OPTIMIZATION OF A VEHICLE FRONT PART STRUCTURE AT AUDI USING ANSA MORPHING AND OPTIMUS

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ABSTRACT - Simulation techniques are used in an early design phase to generate design variants for the evaluation of the components behaviour. The generation of these design variants may be very time consuming. Many aspects have to be considered during the setup of the different simulation inputs. The geometry must be correct, the mesh quality must be adequate and all boundary and loading conditions for the simulation must be applied correctly. The use of mesh morphing techniques brings an enormous benefit as existing simulation models, which are already validated, may directly be used for the parametrization. The availability of mesh reconstruction algorithms ensures the quality of the finite element mesh during the modification procedure.
In this paper, mesh morphing techniques in ANSA are used on the optimization of a vehicle front part structure. Different targets like the weight, packaging, and other functional requirements had to be considered during the optimization. The introduction of shell thickness modifications as design variables did not lead to satisfactory results. So larger geometry changes where introduced by mesh morphing. An existing simulation input is parameterized and the new defined control points may be used as design parameters. The underlying mesh is modified corresponding to the control point movement. This parametrization is now to be used in the optimization system OPTIMUS to build up an automated workflow, which may be used for optimization.

TECHNICAL PAPER -

1. INTRODUCTION

During the concept phase, one is faced with the problem to quickly evaluate different design variants. The influences of changes of different design parameters have to be evaluated to be able to find a design that fulfils all requirements. If the parameters to change are geometric parameters, it is a challenging task to do a parameterisation that may be used in an automatic procedure for variant calculations, Design of Experiments (DOE) or optimization. For these methodologies, the modification of the design variables has to deliver an updated simulation input deck without manual interaction in order to be used in the automated processes. Geometric changes may be implemented in different ways. One possibility is to change the underlying geometric information directly. This always implies that a finite element mesh has to be automatically applied on the modified geometry. For complex geometries having specific loading conditions and joints this is not automatically to achieve.
Powerful methods to do a mesh based parameterization are mesh morphing technologies. Any existing finite element mesh may be used for this kind of parameterization. The introduction of control points parameterizes the mesh. These external control points may be displaced and the mesh is following the external modifications. The mesh topology remains unchanged during this modification and nodes having active boundary or loading conditions are treated as hard nodes and will not be moved during this modification procedure. Different morphing approaches exist in order to define a large variety of parameterizations.

In combination with the optimization software OPTIMUS, the batch morphing technology in ANSA is a powerful toolbox to implement automatic changes on simulation files in order to do variant assessment or design optimization.
Different morphing technologies and the integration of the morphing setup into the optimization workflow will be presented on an optimization of a car front part structure.

2. PARAMETERIZATION USING MESH MORPHING TECHNOLOGIES

In the concept phase of new cars one is faced with the problem that many new design variants have to be evaluated. At the same time, the simulation models for the design variants do not exist and have to be quickly generated. For the use of parameterization techniques in an automatic optimization procedure one has to ensure, that the new design variants can be generated in a complete automatic procedure with no user interaction. The generated designs have to be of good mesh quality in order to be solved by the corresponding simulation tool. Additionally, all existing evaluation capabilities (e.g. scripts for post processing, …) have to be easily adapted to the new simulation input decks.

3. CAD BASED GENERATION OF DESIGN VARIANTS

One possibility for the generation of design variants is the generation of a new CAD design of the component. If parametric CAD models exist, the generation of new design variants can be achieved very quickly. The advantage of this approach is that all changes are directly applied on the geometry what implies that no new geometry has to be generated manually for the transfer back into the design process. On the other side, a simulation mesh has to be generated on the modified geometry and all boundary and loading conditions have to be applied. As the node and element ID's are changing during the automatic mesh generation, this additional information may not be defined mesh independently and often requires manual interaction.

4. MESH BASED PARAMETRIZATION BY MESH MORPHING

A very effective way to generate design variants of complex simulation models is the use of mesh morphing technologies. Mesh morphing allows generating design variants based on an existing finite element mesh containing all detailed load case definitions. The mesh is parameterized externally and may now be modified even in an automated procedure. The mesh topology remains unchanged and all loaded/fixed elements and nodes are automatically frozen during the modification. Additionally, one may specify frozen and nested nodes what allows a large field of application for mesh morphing. For the parameterization by morphing, different approaches exist. In ANSA, two main approaches are implemented:

Direct Morphing

In direct morphing, the displacement values are directly applied on the mesh. The movement may be specified on nodes in the model. A transition zone is defined which is used for mesh adaptation. The nodes in the transition zone are moved smoothly between the moving nodes and the fixed nodes. This approach may be used to implement in plane or out of plane movement.

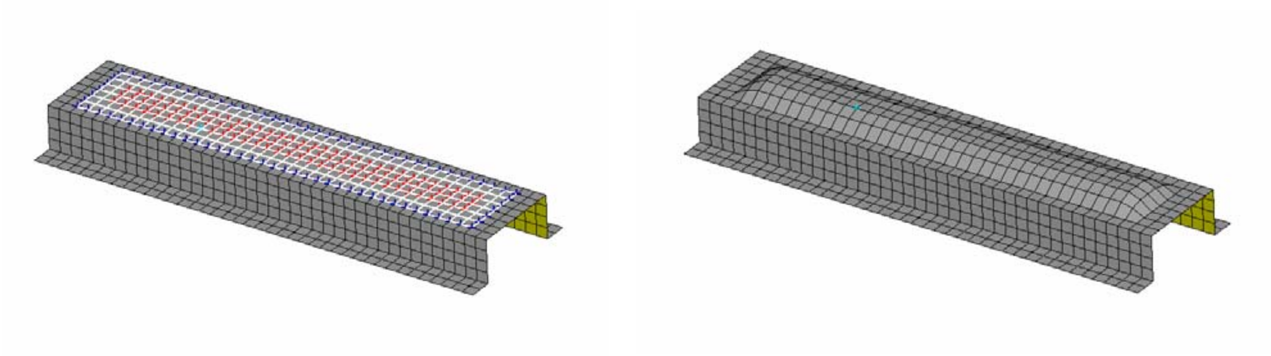

Fig. 1: Example for direct morphing

Box Morphing

A possibility to define more complex morphing parameters is the use of the box morphing technology. Morphing Boxes are defined additionally to the finite element mesh. The mesh is loaded into the boxes, and so all nodes and elements may be assigned to a certain morphing box. The corners of the morphing boxes are the control points for the modification procedure. If a control point is moved, the shape of the box is changed. Each node, which is loaded into the morphing box, now is displaced according to its geometric position in the morphing box.

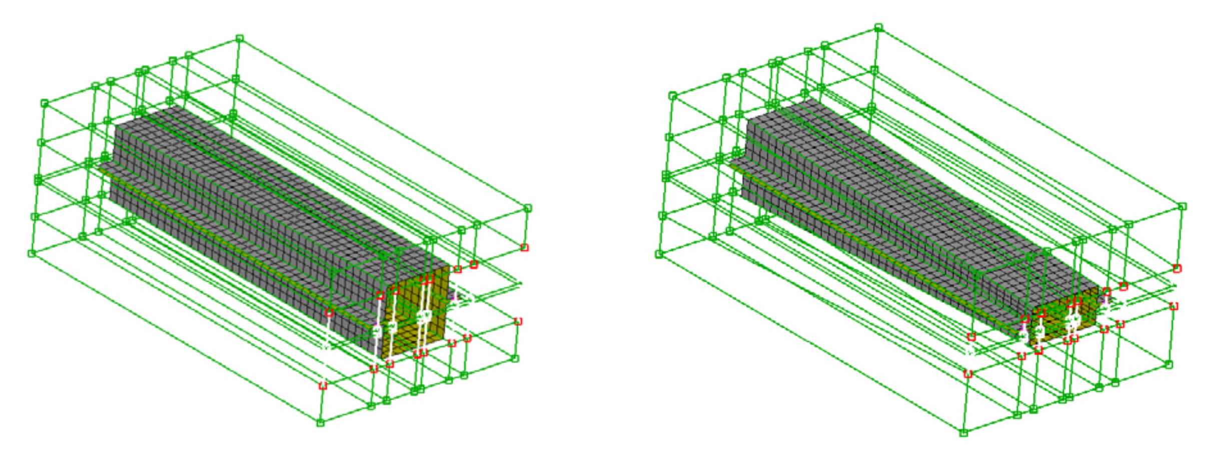

Fig. 2: Box morphing example

Mesh Reconstruct

During the mesh morphing procedure, the nodes of the existing mesh are moved but the connectivity of the mesh remains unchanged. For large geometry changes this may lead to large modifications of the element edge lengths. These modifications of the mesh may lead to poor quality meshes that may not be used in the simulation, as the results will not be meaningful of even the convergence of the solver may not be ensured. In ANSA this problem may be solved by applying a so-called reconstruct on the critical components. The reconstruct generates a new mesh based on the existing one but applying new values for the demanded element edge length.
All parts that are critical concerning the element edge length modification during the morphing procedure are reconstructed at the end of the morphing step in order to keep the quality of the finite element mesh for the crash analysis.

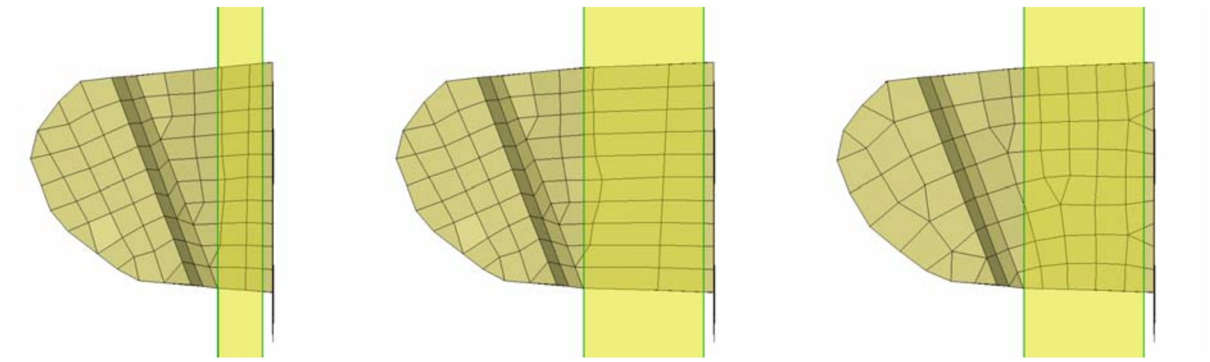

Fig. 3: Example for Mesh Reconstruct after Morphing

Automation of a Mesh Morphing Setup in ANSA

The morphing setup may be automated in ANSA by the use of ANSA scripting. Once, the different morphing parameters are defined, one can access these parameters via scripting and run ANSA in batch mode. So the new mesh configurations may be generated based upon the changing parameters and the morphing procedure may be implemented in automated simulation workflows. This is the prerequisite to be able to use morphing in an optimization.

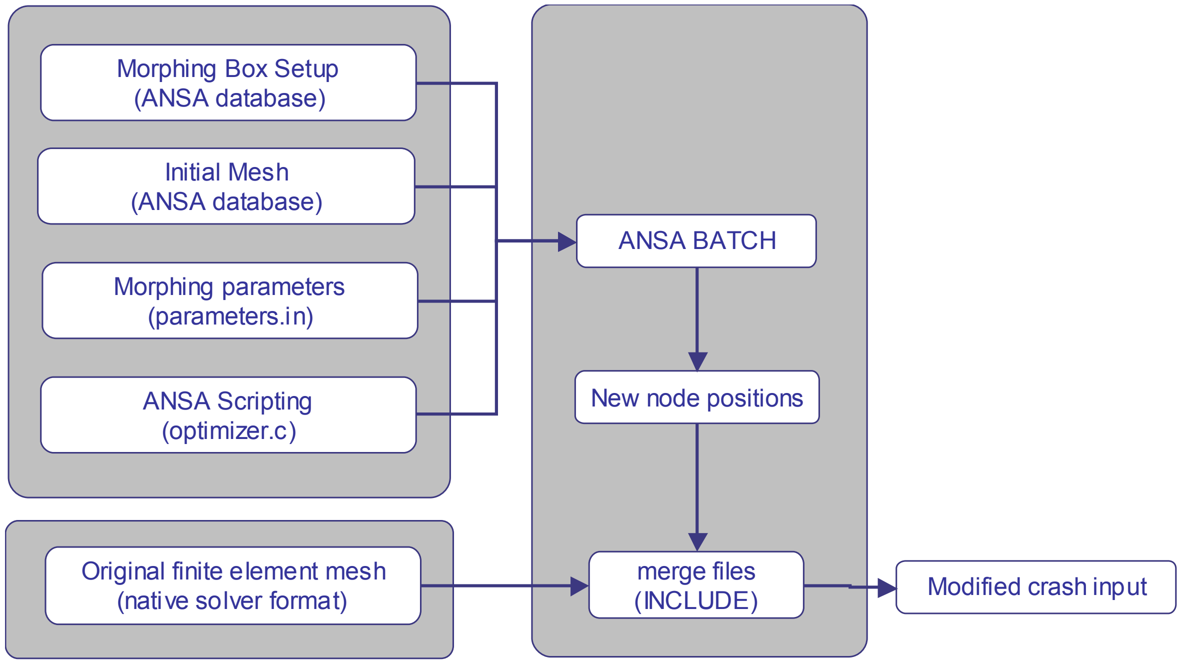

Fig. 4: Batch morphing setup for automated procedure

5. OPTIMIZATION OF A CAR FRONT PART STRUCTURE

PROBLEM DESCRIPTION

The aim of this optimization project is to improve the crash behaviour of a vehicle in a concept stage. The relevant response is the Occupant Load Criterion (OLC). The OLC is a criterion for occupant safety, which is determined during deceleration of the vehicle. These OLC values are calculated based upon the results of a front crash analysis.

6. SHELL THICKNESSES OPTIMIZATION

The optimization target is to find a design with OLC values in a feasible domain. In a first step, this target is to be reached by a modification of the shell thicknesses of the front part. As design variables, 20 sheets are selected, for which the thickness is modified. The simulation process is automated in the optimization system OPTIMUS. The thicknesses may easily be parameterized for the optimization. The thickness may directly be modified in the property definition in the finite element input deck. In OPTIMUS, so-called template files are generated, where the values for the thicknesses are replaced by OPTIMUS variables. For each design variant, which has to be evaluated for an optimization method, the OPTIMUS variables are substituted by the actual variable values. This allows to quickly automate the modification of the shell thicknesses.
The optimization target is to minimize the maximum OLC value of the design. A self adaptive evolution strategy was used in order to approach the optimum solution in the design space.

The optimization could improve the design and a design could be found with a smaller OLC value than the initial design. The target range of the OLC values could not be reached by changing the shell thicknesses only – a feasible design could not be found.

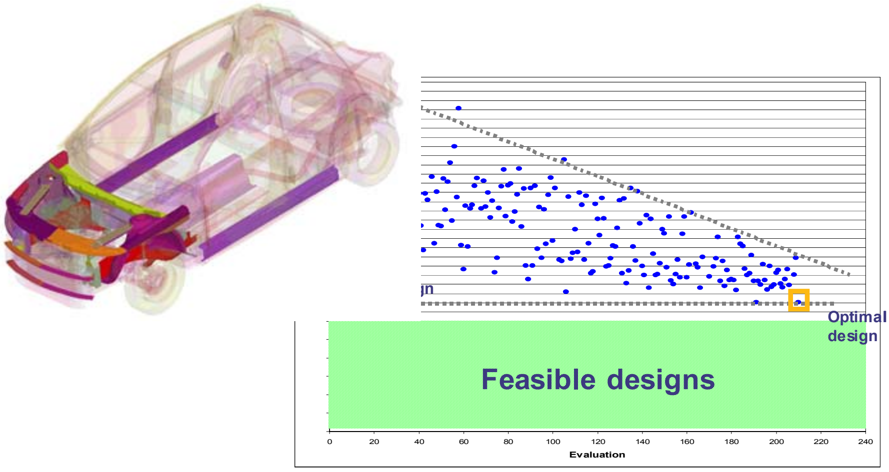

Fig. 5: results of shell thickness optimization

7. MESH MORPHING OF THE FRONT PART STRUCTURE

As the optimization of shell thicknesses did not end up in a feasible design, a new approach was chosen. An increasing deformation zone is necessary to fulfil the OLC requirements. In pre-examinations, 3 areas of possible modifications where detected. The distance between front wall and the engine should be changed. Additionally at the front of the car the distance between engine and cooler as well as the distance between the cooler and the bumper where possible design variables.

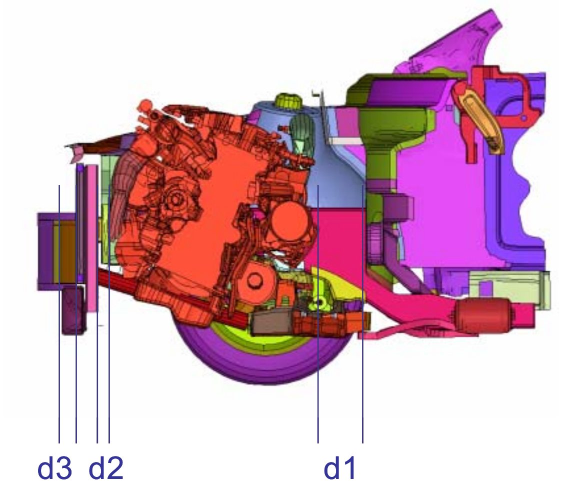

Fig. 6: Description of morphing parameters in car front part structure

3 Design variables are introduced:

- D1: Distance between front wall and engine
- D2: Distance between engine and cooler
- D3: Distance between cooler and bumper

The geometric changes are realized by mesh morphing. The use of morphing technology allows using the already existing simulation model with all existing boundary and loading conditions. Additionally, the post-processing routines could be easily reused as the mesh topology may be kept in the areas of interest. Only the components, which have to be changed by the corresponding design parameter, may be loaded into the morphing boxes. This enables the definition of quite complex design parameters for the geometry changes.

Parameter D1

The modification of Parameter D1 basically includes the length change of the front side member, the y-connections and the back part of the wheel housing. All parts in the front of the car (engine block, bumper, …) get a translatoric movement in x-direction of the car.

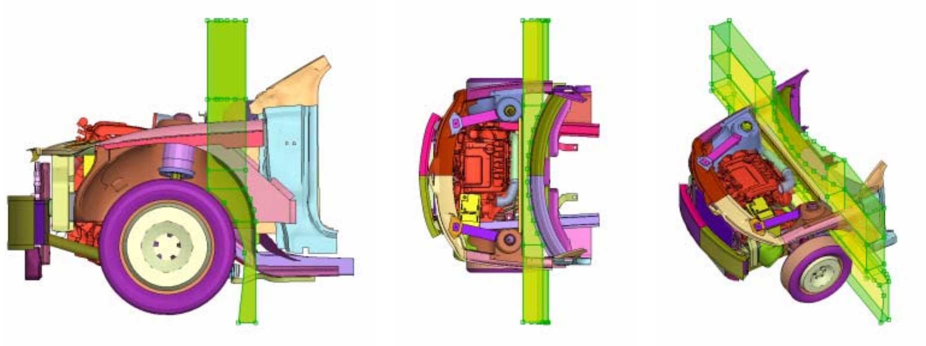

Fig. 7: Morphing parameter D1

Parameter D2

The second morphing parameter includes the front part of the wheel housing and the bottom and top front members. The engine, which geometric position is also located inside the morphing boxes, is not loaded for the modification of the parameters. The engine position will not be modified in this morphing step.

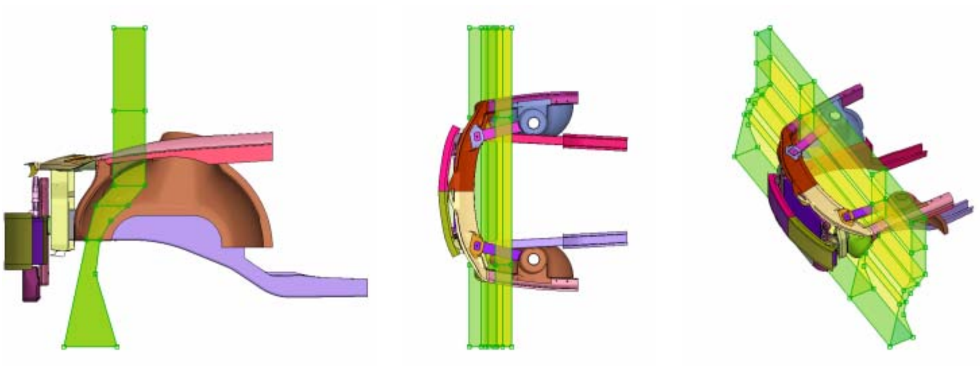

Fig. 8: Morphing Parameter D2

Parameter D3

The third morphing parameter is only affecting the front of the car. The bumper is moved in x-direction. This is realized by a change of the length of the crash box.

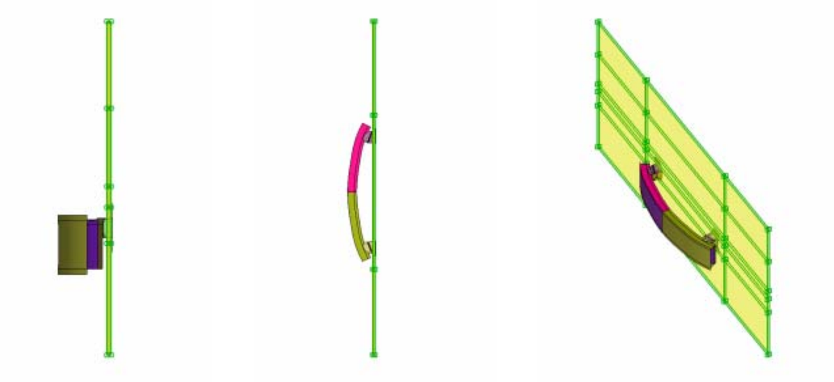

Fig. 9: Morphing Parameter D3

Assembly of the morphing boxes

The complete morphing setup includes a connected set of morphing boxes. A translational displacement in x-direction is defined for the control points of the single morphing parameters. Stepwise, the single parts of the front part structure are loaded into the morphing boxes and displaced. First, the parameter D1 is applied and D2 and D3 get the same displacement amount – these areas of the front part structure remain unchanged. In the next step, D2 is morphed and D3 gets the same displacement – the last morphing step is them modification of parameter D3.

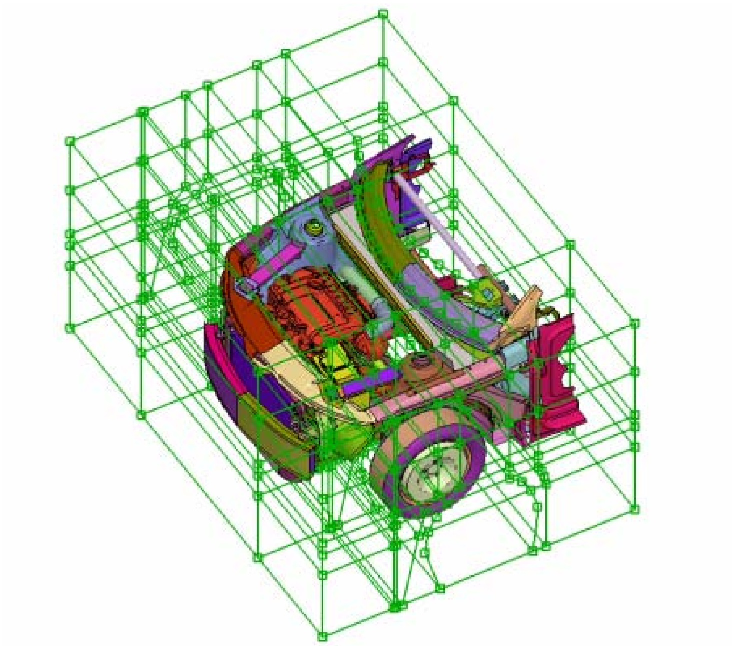

Fig. 10: Car front part structure with Morphing Boxes

This procedure allows to apply the different design parameters and to generate a new input file for the crash analysis. The single morphing areas are not overlapping and therefore not influencing each other.

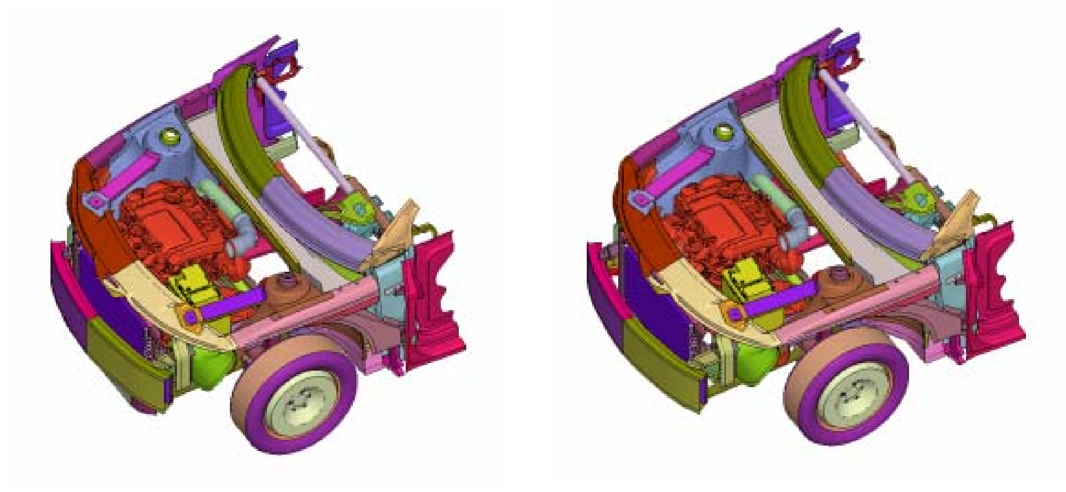

Fig. 11: Morphing of the complete car front part structure

Optimization

The morphing setup is now to be integrated into the optimization loop. Therefore, the complete morphing has to be executed in batch mode in order to generate the different design variants automatically. For this purpose, ANSA scripting is used to implement the morphing procedure in the optimization software OPTIMUS. An input template file for the ANSA batch run is generated where the design variables are parameterized via OPTIMUS variables. The batch morphing procedure is always based upon an ANSA database containing the initial input deck and the morphing boxes. After the batch morphing in ANSA is executed, the new node positions are exported. In case of reconstruction, also the new generated nodes and elements have to be exported.

These files are included into the main deck of the crash analysis. The crash analysis is executed on a compute cluster. On the cluster, the extraction of the accelerations and the calculation of the OLC value are executed by a post processing script. Only the interesting responses for the optimization are transferred back to the optimization host and the corresponding response value is extracted from the result file.

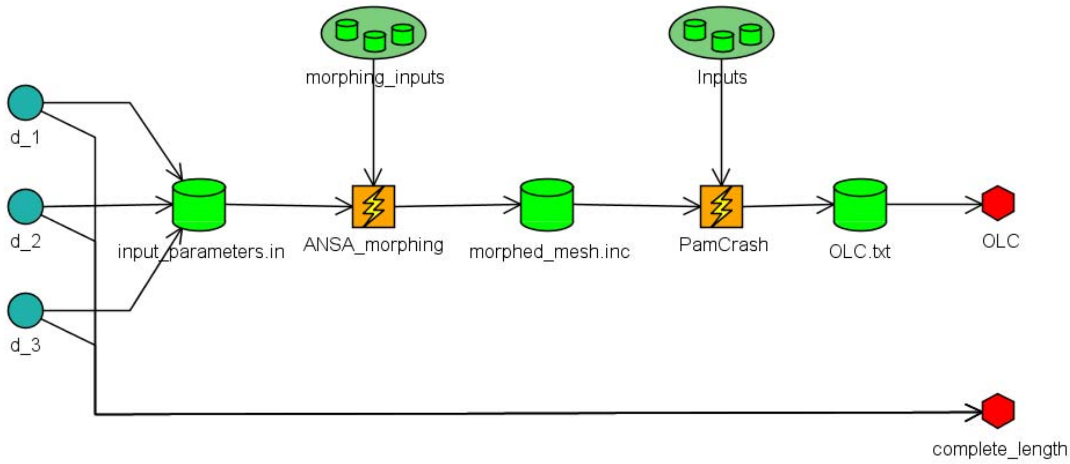

Fig. 12: Simulation workflow including mesh morphing

For the front part structure, the shell thickness distribution from step 1 was used for the initial design. The formulation of the objective was modified compared to the shell thickness optimization. The longitudinal changes in the front part of the car can reduce the OLC values but due to design restrictions, changes in the front structures length should be avoided. So the objective was to minimize the complete length of the front part with a constraint on the OLC value. The necessary changes in the length should be applied in the area where geometric changes have the largest influence on the considered response. A global optimization approach was used for optimization.

Results

Using the optimum shell thickness distribution from the previous optimization, a feasible design could be found. The advantage of the global optimization is the generation of a large number of design variants that also allow the identification of the influence of the design changes on the design criterion. For 2 design areas, a weak influence of the modification of the inputs could be recognized. But for one of the design areas, a correlation between the geometric changes and the corresponding OLC value was found. This area is the most important one to implement the geometric changes, as the influence on the OLC performance is very strong.

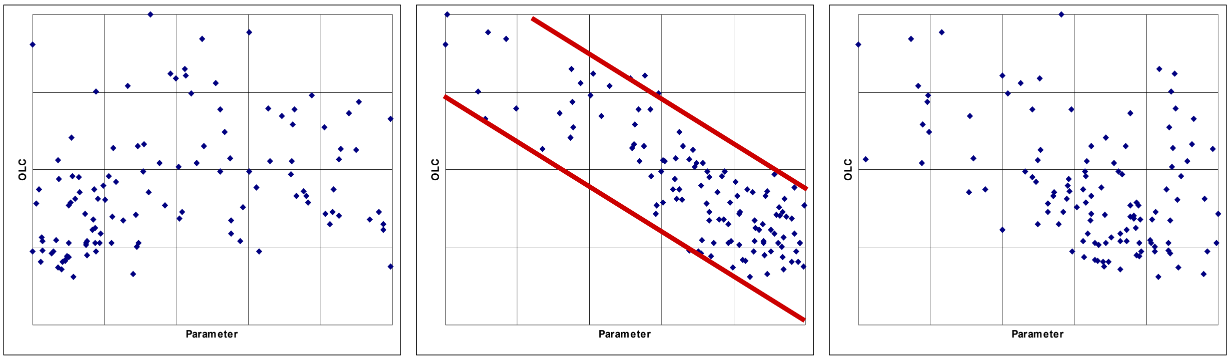

Fig. 13: Important area for design changes

8. CONCLUSION

The use of optimization technologies allows to quickly evaluate different design variants and to optimize components concerning a large variety of objectives considering a large number of constraints. However, the parametrization plays an important role. The design space strongly depends on the selected design variables. The easiest way to parameterize an input for a simulation procedure is to access and modify values in the simulation input deck. The number of parameters here is very limited so one is faced with the challenge to introduce more advanced parameterizations. The modification of a component's geometry is often necessary in order to widen the design space. At the same time the introduction of geometry parameters for an automated use in an optimization procedure is not easily to achieve as mesh quality plays an important role for simulation.
The example of the vehicle front part structure shows, that the modification of the shell thicknesses only did not lead to a satisfactory design performance. Larger geometric changes where needed in order to have a larger design space for modification. The use of mesh morphing technologies was the selected parametrization technology as existing and validated input decks can easily be used and the mesh quality can be checked and modified if necessary.

Morphing is used to quickly adapt existing simulation inputs to new design variants. The automation via scripting allows integrating these changes into automatic Design studies like Design of Experiments or complete optimization projects.

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