High Speed Concept Development: full parametric surface modelling and automatic creation of simulation models using the Fast Concept Modeller (FCM)

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Abstract

Over the years the vehicle development process has undergone a radical change. Creation of concept geometry is meaningless without its functional (CAE) validation. The Fast Concept Modeller (FCM) creates a common model which can be used for creation of geometry design and its variants, functional validation and feedback of optimisation results directly to the geometry. The following document discusses the existing problems in virtual vehicle development process. It outlines the FCM modules along with their advantages which overcome the pitfalls in today's process. This document presents an innovative process solution that serves as a forerunner to the development of a fully automated, multi-disciplinary optimisation.

Keywords: FCM, Parametric modelling, CAD-CAE, Batch Mesh, Beam-Shell Method, Optimisation

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1 Introduction

With every passing day, increased importance is being laid upon the virtual vehicle development. In order to satisfy the market needs, a dramatic rise in the variants and derivates of each variant has been seen. The car makers are making strides towards capturing newer markets, niche segments and exploring the unexplored quarters. Additionally, the trend towards light-weight design, reduction of fuel consumption, reduction of CO2 emission, alternative drives defines new requirements. Other environment variables, for example the current world economic crisis, have made the automobile industry to re-think its strategy and redefine the targets for the future. The technological advancements have given a new perspective to the design and development processes. Because of this there is a continuous rise in the product complexity: higher number of variants, package-based designing methods, requirements towards comfort, security to name a few. In order to be competitive, not only the process times have to be reduced but also the development costs have to be kept under control and the manufacturers have to constantly adapt themselves to the changing market trends.

Apart from project management, it's the entire development process that is responsible for the quality of the product, efficiency of the team and finally leading to the financial success. One of the biggest challenges faced by the auto manufacturers is the reduction of investment risks and investment costs in the early phases of the product development. Hence the concept phase provides a greater potential for the reduction of costs and times. Through the interlinking of processes, deployment of integrated systems and adaptation of methods the entire complexity of product development can be streamlined.

Package and modular designs have been gaining importance. Components once developed should be used for a range of models and vehicle derivatives. Engines, batteries, accessories are some typical examples of such components. Design engineers working in the concept phase need not re-develop these components for every vehicle and can rather use the existing designs for newer models. Out of a catalogue of available module designs, he would need to merely pick out the suitable module that satisfies the geometric and functional requirements of a range of derivatives, for example using the same platform for a limousine and a SUV.

Some of the design parameters mentioned above are conflicting. For example, the cars should be lighter on one hand but at the same time passenger safety has to be ensured. This leads to multi-disciplinary development process in which not only such parameters but also systems like chassis, electric and electronics or vibration can be tested against each other in order to obtain an optimal vehicle configuration. In the future, validation of concepts would be more and more virtual. Deployment of high performance CAE-systems can cope with the variety of load cases associated with the higher variety of derivatives being developed. The speed and relevance of the simulation results help the designers to pose new challenges to these systems. Furthermore, as a cost cutting measure, the budgets for prototypes will be reduced to an extent that only one complete prototype per derivative will be built and tested.

2 State of the art

Creation of new vehicle concepts needs greater flexibility. The initial and concept phases of vehicle development begin with the package-plan and definition of the required components. 3D-Models help in an easier and faster evaluation of newer concepts, packages and Body-in-White variants. To achieve this flexibility, special tools and methods are implemented that help in creation parameterised 3D-geometries that can easily be modified and functionally evaluated. There are two ways to achieve this: using specialised tools for concept study based on the typical CAE-methods or deployment of standard CAD-systems that are used in the design of production components. Both these methods have their respective compromises and disadvantages.

For any new concept, the geometry available in the initial phase is in the form of sketches and cannot be used for further functional evaluation. In the CAE-based methods, new geometries have to be created and these would then be meshed, simulated and optimised. In case of further development of existing vehicles, it's the optimised geometries that are fed in as inputs for the process. Due to the incompatibility between the CAD-tools for the concept and production development, these inputs are imported as "datum-geometries" in the special concept modelling tool. Additionally, the available mesh data can also serve as inputs. Since the inputs are isolated, they have to be re-modelled to be put into productive use. This highlights the issue of missing process-continuity. This discrepancy is pre-programmed and is carried forward to the production stage as well when the validated concept models are passed on to the standard CAD-System. Due to the mentioned incompatibility, an interface has to be used for this purpose. Most of the parametric representations are lost and the imported geometry serves merely as a forerunner. Should a concept change be needed at the production stage, the changes can only be made in the available concept models and the respective data. But these changes have to be remodelled in the production models as well.

In contrast to the CAE-based concept study, deployment of a standard CAD-system offers a higher degree of process-continuity, although with reduced flexibility. A strict set of methods have to be followed by the design engineers to create robust and stable models that can cope with the required changes carried out in the concept stage. Because of the nature of complexity of a standard CAD-system, provisions have to be made in the very early stages of modelling for the changes that would eventually follow. Compared to the CAE-based method, this is a time intensive process. Nevertheless, it is not ruled out that radical concept changes will not need re-modelling of the geometry. As a direct consequence, based on the existing models relatively small concept changes can be simulated but the newer concept is strongly influenced or directly dependent on its predecessor. This restricts the freedom one needs while designing innovative concepts which do not have any templates available or concepts which require complete rethinking of the basic idea itself e.g. vehicles with hybrid drive-train technologies. This CAD-based concept development needs the additional CAE-block. The functional validation of the concept models have to be carried out in standard FE-software. As a result, in addition to the concept geometry models the FE-relevant data have to be managed separately.

Either way, the concept stage is currently littered with process islands with bridges between them missing.

3 Fast Concept Modeller

3.1 Motivation

The Fast Concept Modeller (FCM) serves as the missing link in the process landscape. It provides for intuitive creation of concept models in an environment that the designers are currently used to. Special attention was paid towards associative, parametric modelling, so that even unplanned changes to the original concept can be made possible. This should not only be fast, easy and robust but the software should also be user friendly and user oriented.

Integration in CATIA V5, one of the leading CAD-systems in the automobile industry, ensures a smooth transition from the concept phase to the production phase. The FCM objects and their parametric can be directly saved as CATParts. Hence, it eliminates the need for an interface, re-modelling or data conversion. The levels of detail in FCM geometries can be gradually increased by creating holes, fillets and swages, which serve as basis for further design and development of individual production parts. CATIA V5 itself is a powerful tool and using the available tools in conjunction with FCM only adds to the advantages. Furthermore, because of the standard data type (CATParts and CATProducts), conventional PDM-systems can be used to handle concept data as well. In addition to the standard user administration rights and version management, it serves as a common platform bringing the worlds of concept design and production design nearer.

Every manufacturer has its own CAE tool landscape. Because of the known IT-related restrictions (Windows, UNIX) the communication between the CAD and CAE systems is possible only through platform independent tools and interfaces. Coupling with the existing CAE-process, without the deployment of newer systems was one of the driving factors in the development of FCM. The data set can be directly exported from FCM as native CATIA V5 geometry with accompanying CAE-information in an ASCII format to the existing (or a future) batch-mesh process.

IT-system, technology and process are directly dependent on each other. Deployment of any new system or technology requires extensive change-management.

Added to that is the factor “human”. Greater is this change, more is his resistance to it. A tool should not only be efficient, but also learnable. Because of the reduced number and the intuitive nature of its functions, FCM can easily be learned by CAD-beginners and CAE-engineers. The user needs to concentrate on the work at hand and not the tool.

3.2 The Process

FCM is an application for faster and easier creation of 3D vehicle concept models based on which relevant information for NVH, crash or static analyses can be directly exported. This innovative tool serves as the backbone for the entire concept development process and provides a common platform for the CAD and CAE users to work together on the same model. Automatic feedback of optimised results into CAD is not merely a dream anymore.

3.2.1 Parametric modelling

„Parametric modeller“, the geometry module of FCM, ensures faster, easier and intuitive design of full parametric models. These are not only watertight models, but also robust so that they can be easily modified and updated. Following picture illustrates some of the functions of this module.

Abbildung 1: FCM Parametric Modeller

The commands based on new algorithms help in faster and precise modelling in fewer steps. The association between objects can be created, modified or deleted at the click of a button. For example, in case of associative points if a parent is deleted, the system automatically adjusts to the situation by breaking the links. With the help of higher hierarchical objects, complex structures can be modelled using single FCM objects.

Modelling in the concept phase needs to allow for changes. Deeper the parent-child relationship in the history of a model, more complex it becomes to make modifications to its design. Because of the flat hierarchy (max. level 4) of FCM geometry objects, no detailed planning is required at the start. There is enough room for free thinking and models can be created as the idea develops. Also, the parameters for FCM objects can be accessed just like for any other native CATIA V5 object.

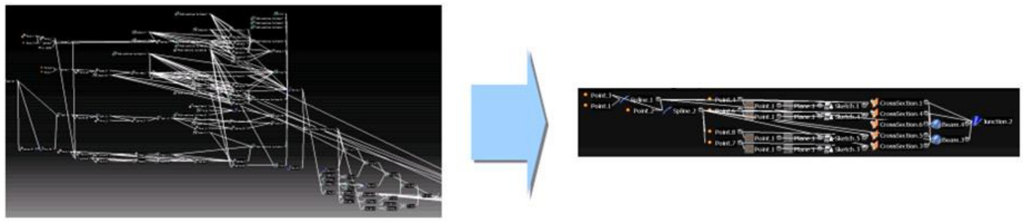

Abbildung 2: Comparison of the history tree of a B-post in V5 GSD (an extract) vs. FCM (complete)

FCM is a workbench in CATIA V5. Hence, the deployment of FCM does not limit the design space to FCM objects in any way. With the help of standard V5 GSD tools, the levels of detail can be gradually increased till the model has reached the production stage.

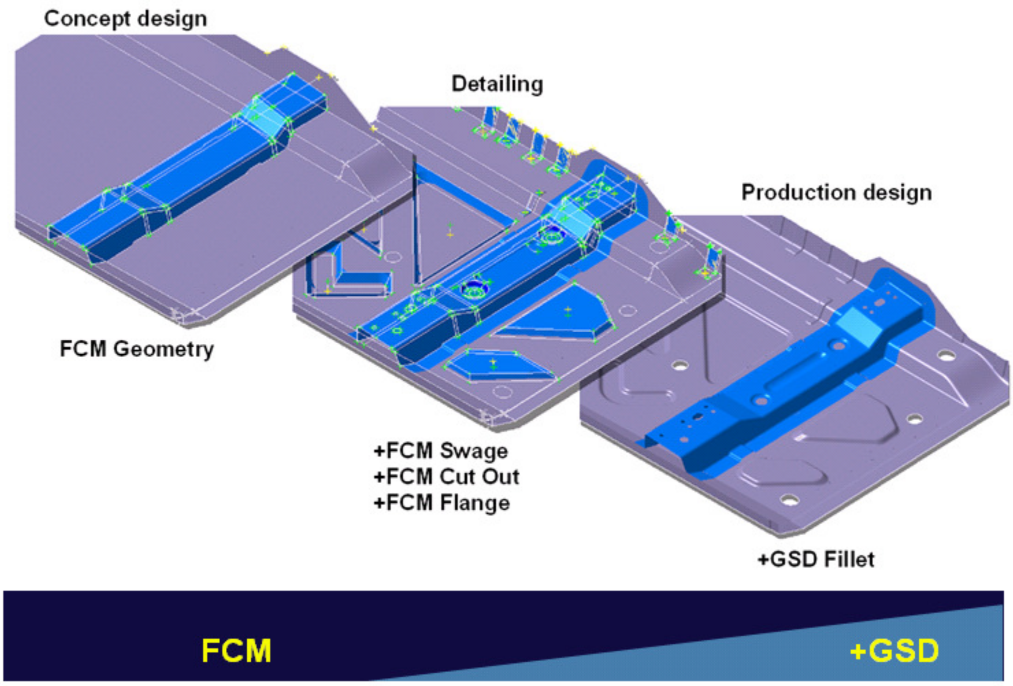

Abbildung 3: From concept to production design

FCM facilitates modular way of working. Once the designs of vehicle components are ready, they can be stored in catalogues. The same applies to cross-section sketches of components. These can be retrieved and used for designing newer derivatives of a vehicle or for the further development of existing designs. The available CAD-data can be loaded in FCM without any conversion. A so-called hybrid-model is created in which the GSD data can be edited using the native V5 GSD functions and the FCM objects can be developed using both the FCM as well as the native V5 GSD functions.

3.2.2 Batch meshing

Through the CAE modules of FCM namely “Analysis Pre-processor” and “Structure Analysis Pre-processor”, a very strong interaction between the geometry and analysis worlds is realised.

Abbildung 4: FCM Analysis Pre-processor

FE-information like material, property ID, material thickness, connection geometries are directly created and stored in the CAD-model itself thus eliminating the time and effort involved with the collection of required information, re-modelling and basic attributing of the models in a CAE-system. The system interface is further reduced (or eliminated) in a way that that the CAE expert works directly on this attributed model and defines further attributes like load cases, measure features, tailored blanks and rigid body elements, which also are stored in the 3D-model itself.

The meshing process can be started from within FCM. The geometries are converted into a suitable format and exported. Accompanying these is a set of ASCII data files containing the information like properties, connection attributes and model elements. Because of the bi-directional communication enabled by FCM, these features are converted into the real FE-elements which can then be visualised and imported in the model. Changes can be made to the model and mesh process can optionally be re-started.

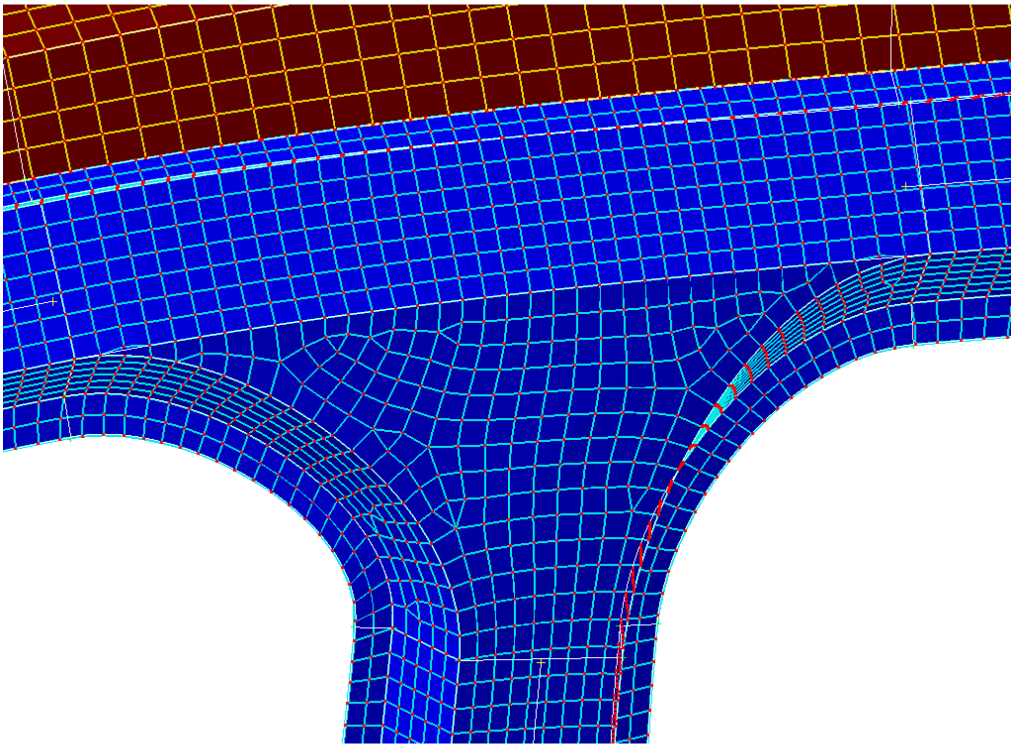

Abbildung 5: Visualisation and import of mesh into the CAD model

A standard FCM-installation comes with the interface to TEC|ODM because of which the user can not only create robust concept geometries, but also get an optimised mesh for the same.

Additionally, interfaces to CATIA mesher and other standard mesh programs are also available. Depending upon the type of analysis, it is possible to pre-define the solver for which the mesh has to be generated.

3.2.3 Beam-Shell Method

Especially in the set-up of very early vehicle concepts, FCM provides for the creation of vehicle body frame as FE-Beam elements. The objects can be discredited in FCM itself and exported in the standard NASTRAN format. Not only the standard cross-sections but also arbitrary cross-sections (ABCS) are supported. Based on the exported data, cross-section and material thickness optimisation can be carried out by NASTRAN without the help any other additional software.

One of the prime highlights of FCM is that it is for the first time possible to read and visualise the optimised cross section geometry. FCM goes a step further and makes it possible to feedback the optimised results directly to the geometry and update the CAD-model. Following figure shows how a structure designed in FCM can be discredited in FCM, exported for NASTRAN, updated based on the optimised result and finally feedback to the geometry.

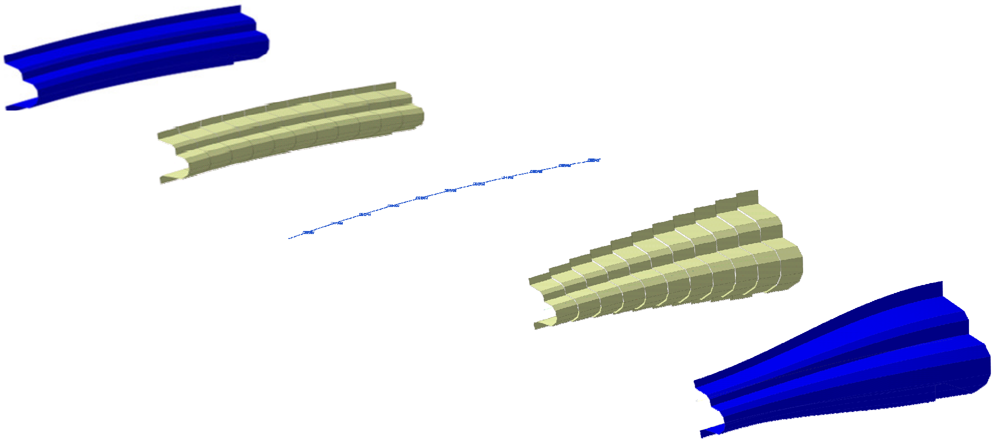

Abbildung 6: Discretization and feedback of optimisation result directly into the CAD geometry

In the Beam-Shell Process, in addition to the FE-Beams discretization, the batch mesh can be simultaneously started. The mesh results can be imported in the model and the two representations can be coupled using the RBE2 elements.

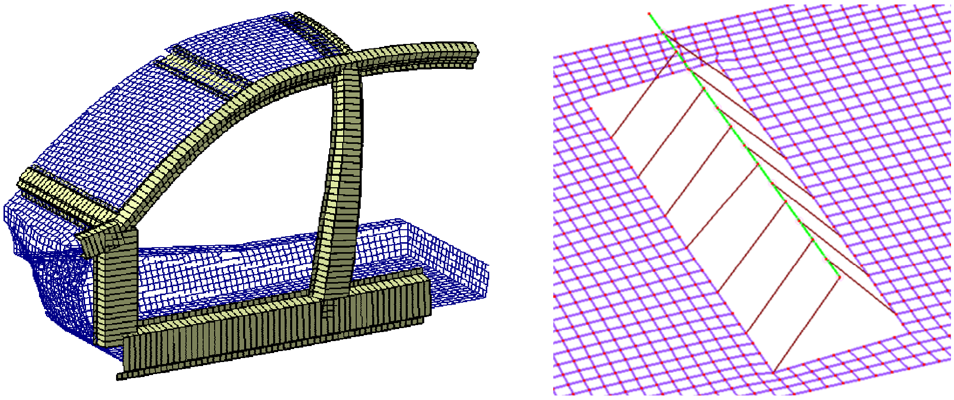

Abbildung 7: Beam Shell method: automatic coupling of shell mesh and FE-beam elements using RBE2 elements

3.3 Advantages

Following is an illustration comparing today's process with the FCM enabled process. As mentioned in chapter 2 earlier, there is no concept development software available in the market that is process-integrated. The traditional concept development is more a compromise than a process. With increasing number of interfaces in a process, the chances of data loss increases.

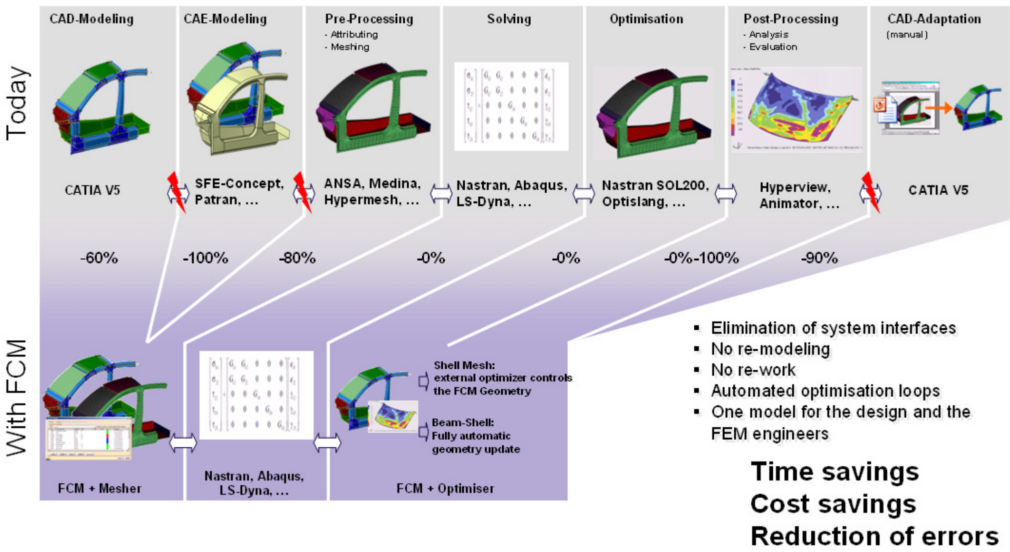

Abbildung 8: Overview and comparison of processes today vs. with FCM

One of the biggest advantages of FCM is its integration into CATIA V5 and thereby into the existing development process. Deployment of an FCM-enabled process bridges the existing communication gap between the CAD and the CAE worlds. Redundant processes like re-modelling are eliminated, reducing not only the overall time, effort and costs involved but also minimising the possibility of errors. This leads to increased process efficiency.

The time saved helps in flexible process planning (forward and reverse scheduling) thereby giving a strategic advantage. “Earlier time to market” increases the chances of success for the product. Alternatively, because of “later starting date”, the financial resources are not bound and can be planned accordingly.

Because FCM uses CATPart as the format for its models, product data management is now possible throughout the process beginning right from the initial and concept phases to production development. The NASTRAN tools available make it possible for the relevant FE-data to be saved within the CATPart itself. Overall, the improvements brought about by FCM can be summarized as:

- Availability of vehicle concepts in the initial stage itself
- Faster creation of simple and fully associative, parametric designs
- Possibility of integrating existing production data into concept development
- Bi-directional coupling of the CAD-system with CAE-process
- PDM for geometry as well as CAE data
- Reduction of costs
- Faster ROI

4 FCM and Optimisation

Because of the sheer number and variety of parameters interacting with each other it is not easy to find an optimum design. Years of experience and Know-How coupled with the time intensive process of individual design evaluation leads to a useful solution. The main disadvantages of this process are that it is manual and that it is completely CAE based. At the end of the day, what is required is an optimised 3D-model. The issues existing between these worlds are well-known. Additionally, if a basic concept change in the geometry is required, the standard CAD-systems do not provide the required speed, flexibility and robustness to make such changes to the model.

A consortium of companies (TECOSIM GmbH, Dynardo GmbH and ForceFive AG) has developed an automated multi-disciplinary optimisation process bringing the basic process elements along with the evaluation of results together in one loop. The entire process is controlled with the help of intelligent scripts. As seen in the figure below, FCM, TEC|ODM and OptiSLang along with the standard solving tools (Nastran, LS-Dyna) form the building blocks of this process.

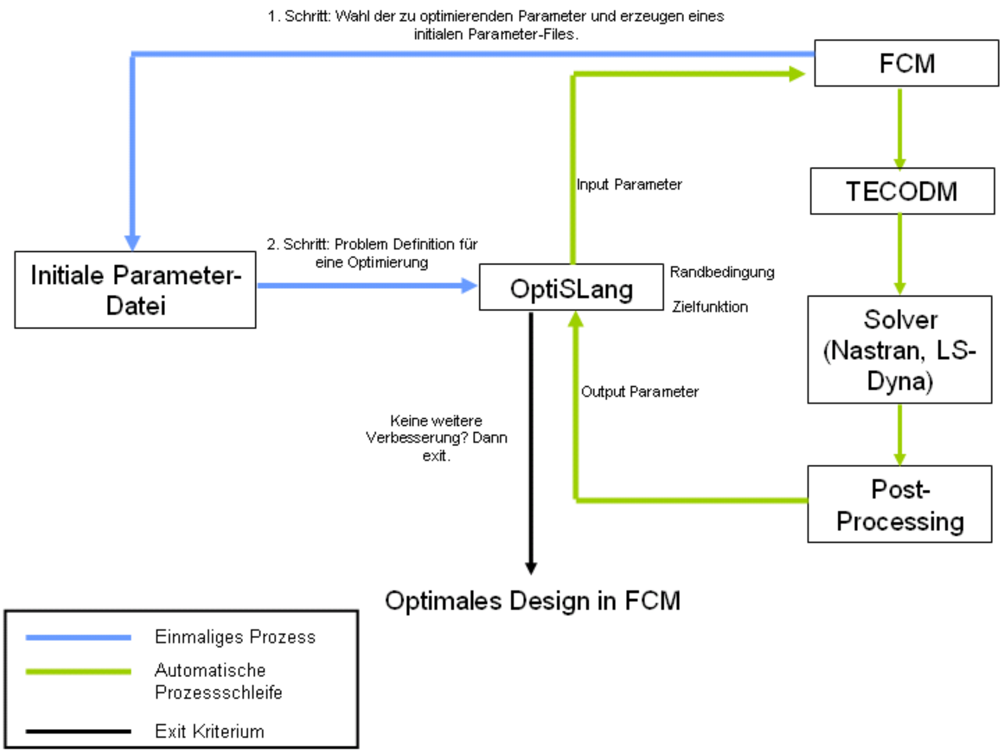

Abbildung 9: Automated optimisation process

The process is divided into three parts: a reference run, the optimisation loop and design evaluation.

The reference run is one manual loop of the entire process. The objective is to get sample data for input and output parameters, define the constraints and load cases based on which the process will be built and executed. The geometry to be optimised is created as a full parametric model in FCM. Using the standard CATIA V5 function Design-Table the control parameters can be defined and exported as a text file which serves as the input parameter file. Some of the typical design parameters are the geometric position of an element or the complete component (variation in X, Y or Z directions or profile guided movements), shape and size of an element (form and design) and number of elements (active or de-active). Because the connection geometries are control at the CAD level itself, corresponding parameters can also be defined as design variables for example the number and configuration of weld points. Interestingly, since FCM itself does a part of the pre-processing and has a direct interface with TEC|ODM, certain FE-parameters like material thickness can also be exported for optimisation. OptiSLang can directly read and understand this exported file as an input file. OptiSLang generates parameter sets lying within pre-defined ranges and satisfying the constraints. Previous simulation run(s) on the same model serve as a further reference for the process. Relevant parameters can be picked out from the respective result files and defined as additional output parameters which help in validating the design before sending its simulation results for evaluation. Based on the target definition, only the relevant results (from above) will be used for the overall process assessment at the end of which an optimised design will be available.

In a pilot project, this theory was put into practise. The seating rail of a car was selected as the target object. The objective of the project was the reduction of the weight of the component without compromising its functional behaviour.

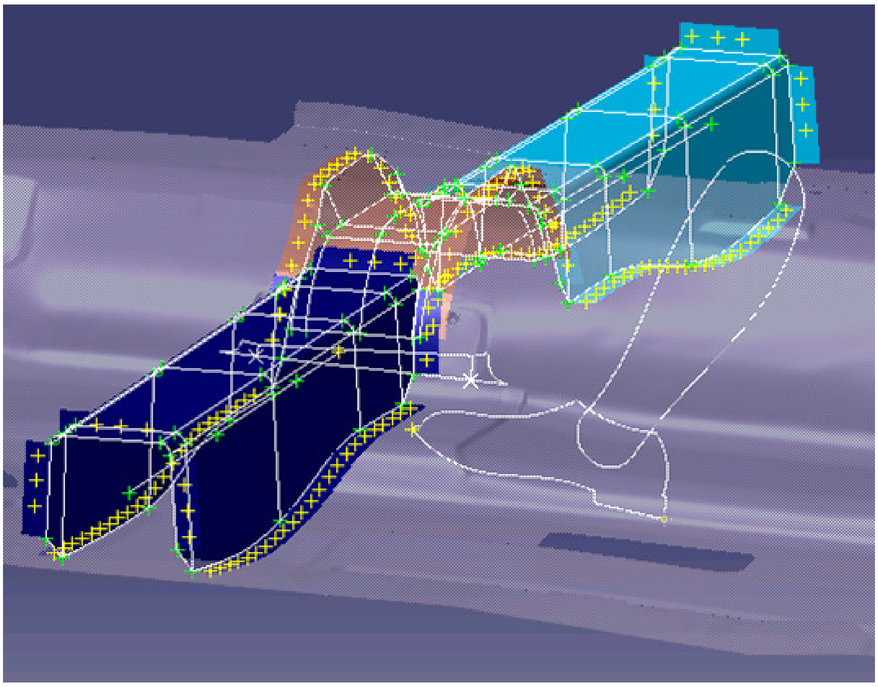

Abbildung 10: Seat Rail model in FCM

Following parameters were selected as control or input parameters:

- material thickness,
- cross section width and
- X-position of the seat rail.

Based on the pre-defined constraints, OptiSLang generated an input parameter set which was fed in as a new Design Table and the FCM geometry was automatically updated. An output file from FCM gave the signal whether the update had been successful or not, based on which the Batch-Mesh process was initiated where TEC|ODM generated the mesh for the NASTRAN and LS-Dyna simulations. Using the load cases defined in the reference run, NASTRAN and LS-Dyna jobs were started simultaneously. In order to satisfy the existing functional characteristics, following constrains were defined:

- torsion stiffness must not be compromised and
- deformation during side crash must not deteriorate.

At the end of these runs, the respective values were read out of the result files and sent back to OptiSLang as output parameters. These values were then validated and the design was either discarded or saved for overall assessment.

Abbildung 11: LS-Dyna crash simulation (Courtesy: TECOSIM GmbH)

Newer input parameter sets were generated based on Evolutionary Algorithm (EA) and further process loops were executed till the exit criteria was satisfied. The designs and their results were evaluated and the best design for the defined problem was established. From the figure below, it can be seen that the process has a design convergence and the optimum design was 0.315 Kg lighter than the reference design.

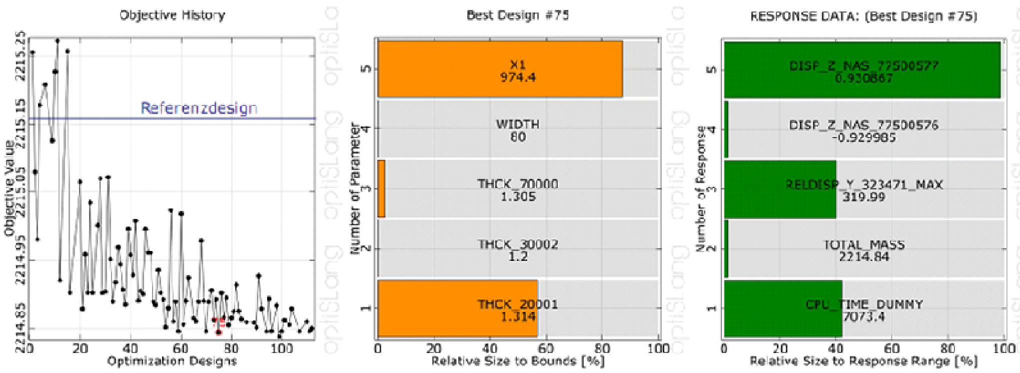

Abbildung 12: Evaluation of results in OptiSLang (Courtesy: Dynardo GmbH)

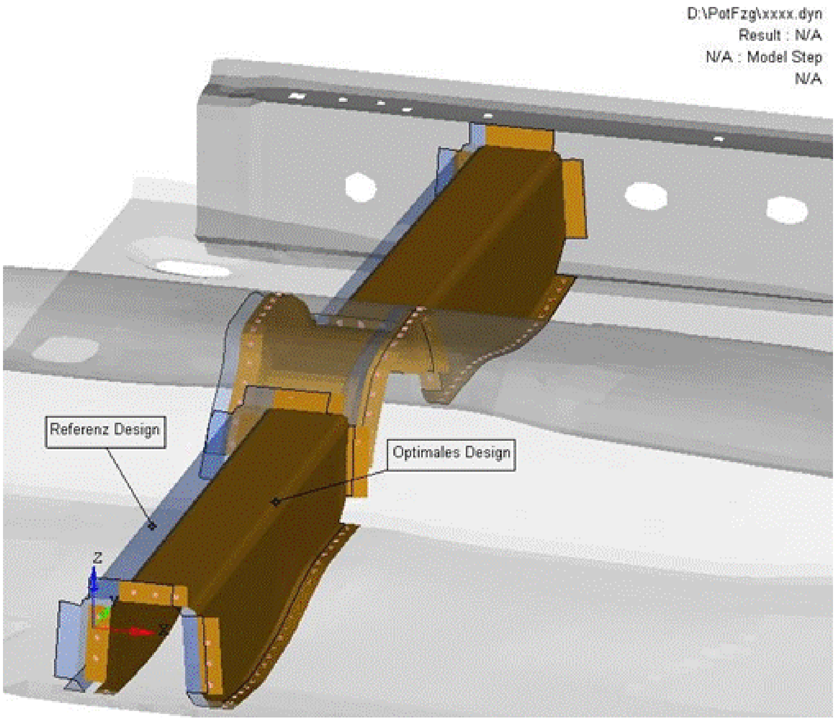

Abbildung 13: Reference design vs. optimal design (Courtesy: TECOSIM GmbH)

The advantages of an automated optimisation process are:

- Optimised design is directly available as 3D-geometry
- Robustness: only for successful geometry updates, the Batch-Mesh process and hence the entire loop will be initiated
- Lesser effort involved in the execution of the overall process
- Intelligent algorithm helps in reduced number of runs
- Overall saving of time and costs
- Batch-mode process that can be executed without manual intervention
- Exploitation of the advantages of individual process elements
- Stepping stone to a fully automated multi-disciplinary optimisation

5 Summary and Prospects

Nearly 80% of costs are defined in the very early stages of product development. In comparison to it, the product knowledge is detailed only in the production design phase. Changes to the concept at this stage could be very cost intensive. With the Fast Concept Modeller, the product development is optimised in a way that high-quality concept models are made available. Accompanied with the respective CAE-data and simulation results, these models gain significance and help in increased product knowledge at the concept phase. This reduces not only the costs triggered by concept changes, but also the need for a change. While reducing (or even eliminating) the number of required interfaces, FCM serves as a process backbone and offers a continuous and lean process.

Additionally, it supports partner integration. FCM objects can be accessed in native CATIA V5 as non-editable surfaces (thereby safeguarding the concept design) based on which further production development can be made. Should a concept change be desired, the data can directly be altered in FCM. Final update of the CATPart gives a design of the production component which has been modified accordingly. The fact that extremely faster design creation and robust changes are possible in FCM, it provides a competitive edge to the vendors and suppliers taking part in concept design tenders. And with price being one of the deciding factors, chances of project acquisition are boosted.

Simulations have reduced the number and the need of building and testing prototypes. Hardware and software development have reduced the simulation time to within hours. With the increasing trend towards artificial intelligence (AI), software of tomorrow will reduce the need of “time intensive simulations”. These software, based on their database, intelligence and algorithm, can give accurate initial results within seconds. It is theoretically possible to couple FCM with such innovative software for example, analytical crash simulation or manufacturing simulation giving the virtual product development a completely new dimension.