Collaboration for Future HPC-based Simulation Technologies

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1 Motivation

The use of Numerical Simulation and High Performance Computing (HPC) in vehicle development has already been established for years. Nowadays it is the third pillar of vehicle development along with construction and testing. Computer Aided Engineering (CAE) methods in combination with HPC technologies enable engineers to solve complex problems in a quick and cost-effective way long before hardware prototypes are available. Furthermore it opens up the possibility to analyze not just a single concept idea, but many concept variations parallel. But there are some future challenges in the field of virtual vehicle development. Automotive Original Equipment Manufacturer (OEMs) and suppliers are faced with the need to bring the enormous complexity of interacting system components with the increasing demands on safe, green and smart vehicles with high quality standards in line (Fig.1). In order to minimize the integration costs and reduce time-to-market it is important not only to provide new simulation environments, but also to keep them flexible. New strategies are needed to handle large amounts of data, to facilitate the best possible interplay of soft- and hardware and to optimize the exchange of simulation data along the supply chain. The expectations on numerical simulation software and work flow tools are permanently increasing and therefore the innovation pressure is very high. Just as vehicles must be continuously developed and optimized, a constant adjustment and refinement of CAE methods are necessary to ensure the increasing demand on forecast quality. To stay competitive development tasks should be solved by exploiting the full potential of HPC-simulation technologies. Therefore the development and implementation of new numerical methods are just as important as the change of soft skills of CAE users from a single-domain to a multi-domain simulation expert. The Automotive Simulation Center Stuttgart e.V. – asc(s is exactly facing these trends. As a non-profit association the asc(s is working actively on research and development of new CAE methods through bundling the best competences from science and industry in its strong network.

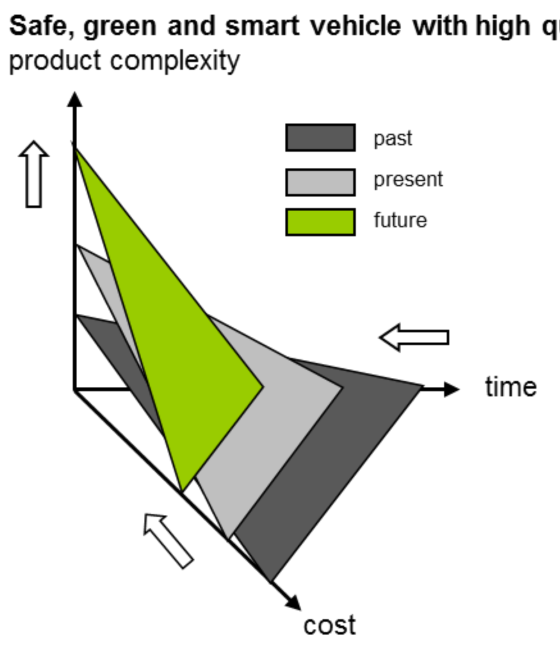

Fig.1: "Magic Triangle" of product development

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2 Future HPC-based Simulation Technologies

2.1 Current and future challenges for automobile industry

The automobile industry has to face far-reaching changes in population growth, urbanization, climate change and advancing environmental and social awareness. Increasing legal regulations, customer requirements and the competitive situation oblige automotive manufacturers to use new CAE & HPC technologies.

- satisfy legal requirements
    - emission levels (air pollution, acoustics)
    - safety
    - recycling
    - life-cycle-analysis

- satisfy customer requirements
    - launch of vehicles at even shorter time
    - launce of different vehicle derivative
    - efficiency
    - performance
    - handling & comfort
    - user-friendliness
    - safety ratings
    - security
    - high quality
    - lifestyle & individualization
    - changing social values and expectations (generation X -> Y -> Z)

- stay competitive
    - globalization
    - world market oriented development
    - affordability

2.2 Top-down and CAE frontloading approach

The exponential growth of product complexity results in new development and production tasks and the indispensable necessity of fundamental new strategies. Today, more than ever before, it is of central importance to push innovative technologies starting with efficient tools for virtual product development by using a top-down approach (Fig.2).

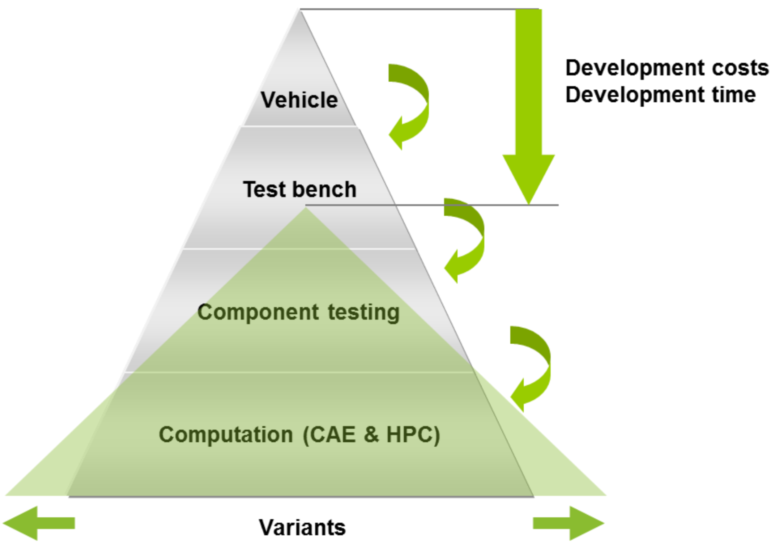

Fig.2: Increased Efficiency through top-down approach

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In addition to the top-down approach a second strategy is focused in virtual product development: frontloading of CAE methods means the enhanced use of simulation and HPC technologies at a very early stage of product development (Fig.3). Many design variants with significant modifications could be considered by a high degree of freedom and low costs for changes. Due to the fact, that this phase is characterized by less information about the complex system interaction and system behavior, calculations of parametric models could be run with low forecast quality and short responsive times. The obtained results support management decisions already in the early phases of a project by avoiding cost-intensive hardware prototypes. Future approaches could include data analytics of simulation data from former developments to improve efficiency at the concept phase. The following phases are characterized by large, high-fidelity and calculation time intensive models with small modifications that yield accurate and detailed insight into the performance of a proposed design.

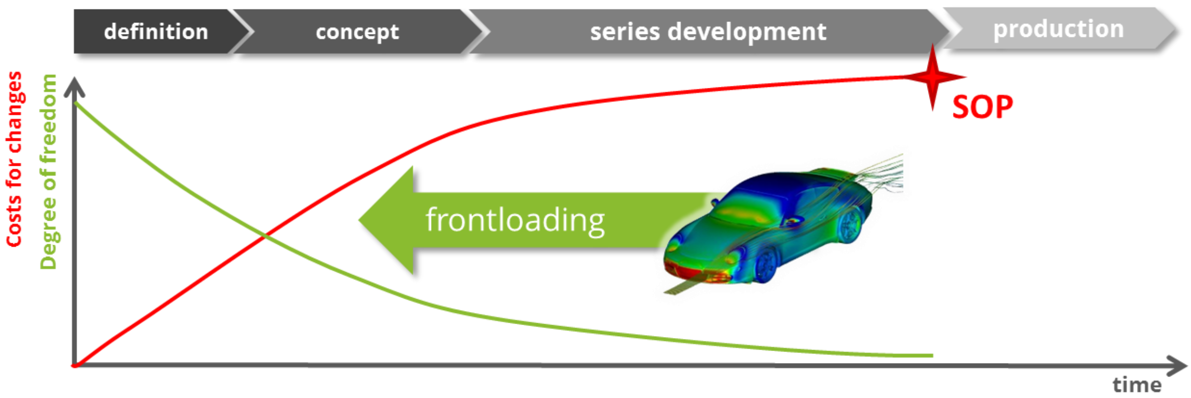

Fig.3: Frontloading: enhanced use of CAE & HPC technologies at early development phases

2.3 Challenges for Future HPC-based Simulation Technologies

High Performance Computing is key infrastructure for innovation in Europe. It accelerates the innovation process by running large numbers of numerical simulation as well as huge simulations to identify local and cross-functional problems and conflicts in short time. To overcome the immediate challenges in automobile industry, HPC is a key pillar for innovation and competitiveness. Future hard- and software architectures should consider the increasing complexity of virtual product development. Software has to be adapted to new hardware platforms (e.g. exascale). Hardware-related adjustments could increase the performance but also means the loss of independency. To exploit more processing elements two central strategies could be considered: Scale-up and Speed-up. Scale-up means to solve a problem with increased problem size in the same execution walltime. In case of Speed-up the same problem is solved faster. Getting a proper Speed-up is more challenging because subdividing a problem into very small parts leads to a bad communication-computation ratio [1]. Therefore challenges for Future HPC-based simulation technologies could be defined as followed:

- software development for rapidly changing parallel hardware
  - new programming languages
  - heterogeneity and multi-level programming techniques
- highly scalable methods for modelling and simulation
  - for many problems new algorithms will be needed
  - mixed-precision will become more important
- handle large amount of data
  - data analytics
  - reduce and transfer data
- job handling
- handle access and workflow for remote compute facilities (remote visualization, cloud computing, licensing)
- resilience and how to handle failure
- low-energy computing from application perspective

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3 Collaboration Platform for Future HPC-based Simulation Technologies

DYNAmore is a founding member of the Automotive Simulation Center Stuttgart e.V. – asc(s. This non-profit association was established in 2008 with tailwind of the German automotive industry as part of the federal HPC-strategy of Baden-Württemberg. It is funded through annual membership fees and third-party contributions. Today more than 20 international members from science and industry are working together to ensure the rapid availability of ISV codes for the next generation of HPC-architecture (Fig.4). The asc(s boosts the innovative power of automotive industry by bringing automotive manufacturer, suppliers, soft- and hardware vendors, engineering service providers and science together in the pre-competitive research stage for simulation technologies which require high performance computing systems. The business model of the asc(s is based on the four columns cooperation, competence network, joint project definition and cost-efficient project realisation. Within the asc(s directly competing companies work together hand in hand acquiring new impulses for the development of their products.

Cooperation - Science and industry cooperate by:
- permanent partnerships and cooperation for joint industrial research
- cooperation at the pre-competitive stage
- fast, commercial availability of high-quality research results

Competence - Use of the competence network by:
- combining simulation expertise from member companies
- avoiding overheads through highest expertise
- solving specific project tasks with the help of national and international experts

Projects - Goal-oriented project handling
- by direct relation to industry
- due to project prioritisation by members
- by taking over the complete project management

Costs - Cost-optimised project implementation by:
- provision of HPC resources for supported projects by the Federal High-Performance Computing Center - HLRS
- provision of CAE licences for joint projects, generally free-of-charge
- application for external funds

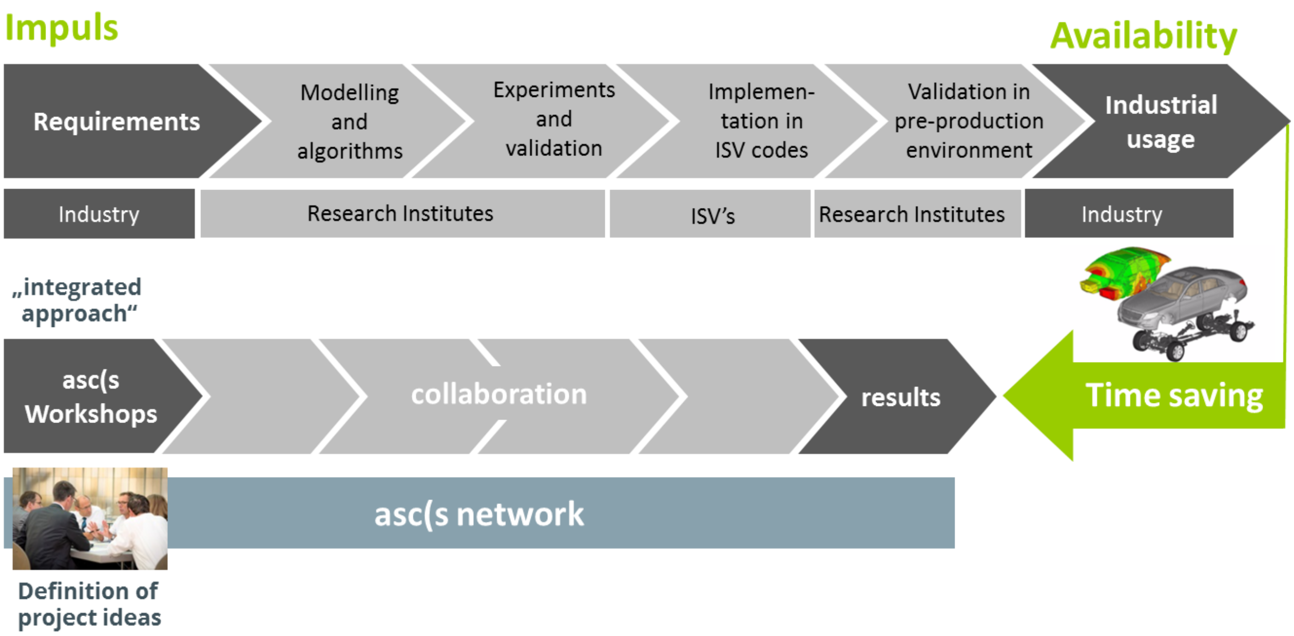

Fig.4: Shortening time to solution through collaboration within the asc(s network

The activities at the asc(s are divided into five clusters:

Cluster Vehicle Drive
Scope: Development and optimization of conventional and alternative drive technologies to increase energy efficiency and driving dynamics.

Cluster Vehicle Structure
Scope: Reducing weight and cost through efficient lightweight constructions with the highest level on quality, safety and resource efficiency.

Vehicle Physics
Scope: Representation of physical effects and correlations to increase functionality, reliability and comfort.

Vehicle ICT
Scope: Methods for virtual design and safeguarding of virtual driving: vehicle networking, driver assistance systems, HMI and traffic flow optimization.

Numerics & digitalization
Scope: Optimization of CAE solver technologies and development of new HPC and IT environments for cloud computing, Smart Data, Industry 4.0 and Internet of Things.

Cluster Workshops are an integral part of the asc(s culture. New solutions for future challenges are discussed, potentials are explored and collaborations are decided.

4 Project Example

4.1 BMBF Joint Project Crash-Topo

The asc(s Project Crash-Topo (end 2013) was focused on the development of an industrially operational procedure for topology optimization of the cross sections of extruded profiles, taking into account crash load cases. The project was founded by the Federal Ministry of Education and Research Germany (funding scheme SME innovative). The project team consisted of the SMEs DYNAmore GmbH and SFE GmbH and the research institutions Hamburg University of Applied Sciences and asc(s (coordinator). Further support came from the cooperation partners VW-Osnabrück GmbH, Prof. Fabian Duddeck (Technical University of Munich) and the associated partners Adam Opel AG, Daimler AG, Dr. Ing. h.c. F. Porsche AG, Constellium Singen GmbH and Benteler Aluminium Systems Norway AS.

To solve the above-mentioned issue a three-step method for topology and shape optimization was established (Fig.6). The modular design of the work flow allows to use of different software tools separated from each other and to couple them via corresponding interfaces with other software applications. To this end, appropriate interfaces have been created. This ensures a diverse and widely use in industrial applications. In addition, thanks to the collaboration with the High Performance Computing Center Stuttgart (HLRS) the necessary adjustments for the operation on HPC cluster systems were done.

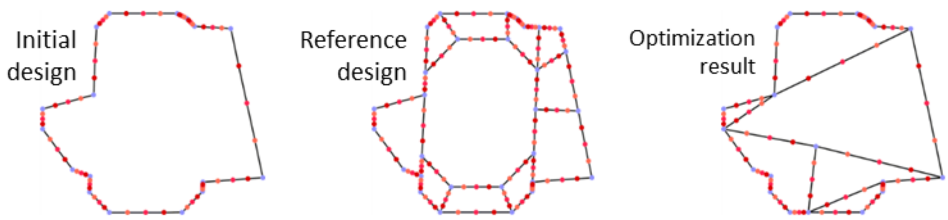

Fig.5: Graph-based representation of cross-sections of extruded profiles

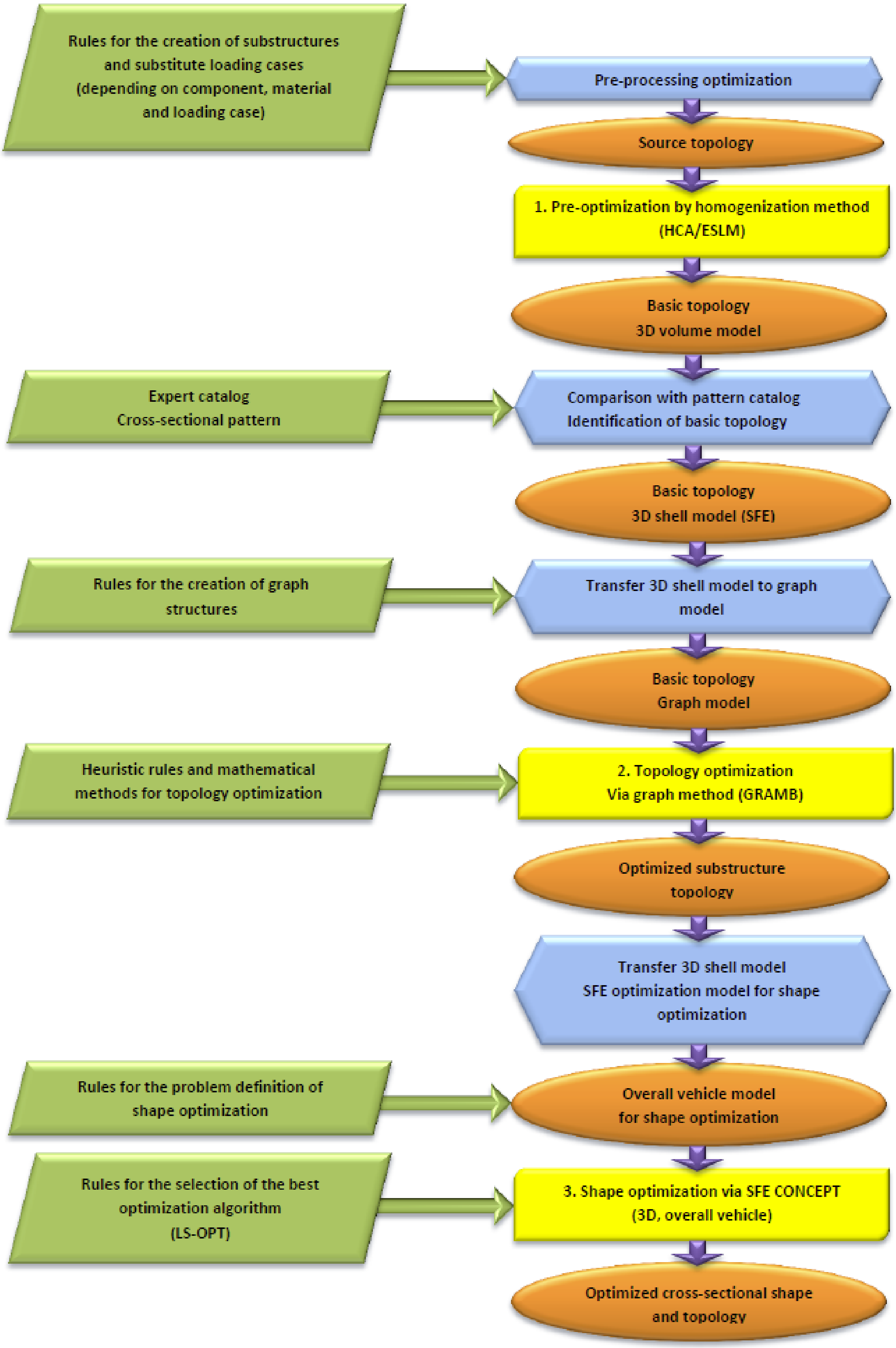

Fig.6: Crash-Topo flow diagram of three-stage topology and shape optimization

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As a starting point work has been undertaken in the area of pre-processing by asc(s and SFE. To reduce the computing time, the use of FE-substructures has been studied. It could be shown that the use of substructures in structural optimization is a useful method, in order to save computing time. For the first optimization stage two alternative methods (HCA – Hybrid Cellular Automata and ESL Equivalent Static Load Method) were examined by DYNAmore. It could be shown that both methods are suitable for topology optimization with non-linear loads. For the proposed project application to crash-stressed vehicle structures with the aim of optimizing the maximum energy absorption, the ESL method is preferable.
The results of ESLM could be used as initial design for the second optimization step: the graph- and heuristic-based shape- and topology optimization (developed by Prof. Axel Schumacher and Christopher Ortmann, HAW Hamburg). The profile cross-section of the structure could be described by a mathematical graph (Fig.5). Many geometric and mathematical problems can thus be solved with algorithms based on graph theory. This includes the consideration of manufacturing constraints. The implemented manufacturing constraints are currently based on manufacturing processes of extruded aluminum profiles. This includes the minimum and maximum wall thicknesses and minimum distances and minimum connecting angle between walls and a maximum number of interconnected walls at junctions. The principle of the graph- and heuristic-based shape and topology optimization is the separation of the optimization problem in two nested loops. In the outer optimization loop the topology of the structure is to be optimized by using expertise derived from heuristics. This use simulation data and information on the mechanical properties of the structure in order to make changes to the structure. The heuristics can be partially combined, but mostly they compete with each other. The control of each other competing heuristics is carried out by a strategy based on priority values. The priority values quantify the urgency of the topology change, which would carry out the respective heuristic. After each iteration of the outer optimization loop a pass is made in the inner optimization loop. Here, the optimization problem is reduced on a conventional shape and dimensioning problem. [2].For validation of this method a full car body model (LS-DYNA) with approximately 739.000 finite elements was used (Fig.7). The graph- and heuristic-based shape and topology optimization procedure has been performed on Cray XE6 Hermit at HLRS. Each function call of the topology optimization performed on 128 cores. A complete simulation (side pole crash) takes about 80 minutes. 3.220 function calls were performed. The superordinated optimization job takes longer than 24 hours.

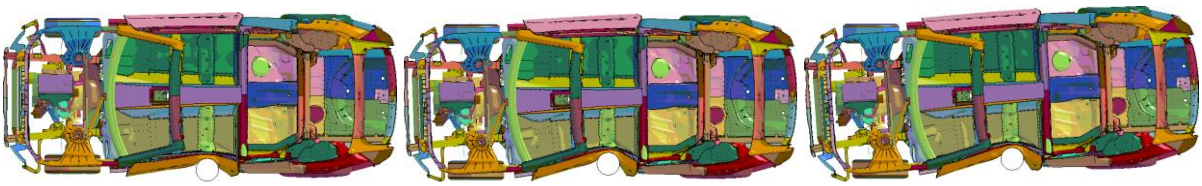

Fig.7: Structural behavior side polo impact (left t = 30 ms, center t = 60 ms, right t = 90 ms)

The optimization result of step 2 provides package space, design limitations and design variables. These variables can be transferred automatically into the SFE CONCEPT model starting with the third optimization step: the parametric 3D shape optimization via SFE CONCEPT. In this step the profile is optimized in the context of the entire vehicle and the associated transition to 3D structures is considered. SFE CONCEPT models are fully parametric in topology and geometry. Many variations are possible by topology pattern overlay, stampings, holes and combination with all other components. SFE CONCEPT models can be automatically transferred to a LS-DYNA model to perform crash calculation during the optimization loops with LS-Opt.

5 Literature

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[2] Schumacher A, Ortmann C: “Topology optimization of crash structures - creativity versus computer-based algorithms”, 11. LS-DYNA Forum, Ulm, Germany, October 9-10, 2012

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