Implicitly parametric CRASH and NVH analysis models in the vehicle concept design phase

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Abstract:

Early validation of new vehicle concepts is becoming more and more important. This validation process must involve many disciplines whilst making optimum use of the information available for the respective development stage and integrating such information quickly into the analysis models. Information has to be prioritized in line with the development stage and the depth of information given at any point in time. Although the design and validation process differs from manufacturer to manufacturer, the importance of early function validation is becoming increasingly obvious.
The functional requirements are determined by many complex factors and often involve a target conflict. Validating passive safety is a priority target compared to other function criteria, such as vibration comfort, vehicle dynamics and acoustic properties.
The need for early CAE validation inevitably changes the traditional design and drafting process. The geometric models for the vehicle body or of its components must be assessable in the early development phase. These models have to be flexible enough to adapt to dynamically changing information depending on the variety of functional requirements.
This article presents the contribution which SFE CONCEPT can make towards the early validation of CRASH and NVH requirements.

Keywords:

Parametric modelling, shape optimization, topology optimization, topography optimization

1 Introduction

The role of CAE during the early vehicle development phase has increasingly changed. Due to the lack of available parametric geometry models, CAE was often restricted to "re-validating" modified predecessor models or to simple principle studies {1}. Today, the design and validation should go hand-in-hand in the early development phase. Since no mature CAD data is available during this phase, it must be possible to directly combine CAE methods with methods for quick parametric geometry model generation. This is the only way to enable CAE engineers to take part in the development of new concepts and to evaluate factors which are crucial for the for fulfilling the functional requirements (refer figure 1.1). This evaluation must be oriented towards the given development stage of a new vehicle concept. The adapted response to the given depth of information in the design process has a central role to play in this context. Even if detailed information is not available during the early phase, it must be possible to generate parametric geometry models based on the design space, topology, styling and package. The topology and geometry models must be judged in terms of value they carry in function validation. These models eventually have to ensure a seamless vehicle development process, i.e. they must form a basis for supporting the concept team of package, CAE and pre-program development engineers as well as design engineers. It must be possible to quickly adapt the topology and geometry models to new package and/or styling information. Furthermore, these models must be capable of supporting shape and topology optimization. In addition, it must be possible to tackle issues related to standardization, communalities in vehicle families and interchangeability.

It is also desirable that these topology and geometry models provide a common data exchange platform which will serve for:

- the reusability of implicitly parametric vehicle models
- the creation and categorizing of a knowledge base
- the use of knowledge base and experience from successfully executed / current development projects
- the "refining" of data and improving the data flow

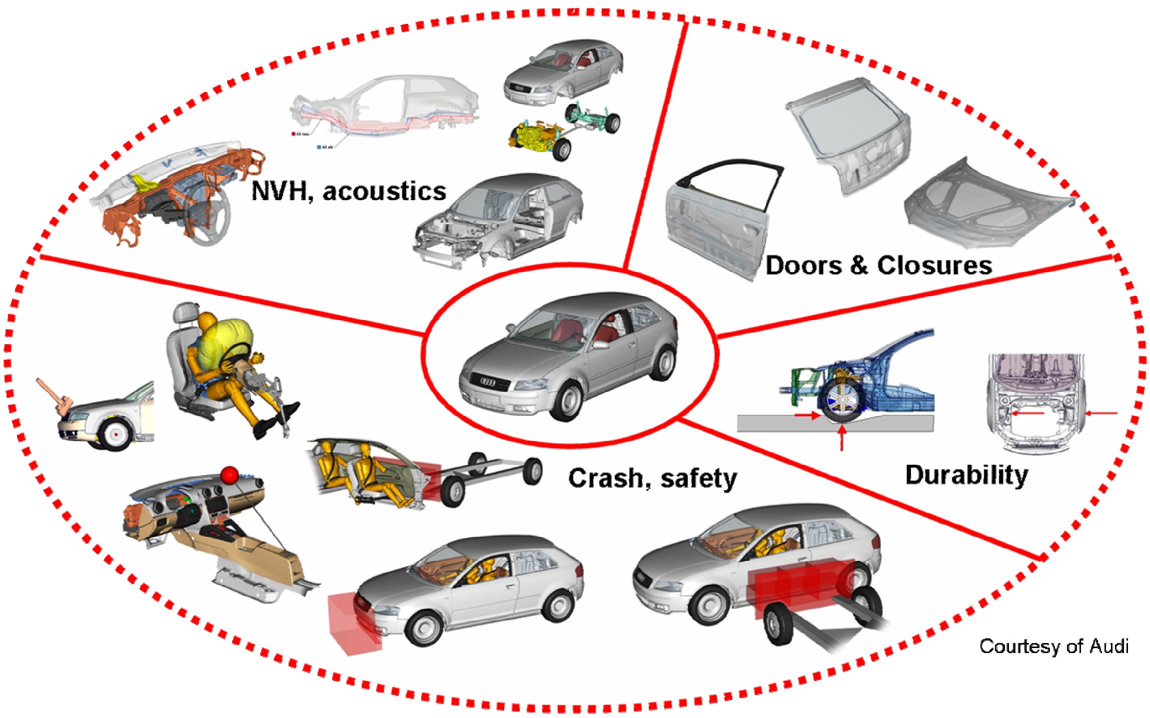

Figure 1.1: Factors influencing the vehicle development process in the early design phase

The implicitly parametric topology and geometry models hold an important place. Based on these models, the concept engineer must be able to make statements concerning crash and stiffness behavior, and check if the resulting geometry is in compliance with the available 2D/3D package or design information. Besides the analysis model, the concept engineer must be able to derive and verify a design model for optimization. The design model should consist of design variables, design space, objective functions and constraints. For this purpose, it must be possible to automatically generate a robust, high-quality, penetration-free FE mesh and the necessary connections (adhesives, spot welds, etc.) along with the FE boundary conditions. It must be noted in this context that the degree of detail of the topology and geometry model depends on the given volume of information during the conceptual design phase. The degree of detail will be a compromise between the precision of the desired result and the analysis effort.

2 Review of methods used in conceptual design phase

Up to now, concept finding has been a challenge for the development teams of vehicle manufacturers. Some articles clearly describe the requirements, methods and goals in the conceptual design phase {2, 3}. Simple design formulas fascinate by their "apparent" simplicity and extremely short response times. It is, however, questionable whether the increasingly complex nature of models (e.g. due to new materials and manufacturing techniques) can be reduced to "simple" design formulas and the validity of “quality and worth” of the results. Furthermore, there is also reason to ask why the available topology and geometry information should not be used if the quick and implicitly parametric provision of this information is possible.

Besides design formulas, design grammars are also discussed today. Design grammars are a very abstract description of a draft/design {4}. It remains, however, questionable whether the topology and geometry which is derived therefrom can be influenced by the concept engineer. The use of design grammars must be judged by the one-to-one correspondence of the geometric model derived therefrom and the ease of handling the topological and geometrical relationship. This relationship must be "transparent" as a precondition for the concept engineer to identify important influence variables of the concept finding process in retrospect.

In SFE CONCEPT, implicitly parametric topology and geometry models are based on a pertinent "design grammar" in conjunction with the modular construction technique. This implicit design grammar enables the assembly of encapsulated components and parts stored in SFE CONCEPT modular construction library. The only difference compared to the above-mentioned is that the topological and geometrical relationship can be easily overviewed and influenced by the concept engineer who does not have to translate complex mapping rules into a mathematical description.

In this context, it is also possible to couple parametric models having different degree of details with existing FE components or part models.

3 Concept design in conjunction with optimization

Despite the many options, shape and topology optimization was so far almost not practicable for realistic simulation models. The detour via beam and beam/spring models, where cross-section optimization was just a sizing problem, enabled the limited handling of this problem class. However, the main problems of these models are reduced forecasting capability and the restriction to linear stiffness analysis. Optimization for certain disciplines, such as passive safety, was not possible with these models.

The ability to perform shape optimization for carbody structure design had so far many hurdles. This option was missed badly, especially in the early design phases even though the design space was available.

The main problem with shape optimization for realistic carbody models – i.e. models with a deviation of just a few percent between experiment and analysis – which primarily consist of shell and/or solid elements was the lack of an infrastructure for generating the shape variables. What was lacking was a "geometry engine" that is capable of generating a pertinent simulation model from any set of parameters. SFE CONCEPT is now able to perform the function of this "geometry engine".

The general difficulty in shape optimization is the fully automatic generation of a complete analysis model from a pre-defined set of parameters. This generation process may, in principle, well be a multi-stage process. The greatest difficulty is to get a consistent FE model. Up till now, the generation of FE mesh, for a BiW model or for a full vehicle model was a semi-automatic process. This process hence required high degree of human interaction. Besides the clean-up and meshing of a CAD-based geometry, this particularly concerned the integration of loads and boundary conditions. In the case of a simple change in sheet thickness, just a single value needs to be changed in the respective model (or file). In the case of shape optimization, this process is much more complex.

3.1 Limitations of morphing techniques

Morphing techniques try to transform one shape to another by changing the FE node coordinates. To this effect, all nodes affected by a change in shape are transformed. Compared to sizing variables for describing changes in sheet thickness, the degree of complexity increases drastically in this case because there is no longer a simple "one to one" relationship between the parameter and the real value in the model description. A shape parameter will typically require modifying several node coordinates at the same time and with different weights. The change in nodal coordinates associated with a shape parameter is called the *shape vector*. Node coordinates can be referenced by several parameters. Generally speaking, each node coordinate is hence a function of all shape parameters. Morphing techniques are well suited for infinitesimal changes in shape parameters. In the case of major changes, however, they quickly become obsolete or can be used with extreme limitations only. The reason for this is the mesh quality which typically deteriorates significantly in the case of major parameter changes. As a matter of fact, stiffness calculations may still be performed. The optimization results, however, must be considered to be critical because the numerical optimization is unable to determine whether a potential increase in stiffness is due to *true* stiffening or caused by *bad* elements that violate the element quality criteria. Non-linear analysis and/or analysis with explicit time steps – such as crash analysis for passive safety - are impossible with *morphed* models. If elements are too small, CPU time increases to infinity whilst in the case of elements which are too large, the buckling behavior which is very important for crash calculations is incorrect. In the case of too small a change in parameters in crash analyses, result *scatter* increases.

4 SFE CONCEPT in early design phase

4.1 General procedure

SFE CONCEPT is based on a consistent description of the vehicle topology. The topology-based approach ensures that the pertinent geometry and/or change in geometry *automatically* follows the topological description {5}. A vehicle model created using SFE CONCEPT is not only fully *parametric*, but the parametrics also spans over various component ranges. This is an important precondition for CAE to be able to *drive* the design during the early phase. The generation and quick modification of models without the availability of CAD data is made possible {6} (Refer figure 4.1 & 4.2). SFE CONCEPT can be used both in interactive mode {7, 8} and in batch mode. The latter also enables its use in shape optimization {9, 10}.

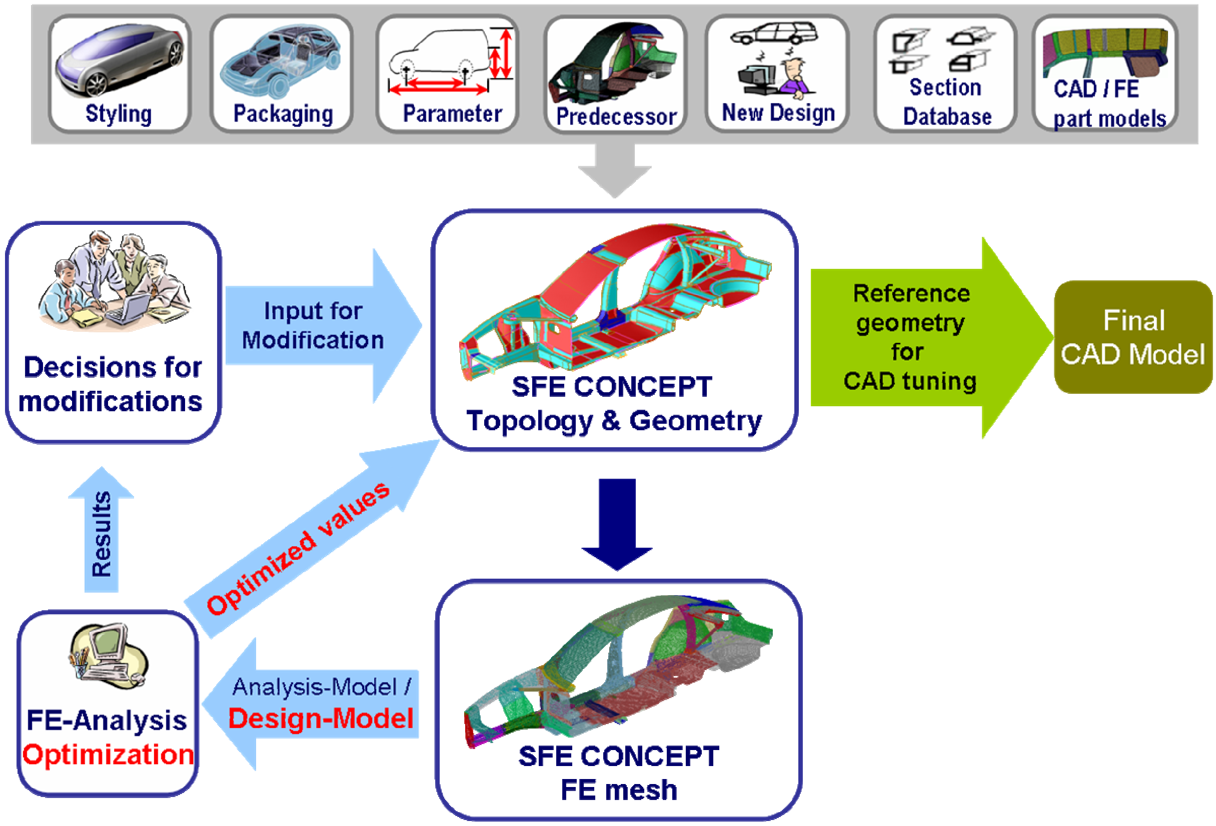

Figure 4.1: Model creation, modification and optimization with SFE CONCEPT

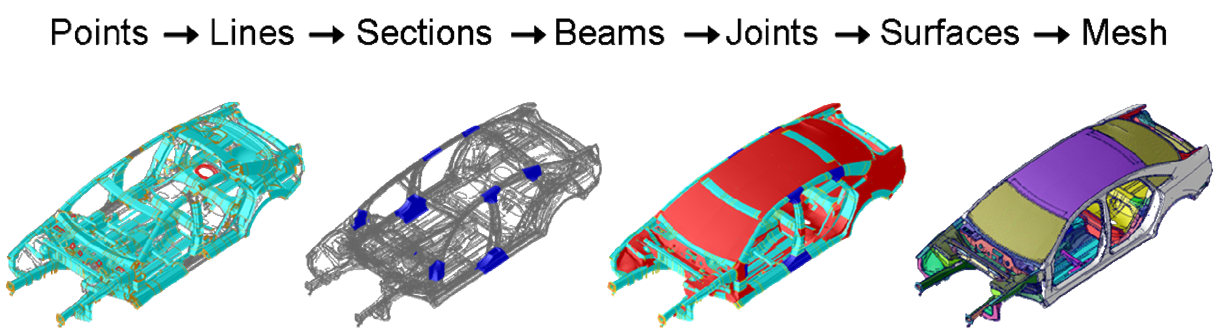

Figure 4.2: Sequence of model creation in SFE CONCEPT

Thanks to the automesher which generates the FE mesh on the underlying geometry, it is possible in SFE CONCEPT to link change in geometry and the resulting modification of FE mesh nodes, i.e. to determine the *shape base vector*. The description of the *shape base vector* is indispensable for gradient-based optimization.
Both the available *shape base vectors* and the updated analysis model can be passed on to the FE solver.
After adapting the geometry and/or topology model to the updated design increments, the "real" geometry is remeshed rather than morphing the previous FE mesh without any relationship to the updated geometry.

4.2 Problem definition

In SFE CONCEPT, design variables can be defined using the so-called "records". The user modifies the geometry interactively and the changes are recorded. Since the model in SFE CONCEPT is fully parametric, any geometry changes can be implemented, such as scaling of individual cross-sections, modifying points or lines, changes in tangents, etc. It is also possible to combine several geometric changes to one design variable. The graphical user interface (GUI) in SFE CONCEPT can be used to define the upper and lower bounds for the design variables.
Control scripts for the FE solver to be used can be imported in SFE CONCEPT. The objective function and constraints must be defined therein.

4.3 Optimization with SFE CONCEPT

The optimization process with SFE CONCEPT combined with a suitable FE solver and/or an external optimization tool consists of so-called *inner loops* and *outer loops*.

To start with, an FE mesh and, if applicable, the pertinent *shape base vectors* are automatically generated from the SFE CONCEPT geometry model. With this information, an optimization run can be started using the FE solver. In the *inner loops*, the design variables with regards to the objective function and constraints are iterated. The optimization is aborted when a predefined convergence criterion is fulfilled, when the maximum number of *inner loops* is reached or when an error due to element distortion occurs. Within the *inner loops*, the FE mesh is modified whilst adhering to the element quality criteria defined in the FE solver.

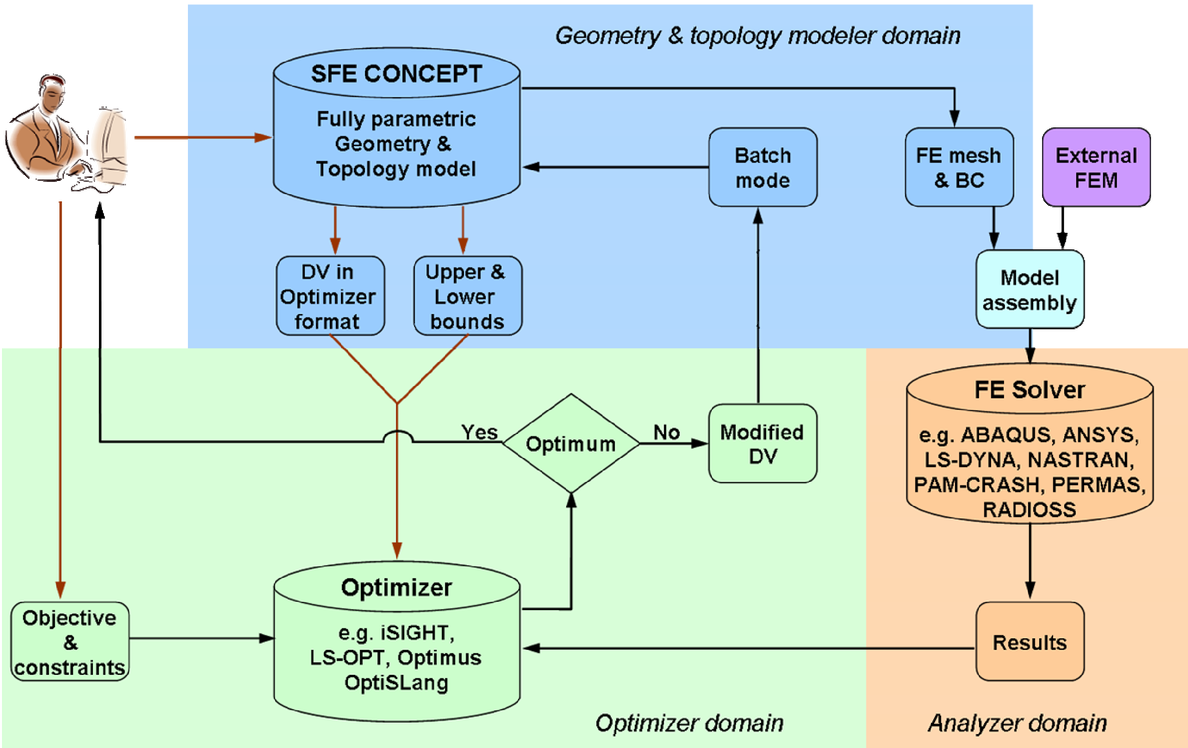

Figure 4.3: Optimization process with SFE CONCEPT

The incremental change in design variables from FE solver or external optimization tool are automatically imported in SFE CONCEPT and the geometry is updated accordingly (refer figure 4.3). From this geometry, a new FE mesh is generated which is hence free from element distortions. This is when a new *outer loop* starts until a previously determined convergence criterion is fulfilled.
The entire optimization process with multiple *outer loops* can be performed without any user intervention.

4.4 SFE CONCEPT MODULAR CONSTRUCTION TECHNIQUE

The modular construction technique in SFE CONCEPT is an excellent way of combining shape and topology optimization. With the modular construction technique, it is possible to encapsulate model parts with their topological connections, to store these in libraries, and to arrange them in a new configuration based on user-defined filter criteria (refer figure 4.4). The crucial advantage is that the encapsulated models bear attributes which ensure the unambiguous topological and geometrical compatibility to other modules.

Predefined modules can be combined to create new configurations, just like using a construction kit system. In this context, the construction kit system can be used to combine modules from different vehicle platforms and vehicle types. In order to ensure geometrical compatibility, the dimensions of the components are automatically adapted using mapping rules.

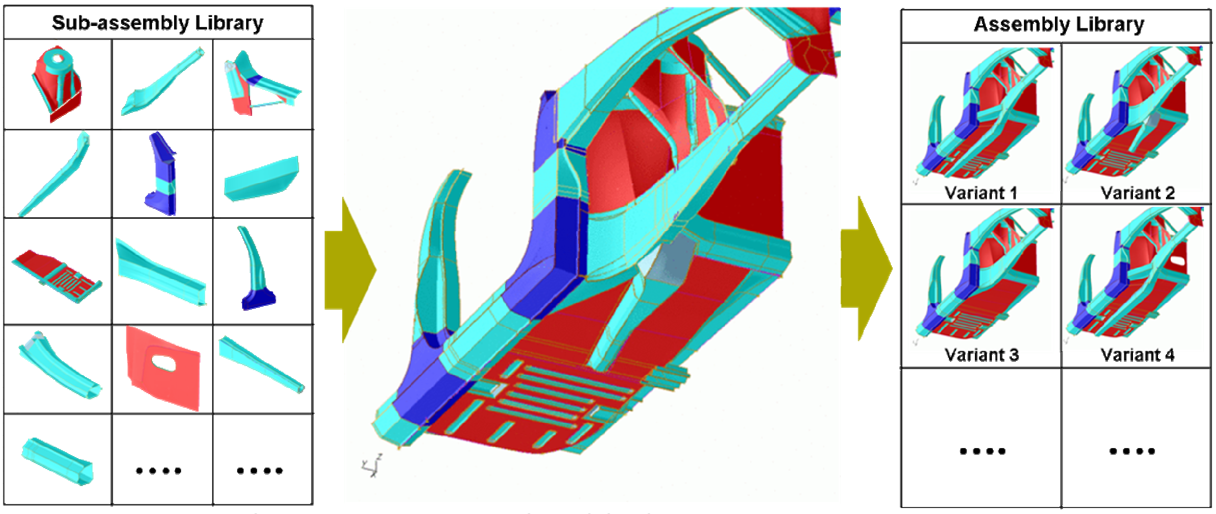

Figure 4.4: Modular Construction Library in SFE CONCEPT

4.5 Topography Optimization

The topography describes elevations and recesses in a panel. They are designed to enable targeted changes in the functional properties of a component.
A topography can consist of individual beads, bead patterns or generally of complex stamping patterns.
In order to use topography changes efficiently, the CAE engineer needs a suitable tool in order to generate stampings as quickly and easily as possible. For optimization purposes, it must also be possible to incorporate these stampings as design variables in the design model.
The latest developments in SFE CONCEPT enable various stamping shapes to be applied to a geometry surface. The stamping definitions are applied as attributes directly on the free form surface geometry. The geometry of the stampings is available in SFE CONCEPT and is also represented in the finite-element model (refer figure 4.5).

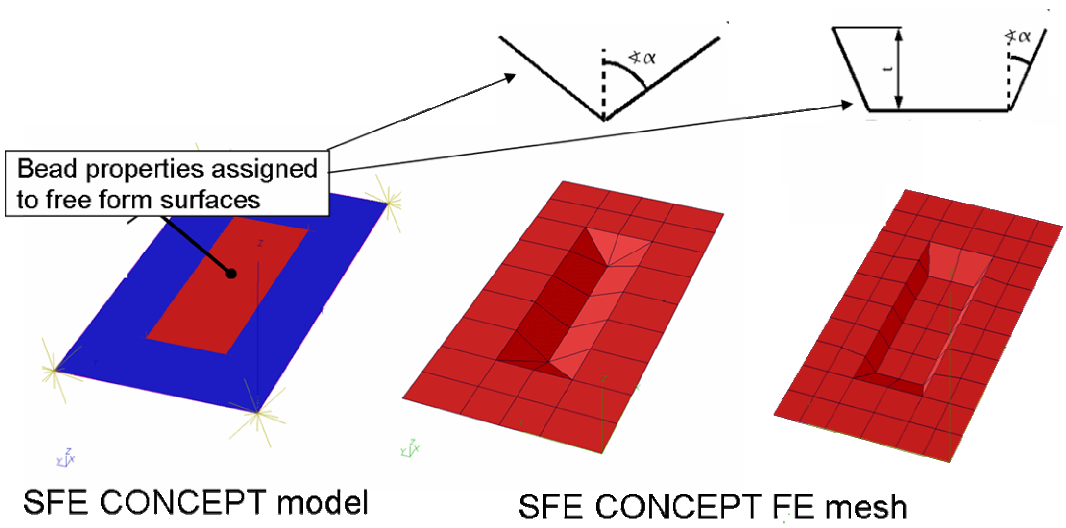

Figure 4.5: Stamping definitions on the SFE CONCEPT geometry surface

Alike the nature of a typical SFE CONCEPT model, stamping definitions are also implicitly parametric. Parameters can, for example, be the bead width and height, draw angle, draw direction, etc. Stampings can be generated in any configuration, with various possible changes which are necessary within the framework of optimization.
It is also possible to apply various stamping configurations overlapping each other using a predefined priority condition (refer figure 4.6). It is also possible to store different variants of stampings in the library in order to apply those on to panels in another model or at another location in the same model.

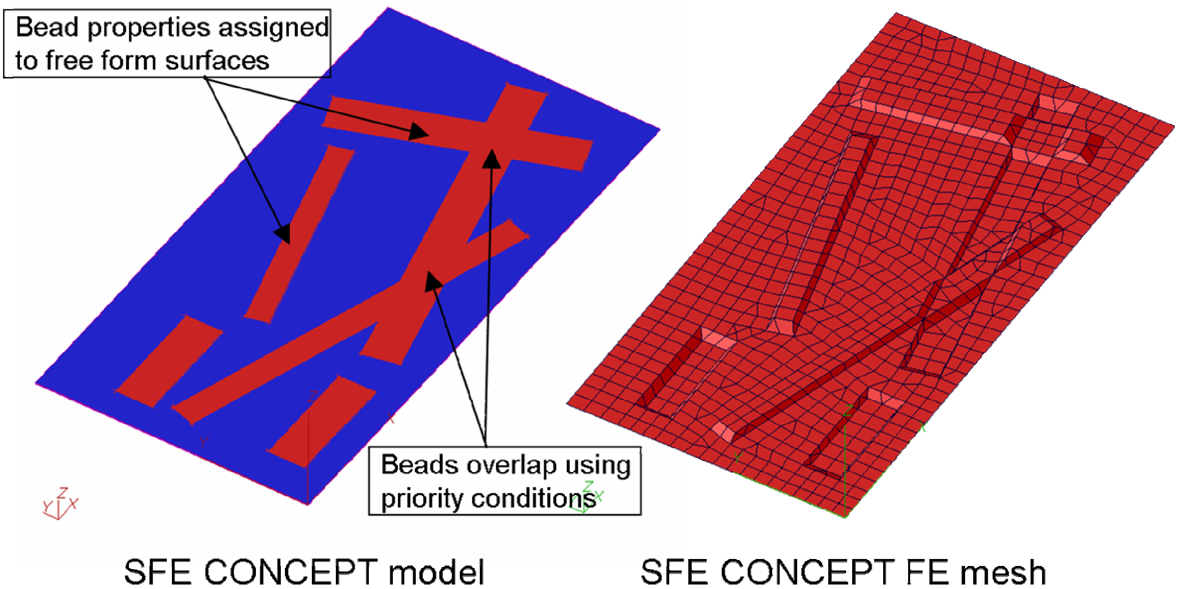

Figure 4.6: Overlapping stamping definitions

5 Summary

SFE CONCEPT, in conjunction with shape optimization and topology optimization, provides efficient techniques and tools for concept development in the early phase. Implicitly parametric topology and geometry models enable CRASH and NVH analyses to be performed during the early stages of vehicle development. The analysis models and design models can be quickly generated for optimization. Besides the simple "modification of FE node coordinates", this also includes complete re-meshing which fulfills the element quality criteria for the solver of choice.

Thanks to the efficient way of defining the design variables, the effort for creating the design model for optimization is drastically reduced.

This new approach opens up new frontiers for designing and optimizing lightweight vehicle structures which has since long become a mandate for the automotive industry.

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