations with an adequate accuracy. With this argumentation it is clear that an effective and efficient virtual engineering and planning process consists of three major components:

- standards for geometry and process technology
- fast CAD tool for creation of geometry proposals
- effective CAE tool for fast and accurate assessment enabling definition of improvements

The more standards are defined and accepted over the whole process chain the less detailed simulations and CAD loops are necessary. Nevertheless realisation of new styling ideas and technological improvements (new materials, improved crash worthiness etc.) always require CAD and CAE support. The backbone of the CAD process at BMW Group is currently the CAD system CATIA V5. All geometry information in the process chain has to be finally delivered in native CATIA V5 data. But especially in the early or so called concept phase of a project it is not necessary for sub processes that all CAD work is done in the backbone system. A typical example is the concept die face for the geometry definition of a forming simulation. With this geometry no physical tool is built and therefore no native CAD data is required. It is more important to realise the ideas and proposals of the engineer as fast as possible with a sufficient accuracy for FE-simulation. Nevertheless the geometric proposals after the engineering loop should be finally available in the CAD system.

For the definition of a concept die face several working steps are (typically) necessary:

- import of part geometry (ideally with native CAD data)
- flange unfolding and lay out of geometry details from following operations
- definition of the basic production idea (double part, symmetry, ...)
- definition of drawing direction
- part preparation (filling of holes, smoothening of boundary, ....)
- creation of blank holder
- design of addendum
- preparation for simulation

All these working steps beside the preparation for simulation can obviously be realised also in the standard CAD system. The most time consuming work is the creation of the addendum in comparison to specialised alternative solutions. This is the main reason why currently the concept die faces are not generally designed in CATIA V5. The accuracy and necessary design work for concept die faces strongly depends on the examination objectives. Especially the prediction of surface quality of outer skin panels necessitates much engineering work for the blank holder. Therewith the first contact of the blank with the forming tools is determined which causes sometimes unacceptable skid or impact lines.

For the FE-simulation of concept die faces a powerful CAE tool is necessary. Beside of short calculation times an easy applicability is of high interest. Nevertheless one has need for well described complex material models and powerful user interfaces to solve extraordinary boundary value problems, e.g. for the virtual assessment of new forming technologies. LS-DYNA fulfils most of these demands and has a high application rate in research work at universities. In the past, the main objectives of forming simulations were only the assessment of feasibility (e.g. occurrence of necking and wrinkles). Nowadays additional and more complex examinations are possible due to improvements of the simulation systems. Some examples are press force calculation, multi stage forming, spring-back, surface quality, failure prediction for complex strain paths. Many of these applications need an accurate stress calculation. For new material grades like ultra high strength dual phase steels the classical material description is not sufficient anymore. The advantage in competition for automotive companies is the controllability in the virtual planning and engineering process even without having experience of series production. The more accurate the material description in the simulation tools the less problems and scrap rate occur in the production.

Normally the first simulation of a concept die face will not lead to a feasible part geometry. In an effective virtual engineering and planning process it is necessary to show the way to feasible and robust production processes. The fast translation of simulation results in geometric proposals is an essential step. The handling of geometry updates is a big challenge for the work with concept die faces. An easy and robust parametric design of the concept die faces is still one of the biggest problems in this context. Even for specialised systems for the creation of concept die faces there is still much room for improvements.

Due to this problem we should not restrict ourselves to single software systems from the general viewpoint of BMW Group. It is necessary to define useful interfaces and data formats. Therewith a fruitful competition and a market also for smaller software companies or university spin offs can exist. An example for such an interface is the description of a forming process based on a concept die face.

It is necessary to define links on the tool geometry and sheet material, the forming direction and additional information like cam positions and directions. Tool meshes and detailed material data should not be included in this interface. The big advantage of intelligent interfaces is the possibility to combine different CAD and CAE systems as well as the possibility for fast modification loops. We expect a higher innovation velocity with widely accepted interfaces due to a wider market and more competitors.

**Keywords:**

Sheet metal forming, virtual engineering and planning process, concept die face

## 1 Introduction

The automotive industry is currently facing a very critical situation. Over capacities together with increased demand for low fuel consumption vehicles and fierce competition have lead to even more cost reduction activities. A very important aspect is the reduction of development times and costs. The realisation of this objective directly leads to the need of a very effective virtual engineering and planning process. Only a few years ago, the optimisation was mainly done in single processes or technologies. This leads to technology optima and not necessarily to the total optimum. With use of the process chain model one has the possibility to resolve this problem. E.g. the process chain painted car body consists of functionality development, forming, joining as well as coating processes. The basic idea of the so-called “Synchroplan” is to define necessary milestones and dependencies between the different single process steps. In Figure 1 a schematic “Synchoplan” is given.

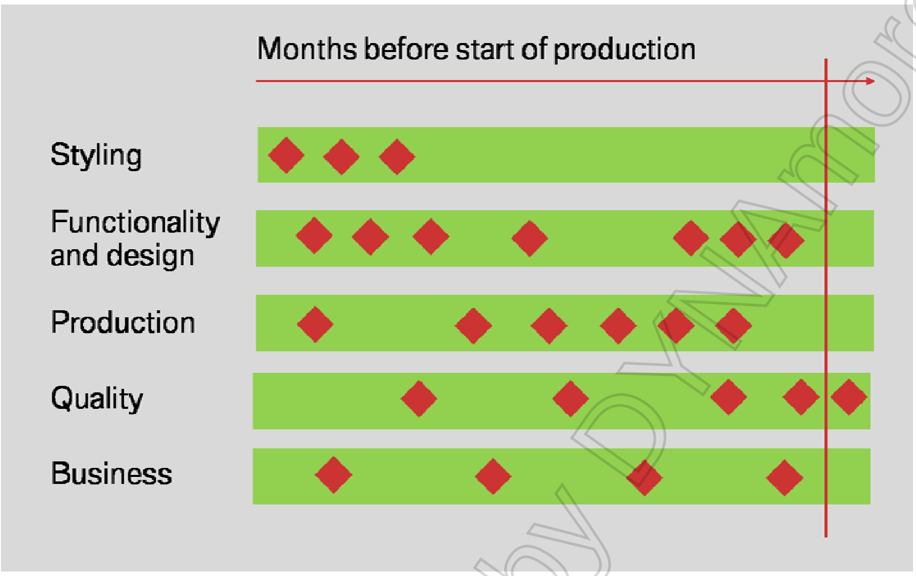


*Figure 1: Schematic “Synchroplan” for process chain painted car body*

The milestones consist of time information, maturation grade of the development process and geometric information. Especially between technology processes and functionality design there are clear defined contents which have to be delivered to every individual milestone. The time for quality loops and therewith the whole development time depends on the efficiency and effectiveness of the virtual planning and engineering process.

## 2 Virtual planning and engineering process

The virtual planning and engineering process is the summary of all planning and engineering activities with support of CAD and CAE tools. These activities can be separated in three major components. The first component is the definition of styling, design and process standards which are available in the CAD system and are to be used as guidelines. The main objective of the standards is transfer knowledge and experiences of older car projects in the new project without causing engineering loops. Examples for such standards are presented in chapter 2.1. Beside standards, individualities and innovations (material, functionality, styling,...) need a fast and effective CAD process. Within the necessities of the Synchroplan the demands on accuracy and response time vary significantly during the development process. In the so-called early development phase a sufficient accuracy with shortest calculation times is of major interest for the cost and functionality assessment of alternatives. Accuracy requirements to the tool design process are determined by the CAE and the meshing tools since no hardware is being built. An example for the fast die design in the concept phase is given in chapter 2.2. The virtual planning and engineering process is completed by a powerful CAE system. Prediction of wrinkles and failure are the common objectives of FE simulation for sheet metal processes. Nowadays additional and more complex examinations are possible due to improvements of the simulation systems. Some examples are press force calculation, multi stage forming, spring back, surface quality, failure prediction for complex strain paths. Many of these applications need an accurate stress calculation. For the failure prediction, physical behaviour of the materials and stability of the finite elements must be "tuned" together. In chapter 2.3., it is shown that one has to take the strain rate sensitivity into account.

## 2.1 Standards for geometry and process technology

In the early phase of product development it is helpful to make use of standards. These standards give guidelines for the product design process with respect to feasibility and robustness without restricting "engineering freedom" which will enable new styling and technical innovations. These standards can have different degrees of complexity. It can start with just single numbers as presented in Figure 2 for maximum flange angles.

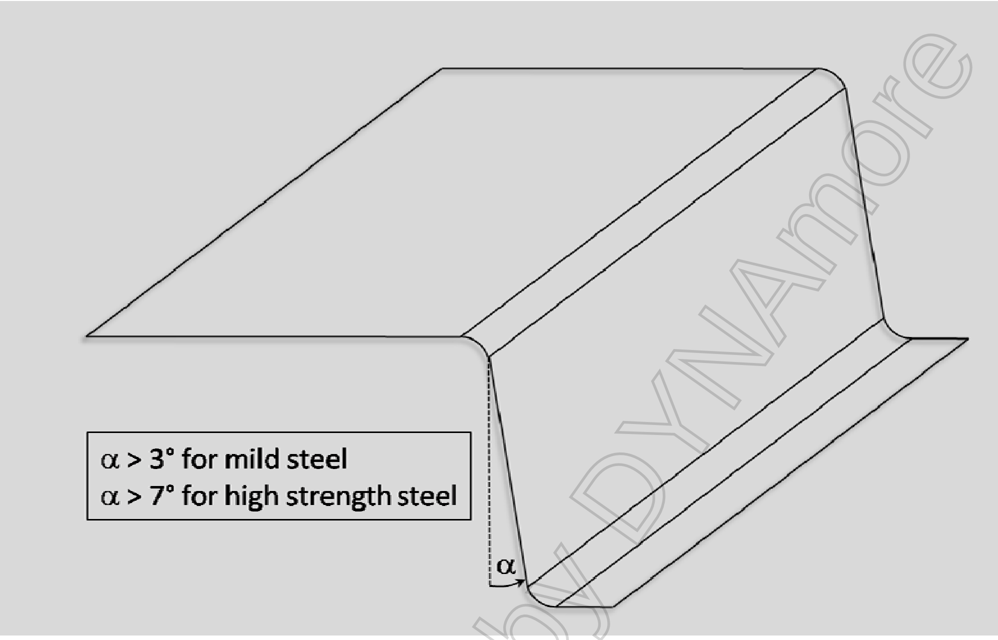


*Figure 2: Design standard for flange angles depending on the material*

For repeatable geometry details (door entrance, rear lights etc.) one can define so-called meta models if these details can be represented by few parameters. The benefit of these meta models is the quick assessment of parameter combinations with an adequate accuracy. This method is demonstrated in [1] for the rear door entrance (Figure 3) of body side outer panel. Passenger entrance comfort is always in conflict with formability requirements to the geometry.

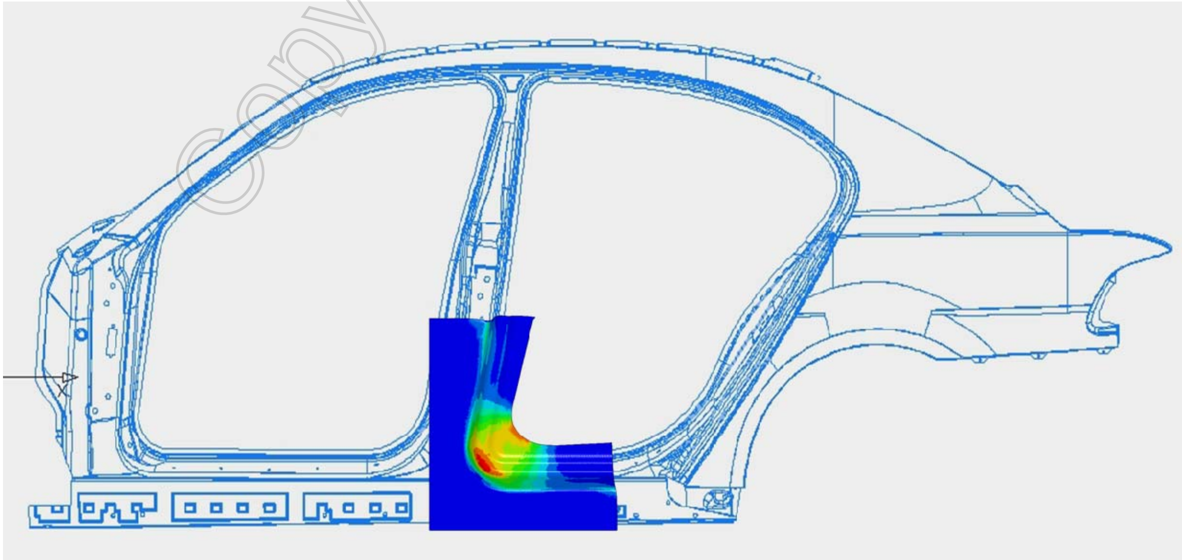

*Figure 3: Rear door entrance of body side outer panel [1]*

In this case it is possible to describe the geometry with few parameters, see Figure 4. With an acceptable number of FE calculations and suitable interpolation algorithms one can create a meta model. Therewith it is possible to evaluate in seconds every possible parameter combination with a sufficient accuracy.

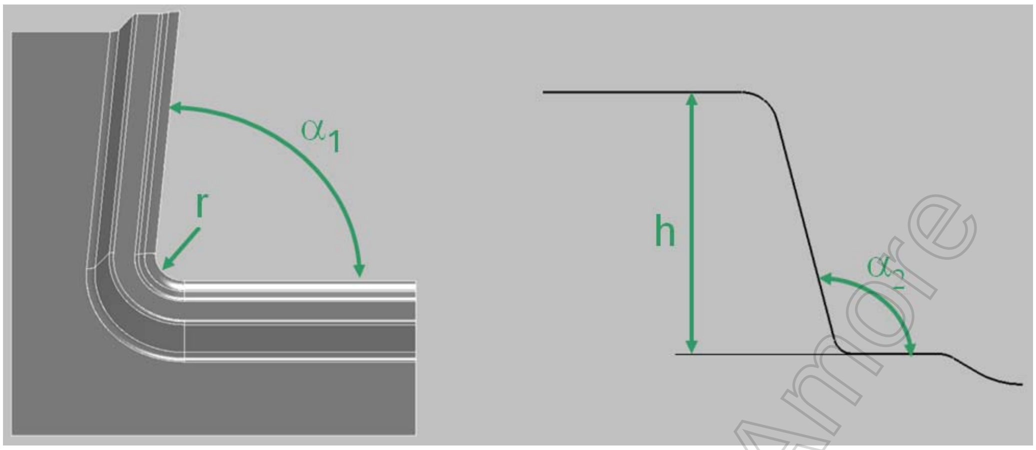


*Figure 4: Parametric design of rear door entrance by only two angles and two lengths [1]*

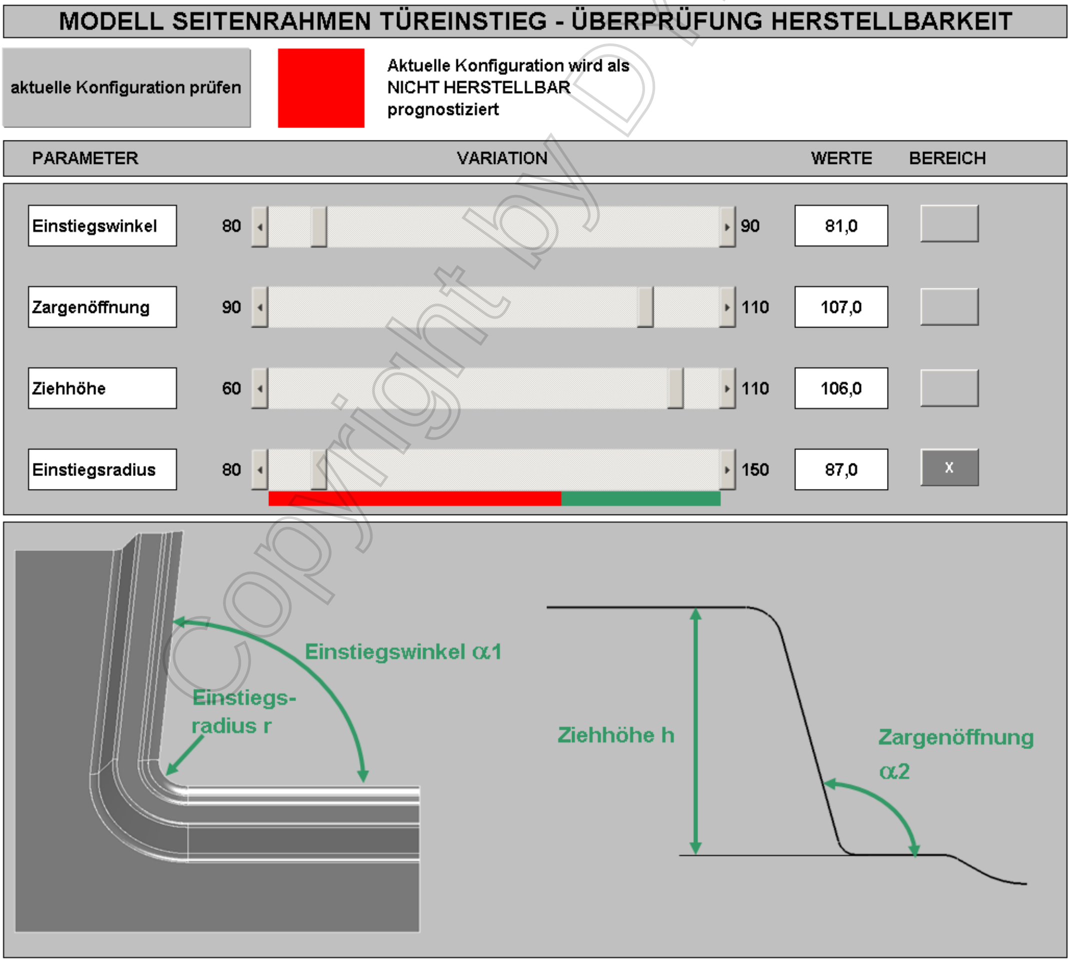


*Figure 5: Example of a fast assessment of parameter set with meta model taken from [1]*

## 2.2 Fast CAD tool for creation of geometric proposals

With the use of standards, (see chapter 2.1) the first parts geometry should better meet feasibility and functional demands. Nevertheless the final optimum can only be reached iteratively. Therefore one has the need for very fast assessment tools in combination with an accurate definition of improvements. Even if the basic CAD system is CATIA the creation and assessment of the alternatives can be realised in a non-CATIA sub system, as accuracy requirements are not set by the necessity of manufacturing a tool. The geometric accuracy for the so-called concept die faces is given by the necessary mesh for the FE tool. Nevertheless the geometric proposals after the engineering loop should be finally available in the CAD system CATIA.

For the definition of a concept die face several working steps are normally necessary:

- import of part geometry (ideally in native CAD data)

The import of the CAD data is the first necessary step if a non-CATIA tool is used for the concept die face. The import can be realised in a standard format like IGS. More convenient is the possibility to use the CATIA native data. The time for this step should be negligible in comparison to the whole time for creation of a concept die face.

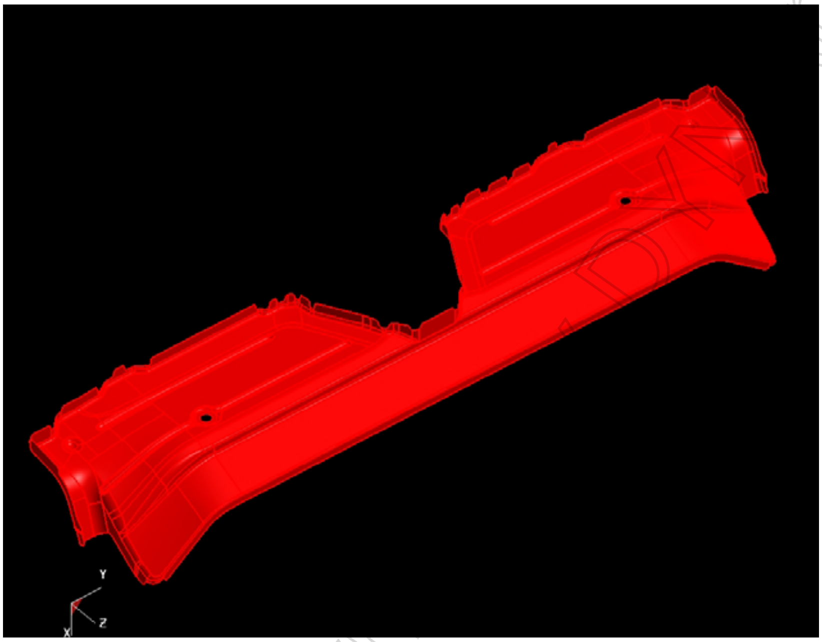

*Figure 6: Import of CAD data of structural part*

- flange unfolding and lay out of geometry details from following operations

This working step is a very important one. Usually only the forming operation for first formability assessments is simulated. Nevertheless, the method engineer must have in mind the whole production process with all forming, restrike and cutting operations. The die face of the first forming operation (the so-called drawing operation) is a consequence of this examination. The system for the concept die face should support this process with suitable functionalities as shown in Figure 7.

- definition of the basic production idea (double part, symmetry, ...)

For this working step one has to take into account some basic production alternatives which have a big influence on tool and production costs. Especially for left hand and right hand parts it is the first goal to produce these parts with one blank if possible. The die face design tool should support this working step by functionalities like symmetry definitions. The production of more than one identical part per stroke is sometimes used but not so often. The reason are higher tool invests and the problem that the different parts with the same part number are never identical in the sense of tolerances. Sometimes the reduction in production costs is significant and it is worthwhile to choose this alternative. More often is the alternative to produce several different parts in one stroke. This alternative should also be supported by the sub-system.

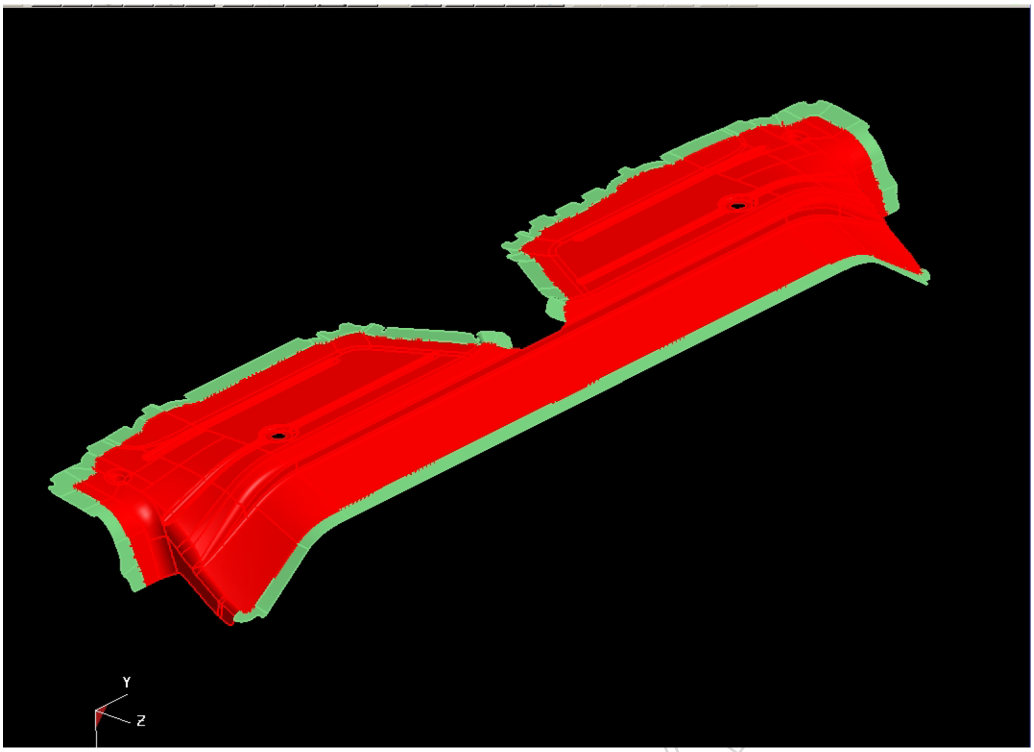


*Figure 7: Example for flange unfolding by tangential lay out*

- definition of drawing direction

If one has found the geometry of the part in the drawing operation the definition of the drawing direction is the next process step. Here functionalities should be available like preventing undercuts or minimizing the drawing depth as can be seen in Figure 8. Sometimes the drawing direction is limited by the production press type.

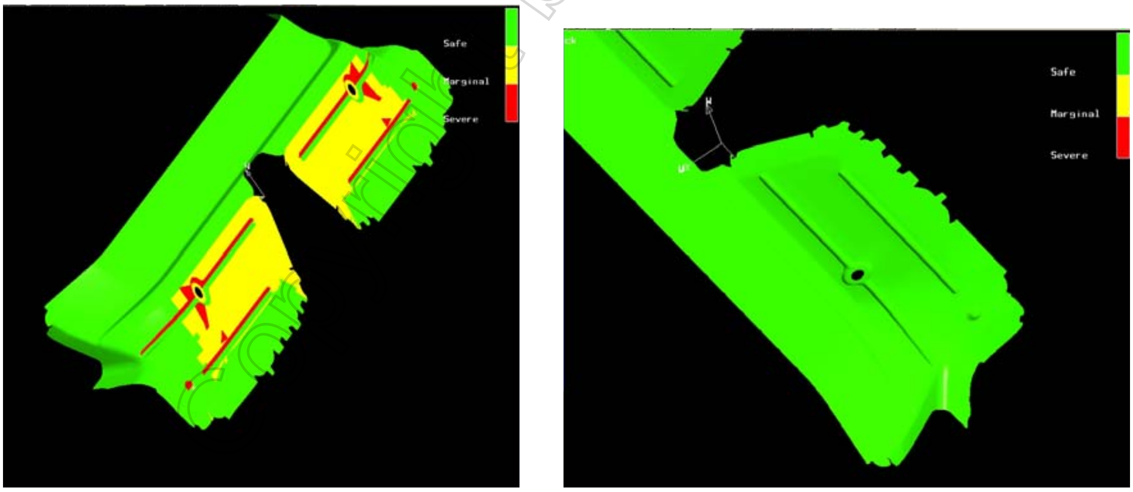


*Figure 8: Definition of drawing direction*

- part preparation (filling of holes, smoothening of boundary, ...)

The importance of this working step is often underestimated. Especially the smoothening of the outer part boundary is sometimes very complicated and can be supported by rather complex mathematical algorithms. The experience shows that a fully automatic solution can be offered for approx. 90 % of the structural parts. For the rest a manual design or CAD work is necessary. The filling of wholes is a much easier functionality and can normally be done automatically in the sub-system for the die face design.

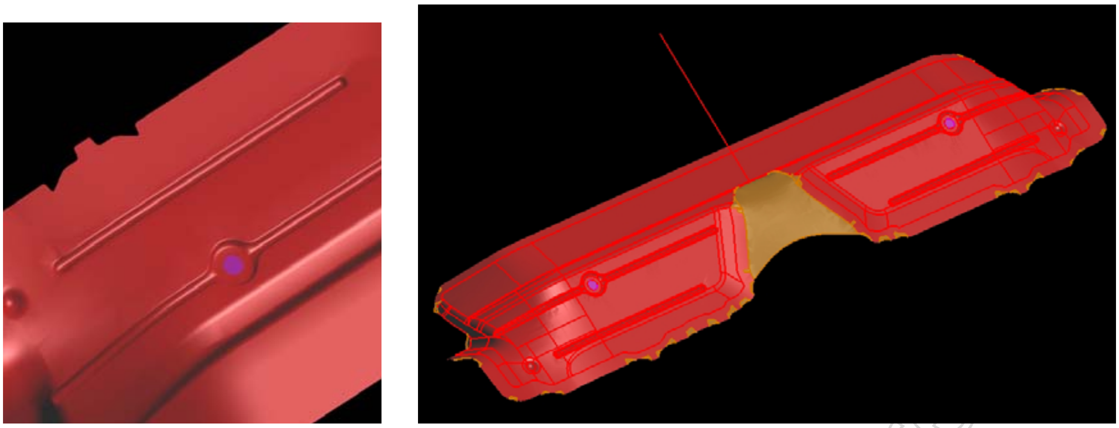

*Figure 9: Filling of holes and smoothening of part boundary*

- blank holder creation

The geometry of the blank holder is often the most important step for the concept die face design. Due to very good prediction of gravity and blank holder closing it is not necessary to have developable geometries. The guidelines for the blank holder creation normally follow the part, see Figure 10. Additional functionalities like "part on binder" should also be supported. This is important for the forming of flanges with minimal production costs.

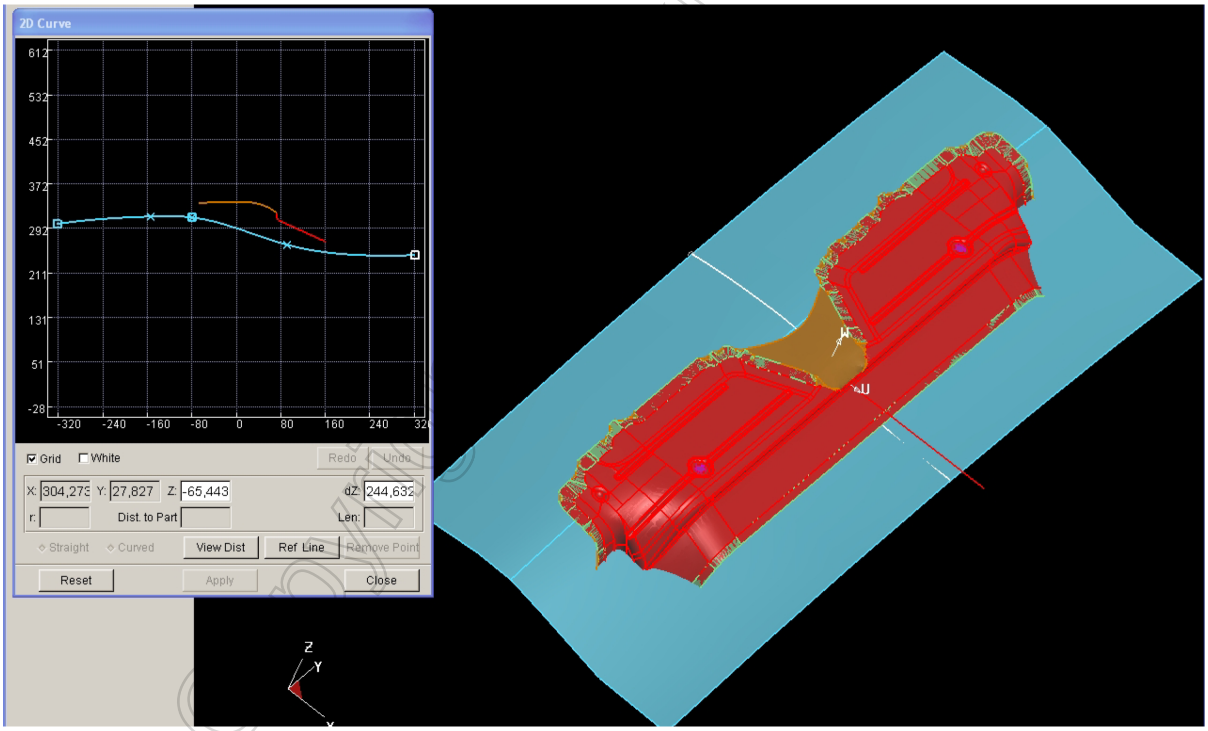


*Figure 10: Blankholder creation*

- design of addendum

The addendum finally closes the die face geometry. Here a parametric design of profiles and surrounding lines like the punch opening line should be offered, as can be seen in Figure 11. Typically a design method in the sense of line arc definitions is chosen. Sometimes one has the need for additional bars or counter bars. For difficult part geometries this working step can be time consuming because the offered functionalities are insufficient. The actual functions show much room for improvements. Nowadays, beside the classical line arc design approach a more styling oriented modelling process of the addendum is becoming interesting to prevent the problems described before. The idea is to close the "gap" between part and binder very simply and create the more complex geometry details afterwards with suitable styling methods. Current knowledge does not allow us to finally decide which method will be the better one. Depending of the part geometry probably both approaches will be found in industrial practices in the near future.

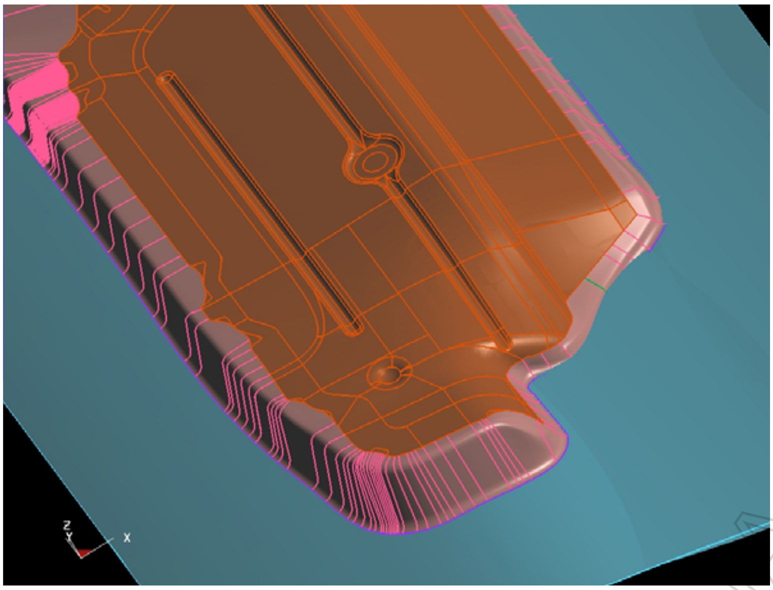

*Figure 11: Creation of addendum by definition of suitable parametric profiles*

- preparation for simulation

After creation of the concept die face the necessary meshes, blank and material definition, drawbead position and restraining forces etc. have to be defined and the simulation with FE tools can be started.

### 2.3 Simulation of forming process with effective FE tool

As can be seen from chapter 2.2 the pure FE simulation is just one element of the whole virtual engineering and planning process in sheet metal forming, but of course a very important one. The objectives in the simulation are normally prediction of failure like necking, the assessment of wrinkles and folding and more complex applications like prediction of surface defects, spring-back or press forces. The failure prediction currently is done with the experimentally evaluated forming limit curves (FLC). The advantage of the FLC is the simple interpretation. The disadvantage is the problem of non linear strain paths. Currently some interesting approaches are developed to overcome this problem, e.g. [2]. But also for the assessment of nearly linear strain paths some problems exist. A very critical one is the strain rate sensitivity of the material. It has been proven that the strain rate is important for the start of necking even for the relatively low strain rates of deep drawing processes, see [3]. With new experimental methods (e.g. [4]) the start of necking can be identified very accurately. The problem is now, that for simulations without strain rate sensitivity the finite elements become numerically instable before reaching strain values of the FLC. This effect is demonstrated for an ideal plain strain test, see Figure 12.

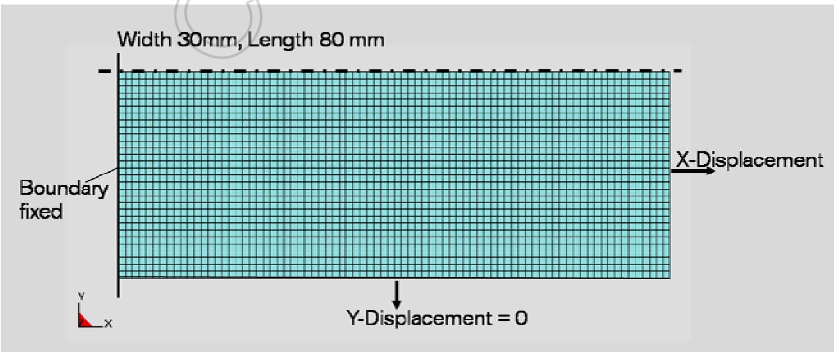


*Figure 12: Ideal plane strain test*

It can be seen that without strain rate sensitivity the failure prediction is too conservative in comparison to the experimental FLC, and feasible geometry proposals would have been rejected, see Figure 13.

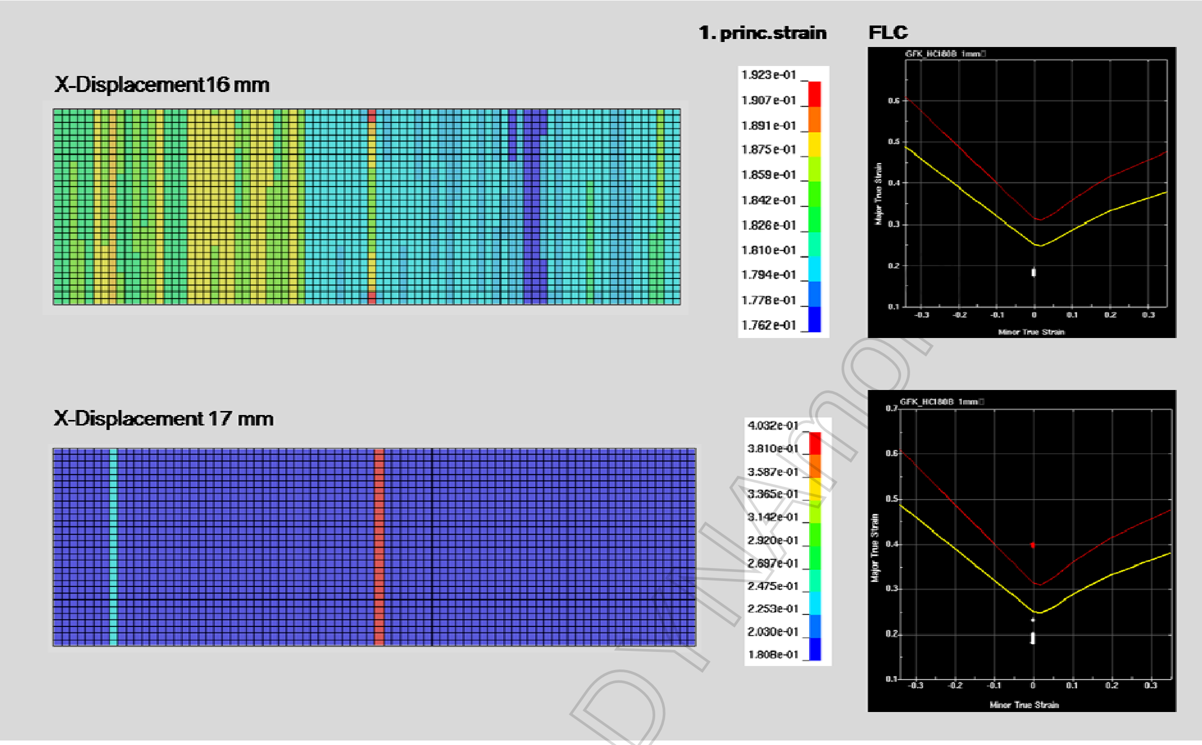


*Figure 13: Results without strain rate sensitivity*

Even with a small strain rate sensitivity which is definitely lower than measured material parameters this effect nearly vanishes, see Figure 14.

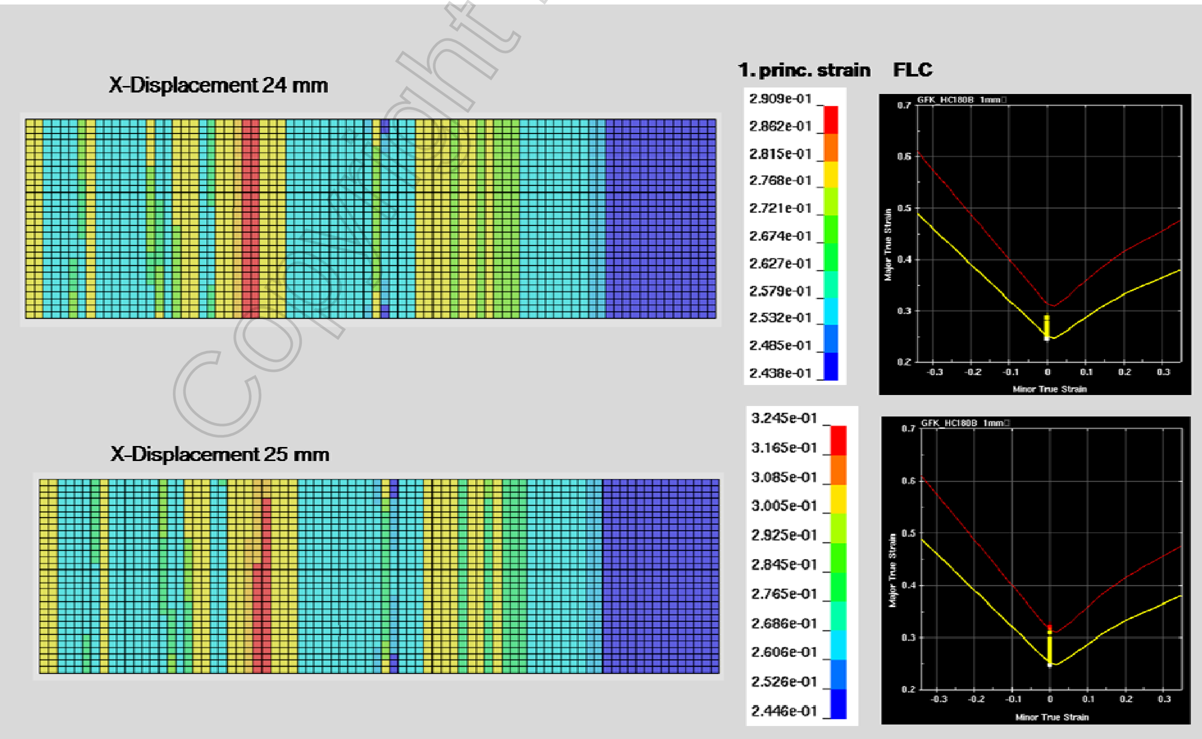


*Figure 14: Results with small strain rate sensitivity*

It is recommended especially for dynamic explicit codes like LS-DYNA to always calculate with a small strain rate sensitivity if no accurate experimental values exist.

In Figure 15 an industrial application is shown. The simulation of a door outer would indicate with no strain rate sensitivity that this geometry is not feasible.

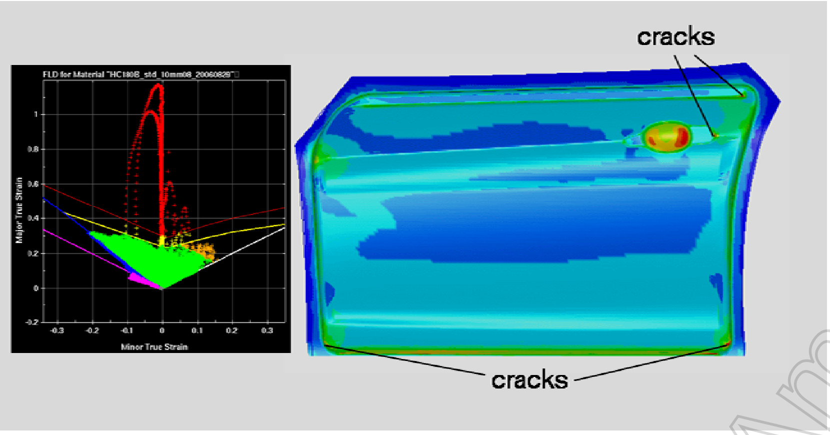


*Figure 15: Simulation of door outer with no strain rate sensitivity*

In Figure 16 the results with small strain rate sensitivity are presented. The big difference is remarkable especially for the strain values in plain strain and the geometry is assessed to be feasible.

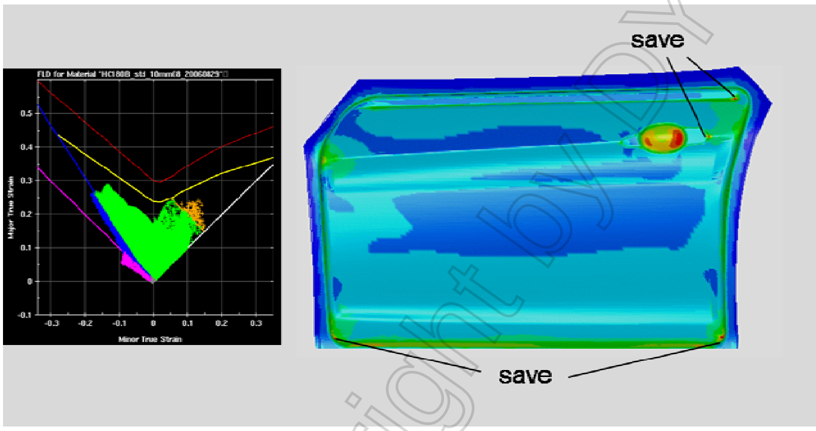


*Figure 16: Simulation of door outer with small strain rate sensitivity*

More complex objectives like spring back calculation, necessary press forces or assessment of possible surface defects for outer skin panels need a very accurate stress determination. The industrial standard is using an anisotropic yield locus with isotropic hardening. There are several influence quantities which are normally not taken into account:

- effects of kinematic hardening
- non-isotropic Young's modulus
- strain depending Lankford coefficients
- measured based yield curve beyond tensile strain

For all these influence quantities advanced material models exist. The challenge is the choice of suitable measurement methods for the additional material parameters.

## 3 Interface design

In this chapter a short view in the future is tried. Currently we have the situation that for the whole virtual planning and engineering process only few systems exist and an adaptive use of these systems is not supported. Therefore it is very difficult for smaller software companies to participate in the market. From the viewpoint of BMW Group this fact is negative as the number of possible competitors is restricted. One possibility to overcome this problem is the definition of a widely accepted interface between CAD and CAE world. Normally every CAx system have such interfaces but in individual binary format. The benefit of an open interface is the possibility to combine nearly every CAD tool with every CAE tool. It seems to be helpful to differ between process and geometry information as proposed in Figure 15.

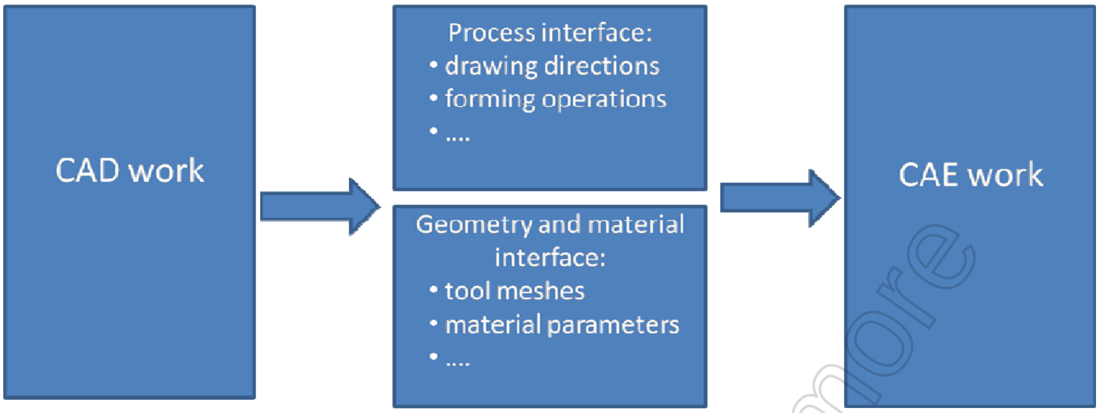


*Figure 15: Schematic definition of process and geometry interface*

## 4 Literature

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