New Approaches for Shape & Topology Optimization for Crashworthiness

keynote lecture

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Outline

1. New Challenges
2. State-of-the-Art in Shape & Topology Optimization for Crashworthiness
3. New Approaches for Shape & Topology Optimization for Crashworthiness
4. Conclusions

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New Challenges: New Structural Concepts!

Aixam Mega
Mega E-City

BMW
E-mini

Bolloré/Pininfarina
Blue Car

BYD
E6

Daimler
Smart ed

General Motors
Volt

Heuliez
Will

Mitsubishi
i-Miev

Nissan
E-Cube

Reva
G-Wiz

Subaru
R1e

Tesla Motors
Roadster

Th!nk
City

Volkswagen
Twin Drive

???

Electric Cars

ETC/ACC Technical Paper 2009/4
F. Hacker, R. Harthan, F. Matthes, W. Zimmer

New Challenges: New Structural Concepts!

www.loremo.com

New Challenges: Electromobility

New Challenges: Electromobility

www.mute-automobile.de www.llb.mw.tum.de

New Challenges: New Materials (CFRP)

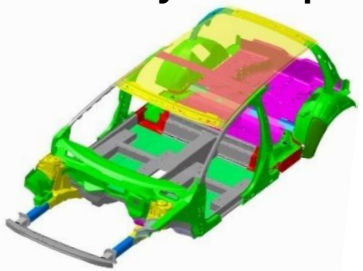
www.bmw-i.de

Lightweight Design (e.g. SuperLightCar EU Project)

SP1 Design Concepts

1) Steel intensive < 2,5 €/kg
2) Multi material, economic (ULBC) < 5 €/kg
3) Multi material, advanced (SLBC) < 10 €/kg

SLC Body Concept



SP2 Materials & Manufacturing Technologies

- Technology-Benchmarking
- Forming
- Joining
- Assembly

SP4 End of 2008
Complete Multi-Material Body structure Prototype Demonstration

SP3 Simulation & Testing

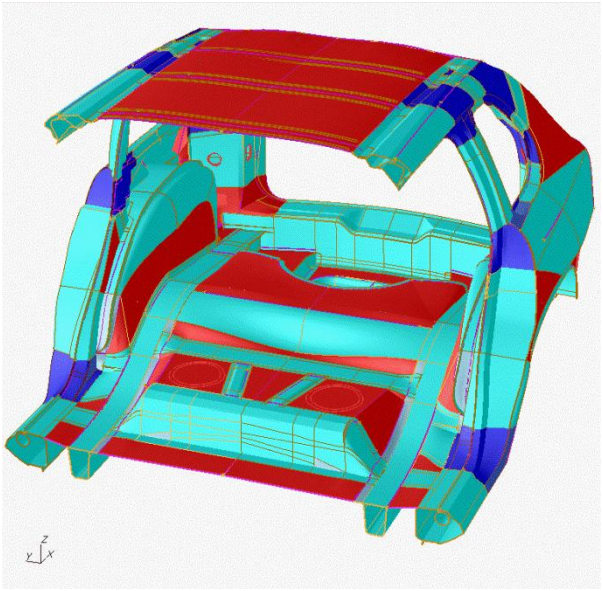
Life Cycle Analysis (LCA) ■ Cost assessment ■ Virtual and physical Testing

2005 | 2006 | 2007 | 2008 | 2009

M. Stehlin, Volkswagen 2008

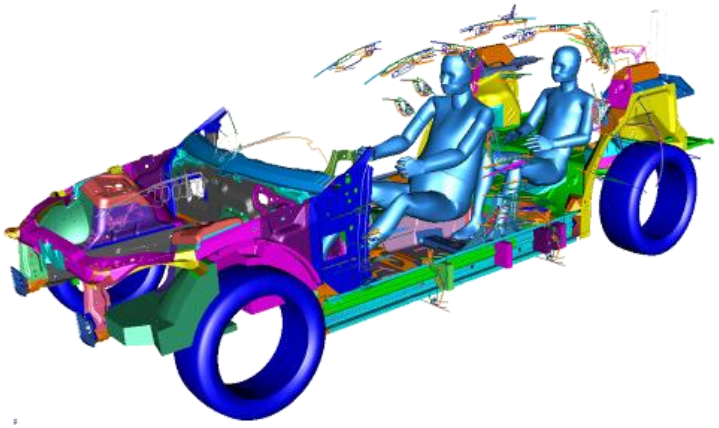
New Approach: Integral Lightweight Design

Established: Multi-material, forming, joining assembly, life-cycle, etc.



SFE GmbH & Porsche

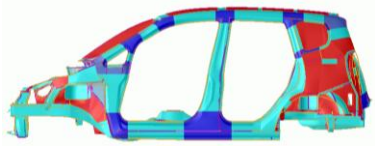
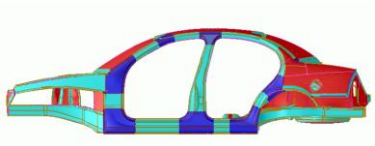
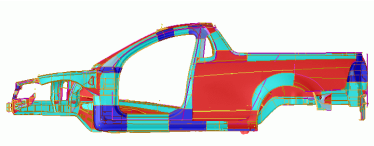
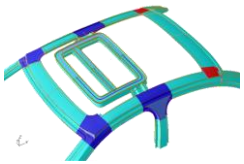
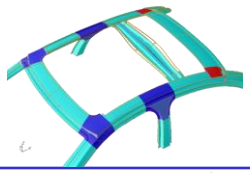
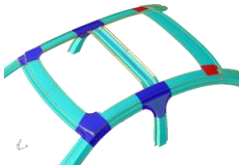
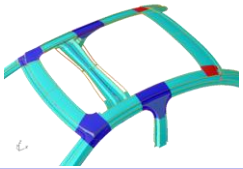
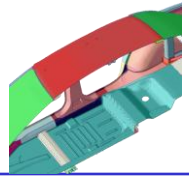
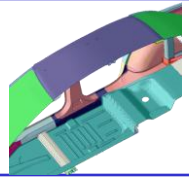
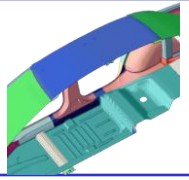
+ Optimal Structure (Size, Shape & Topology)



SFE GmbH

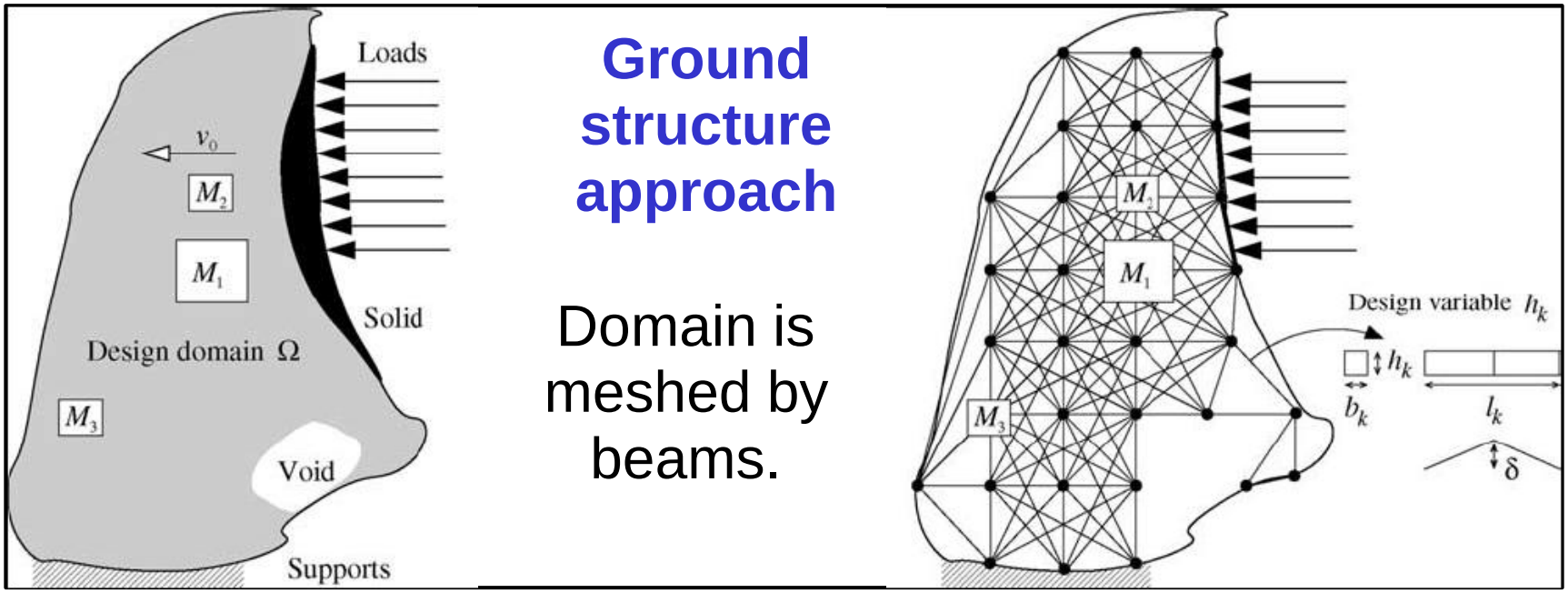
+ Optimal Package & Design (New Concepts)

Shape and Topology Optimization for Crash

Concept			
Material	Steel	Aluminium	Composites
Topology			
Shape			
Size (thickness)			

Zimmer, Hänschke

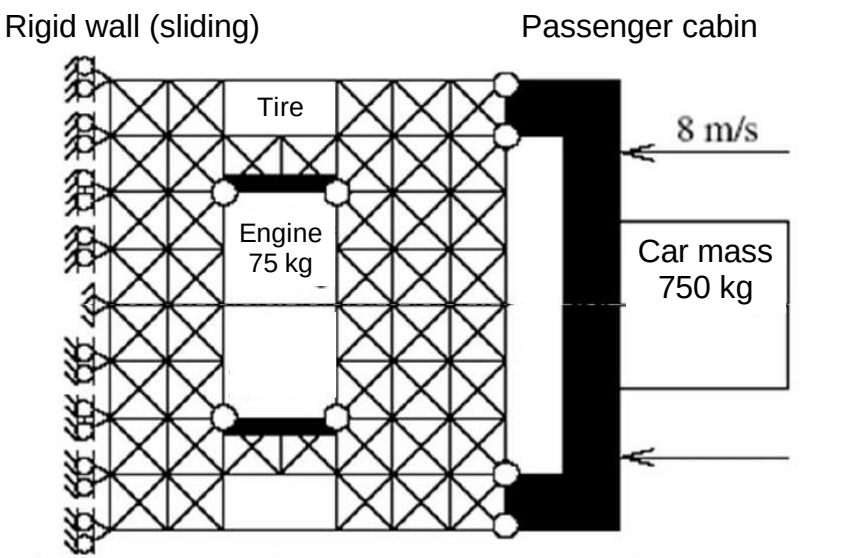
Topology Opt. for Crash (1): Ground Structure



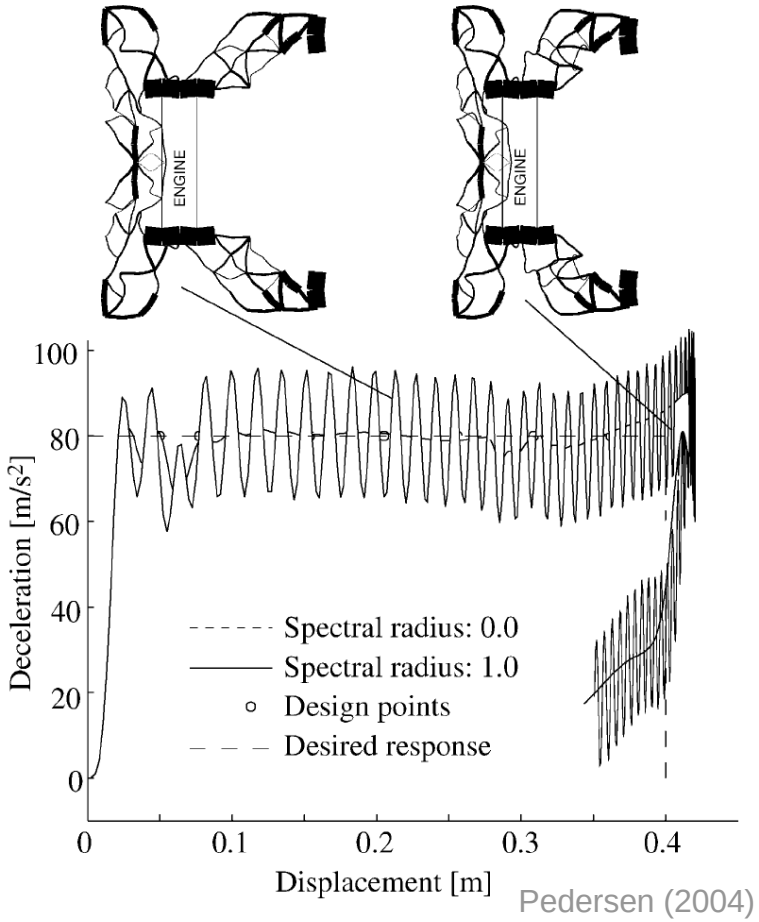
- Design variables: size of cross-section areas
- Objectives: acceleration, displacement, compliance

Pedersen (2004)

Topology Opt. for Crash (1): Ground Structure



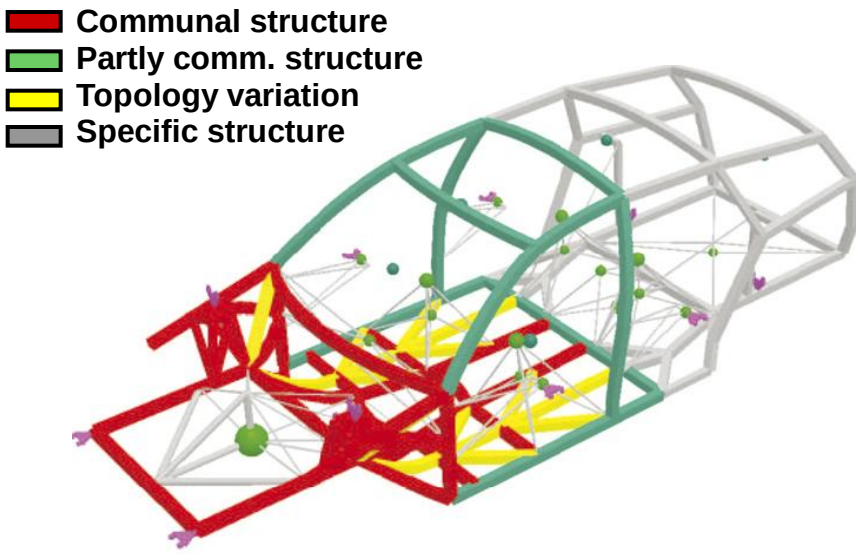
- Implicit FEM
- Analytic sensitivities
- No contact, no inertia
- Low generality in geometry



Pedersen (2004)

Topology Opt. for Crash (2): Equivalent Static Loads

- Nonlinear crash cases represented by **equivalent linear static load cases**
- Only beam elements and single masses
- For optimisation: size variables dimensions of the cross-sections (gauge, height, width, orientation)
- Shape variables: Connection points of the beams



Mass-beam model for size, shape and topology optimisation

Torstenfelt B and Klarbring A (2007): *Conceptual optimal design of modular car product families using simultaneous size, shape and topology optimization*. Finite Elem. in Analysis & Design 43, 1050 – 1061.

Shape Opt. for Crash (1): Morphing

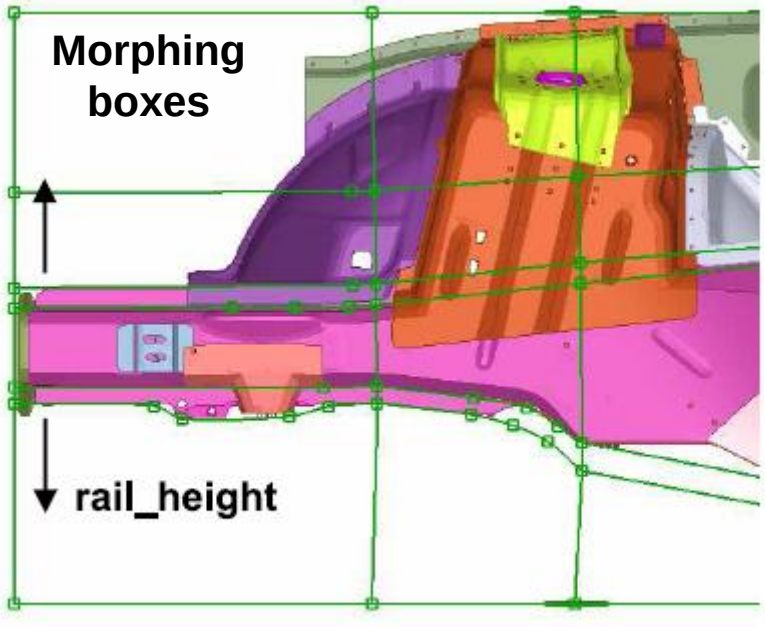


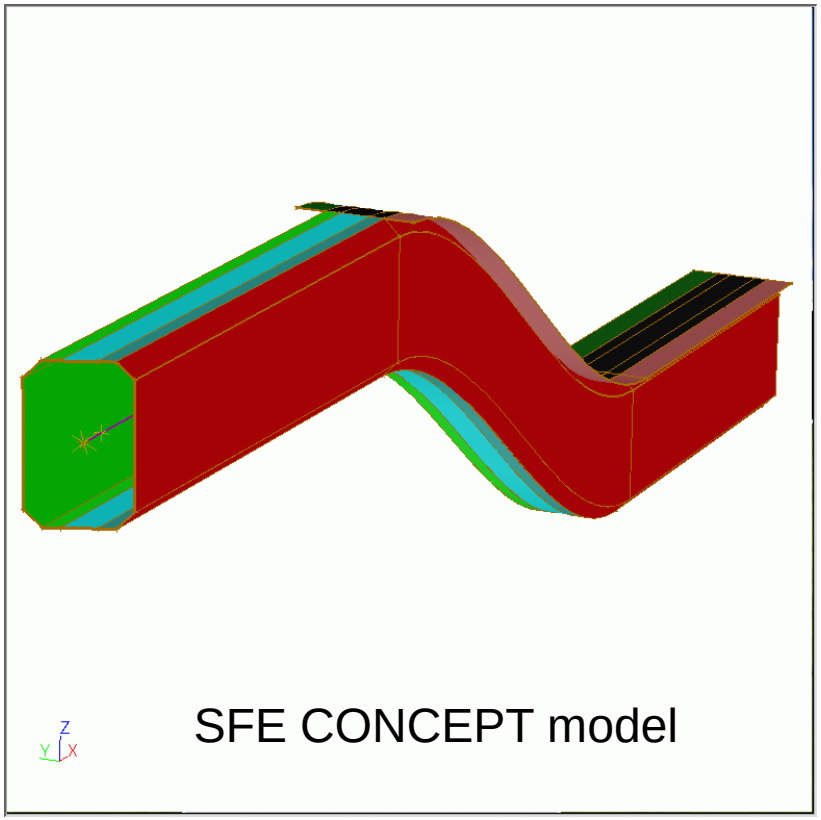
Figure 6: Rail initial shape

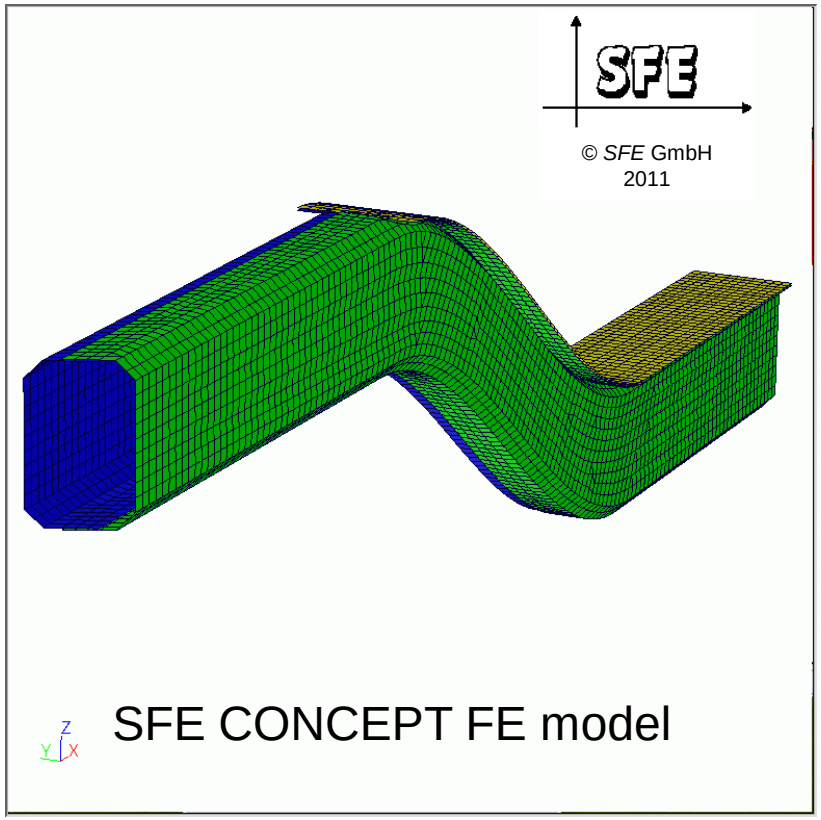
Figure 7: Rail modified shape

Georgios 2009

Morphing can only realise small geometrical modifications
⇨ More flexible shape optimization methods required

Shape Opt. for Crash (1): Beyond Morphing





H. Zimmer, M. Prabhuwaingankar, F. Duddeck (2009): *Topology & geometry based structure optimization using implicit parametric models and LSOPT*. 7th Europ. LS-DYNA Conf., Salzburg, Austria.

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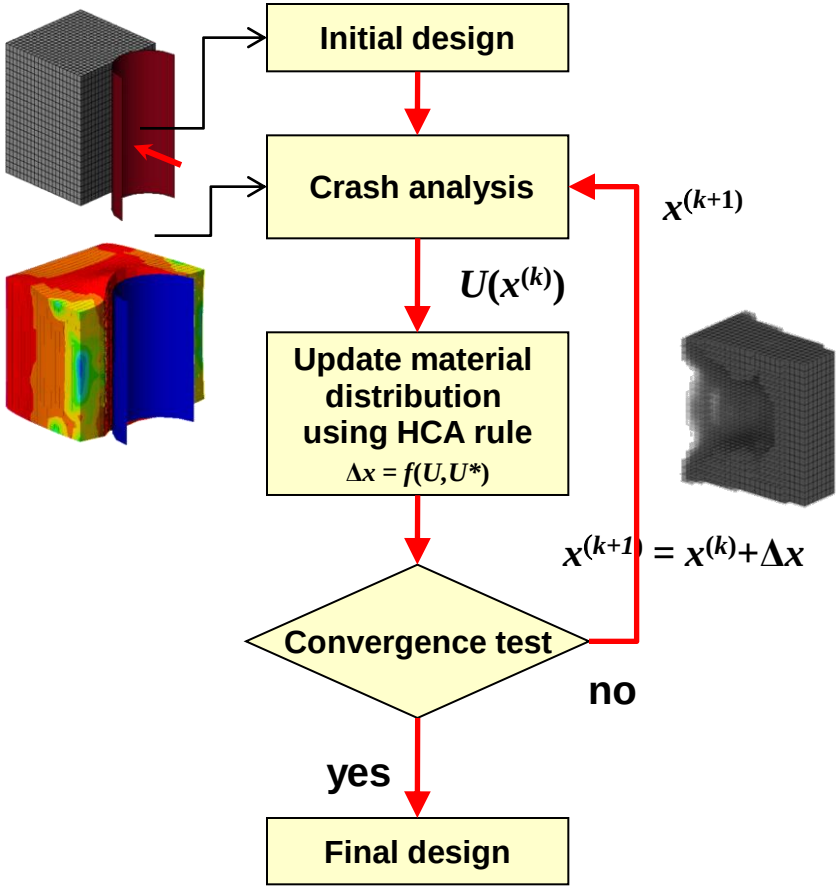
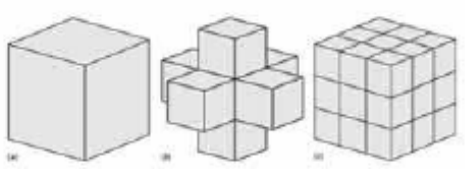
Topology Opt. for Crash (3): Hybrid Cellular Automata



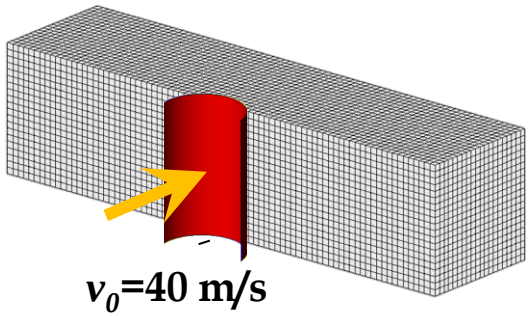
- considering of neighborhood elements in the CA lattice

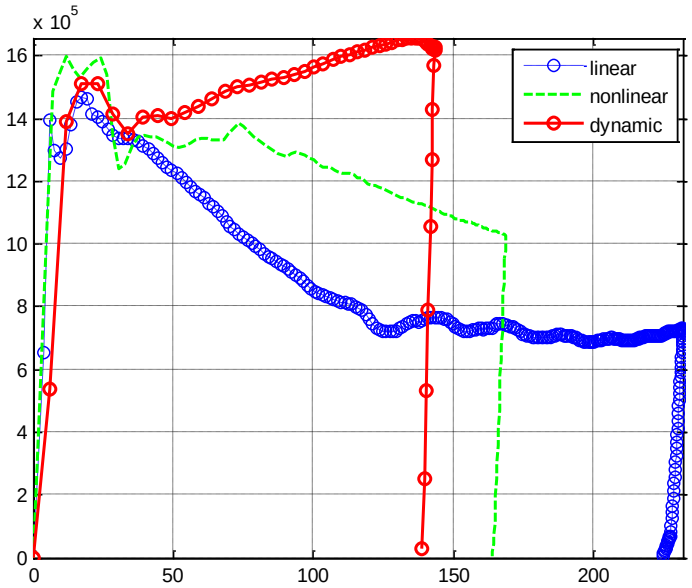


- connection of CA lattice and FE mesh
- density approach (relative density)
- rule based homogenization of energy density
- no sensitivity calculation necessary

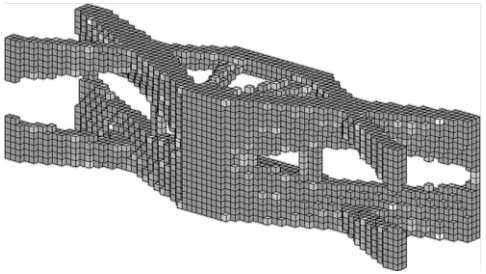
A Tovar & JE Renaud (2008): Altair HyperWorks Symposium

Topology Opt. for Crash (3): Hybrid Cellular Automata

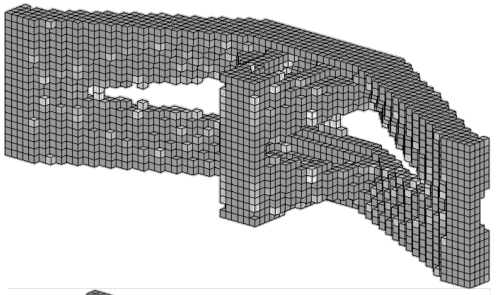




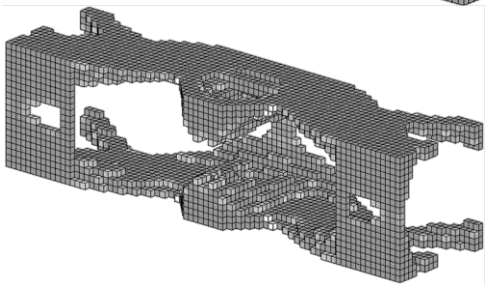
Linear-static



Nonlinear static

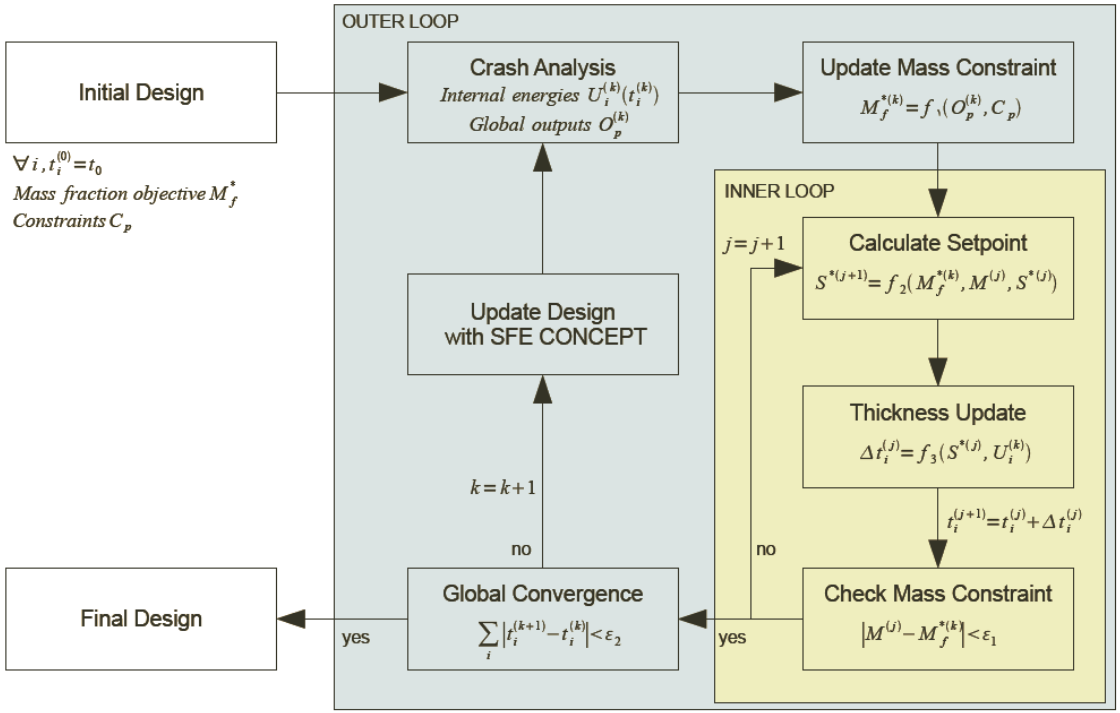


Nonlinear dynamic



A Tovar & JE Renaud (2008): Altair HyperWorks Symposium

Topology Opt. for Crash (3): Hybrid Cellular Automata

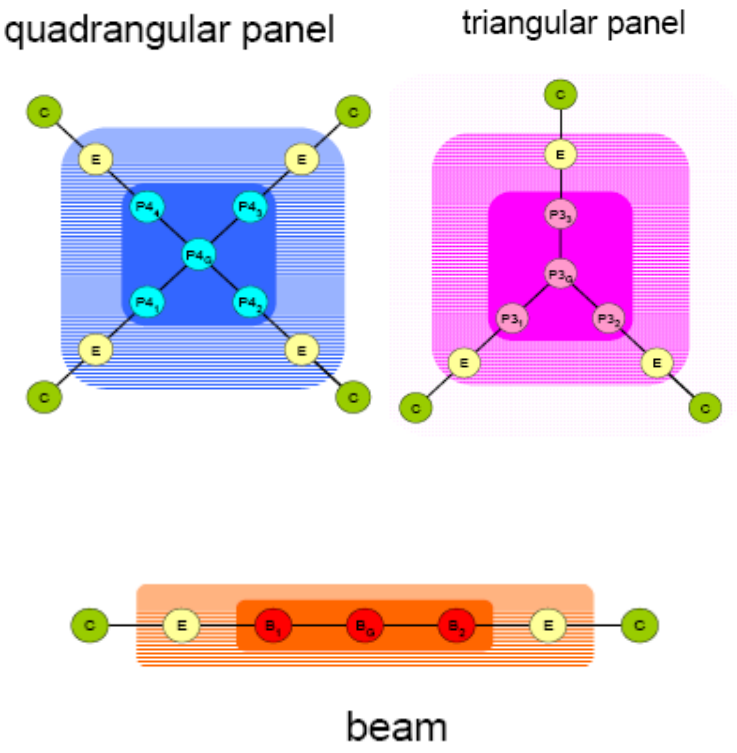


Algorithm overview

Hunkeler (PhD thesis), Duddeck (QMUL)

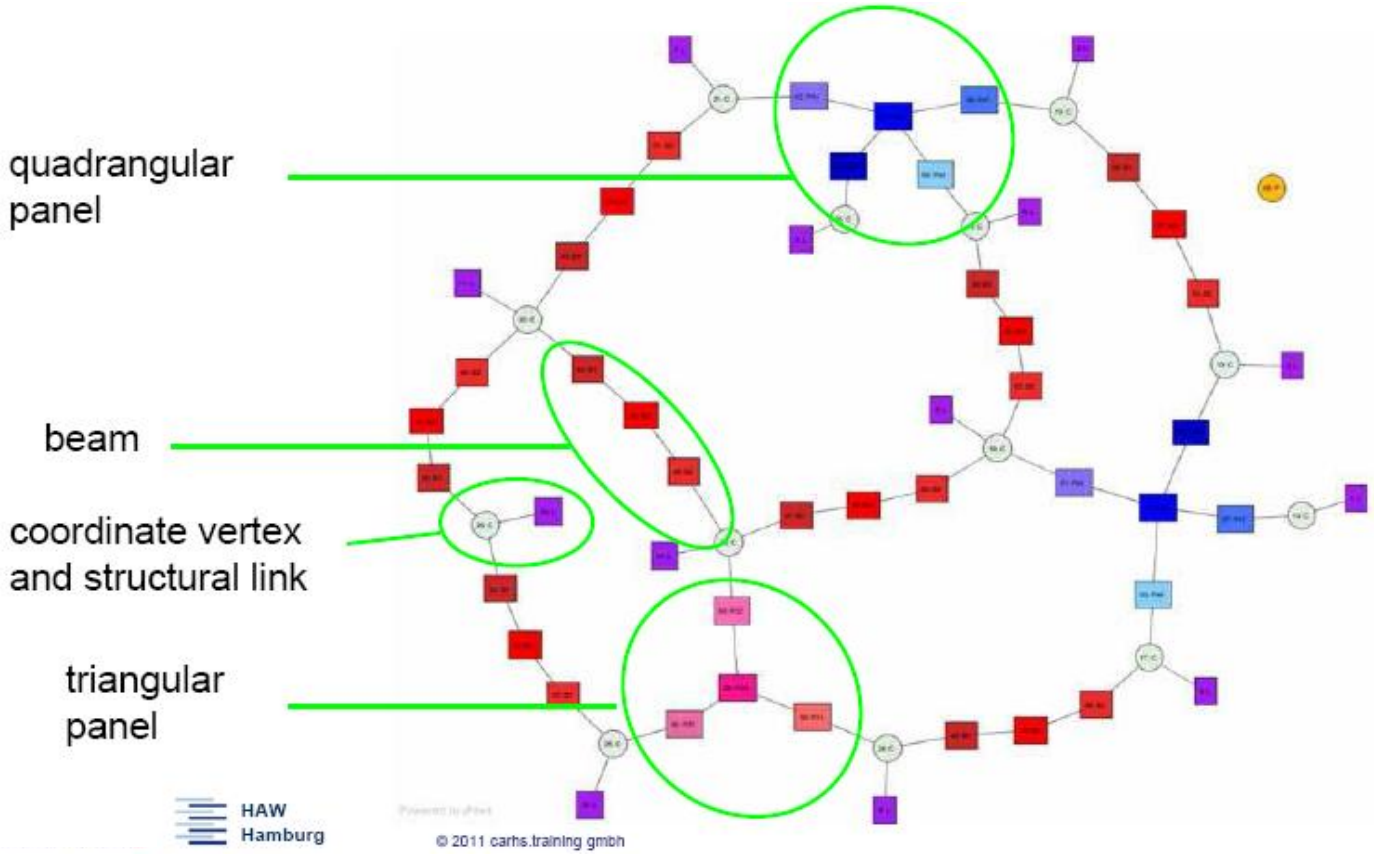
Topology Opt. for Crash (4): Graph-based Method

- Setup of different designs with „library parts“, e.g. beams, panels
- Each library part has a representation as an attributed mathematical (sub-)graph
- Library parts can be connected to make up structures
- Topological changes are applied as changes to the design graph
- Graph based topology optimization is understood as optimization of the design graph topology
- Shape optimization is applied in an inner loop in each topological iteration



A Schumacher & C Ortmann (2011): CARHS Automotive Grand Challenge

Topology Opt. for Crash (4): Graph-based Method



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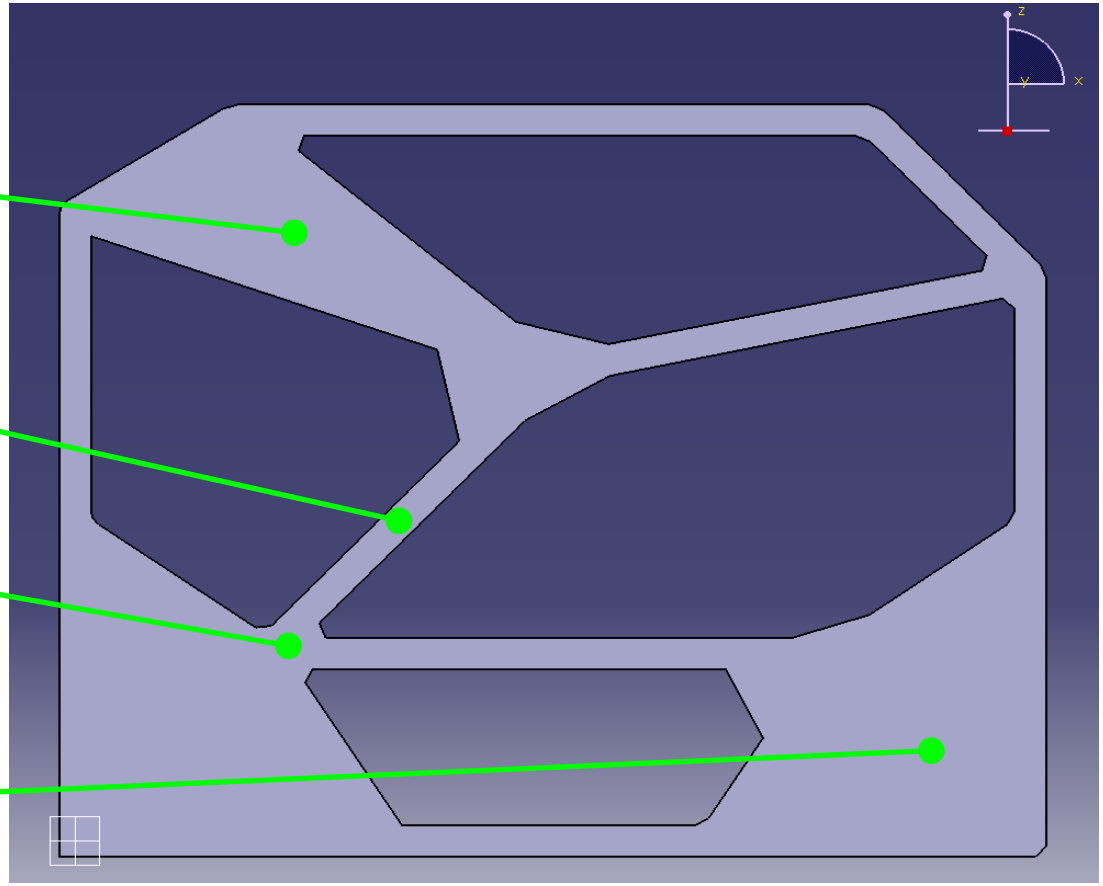
Topology Opt. for Crash (4): Graph-based Method

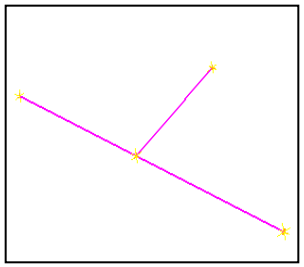
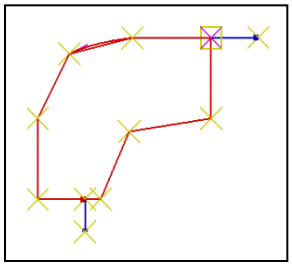
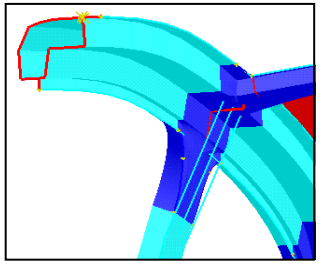
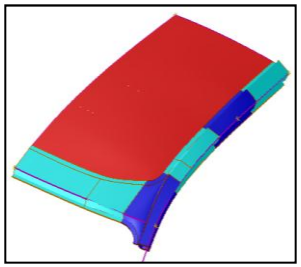
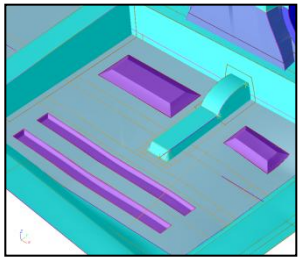
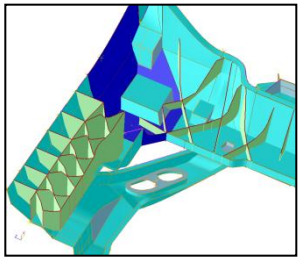
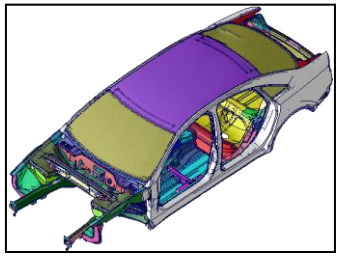
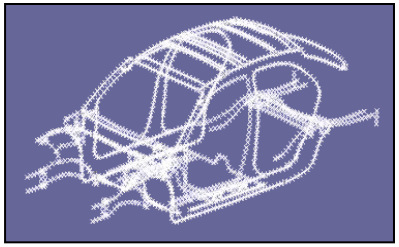


A Schumacher & C Ortmann (2011): CARHS Automotive Grand Challenge

SFE CONCEPT for Shape and Topology Optimization

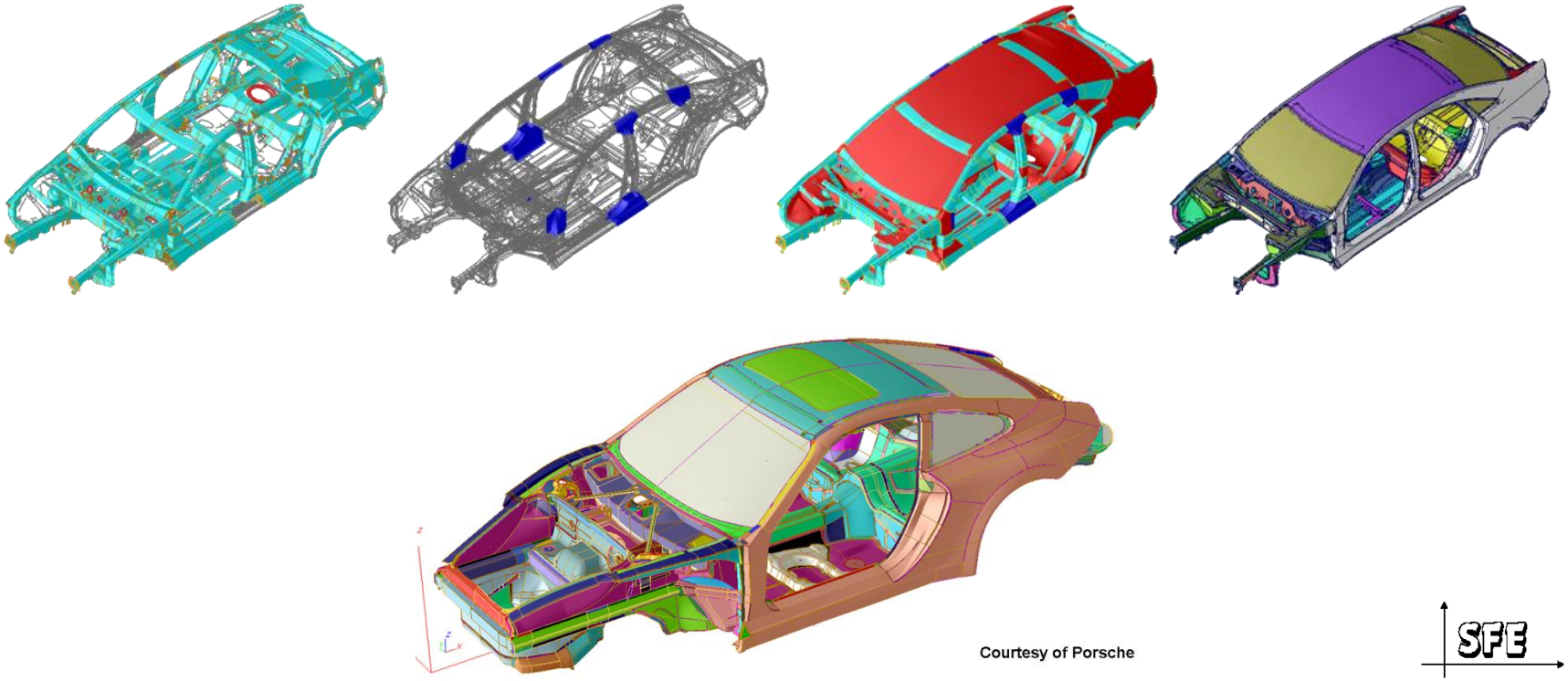
SFE CONCEPT
Parametric Model

- Points and Lines
- Cross Sections
- Joints & Beams
- Freeform Surfaces
- Beads, Stamps, Ribs
- FE Meshes
- Welds, Adhesives
- Loading, Etc.

SFE CONCEPT for Shape and Topology Optimization

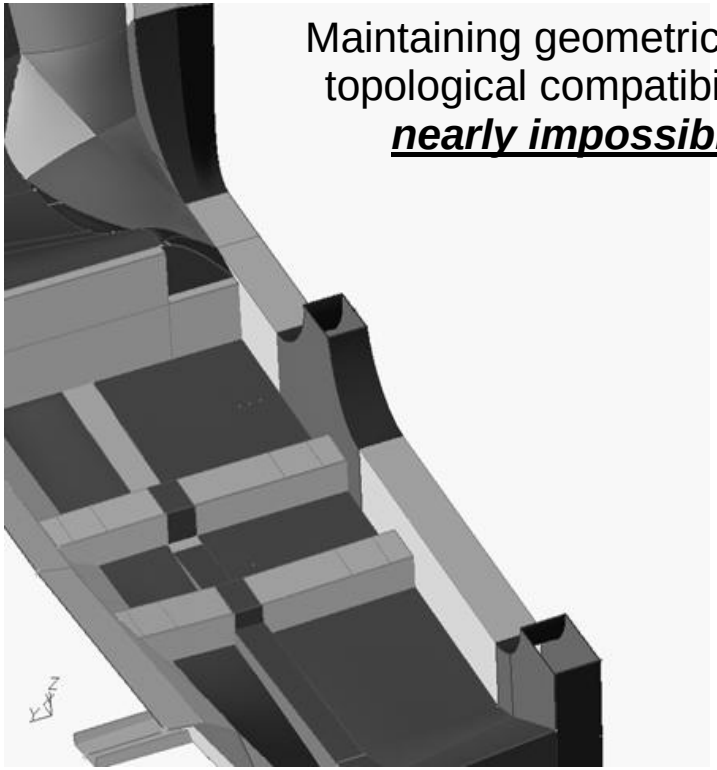
Points → Lines → Sections → Beams → Joints → Surfaces → Mesh



Courtesy of Porsche

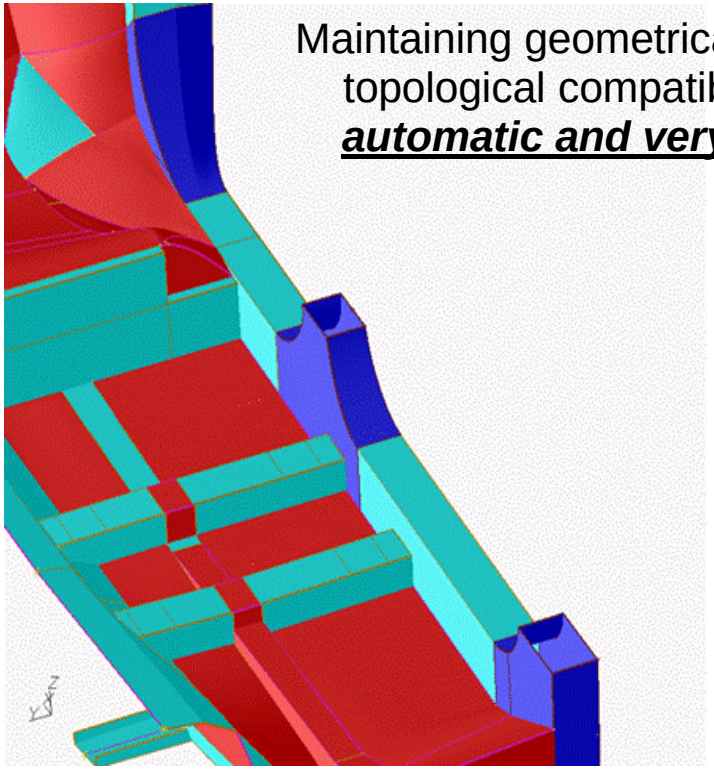
SFE

Parameterization for Optimization (Two Types)



Maintaining geometrical and topological compatibility is ***nearly impossible***

Explicit parameterization (CAD)

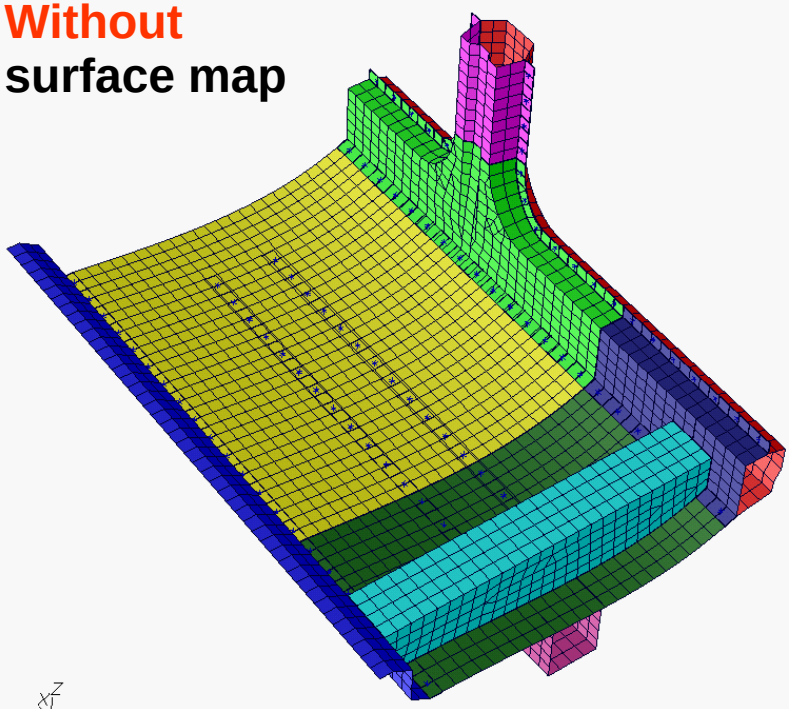


Maintaining geometrical and topological compatibility is ***automatic and very easy***

Implicit parameterization (SFE CONCEPT)

Parameterization for Optimization (Two Types)

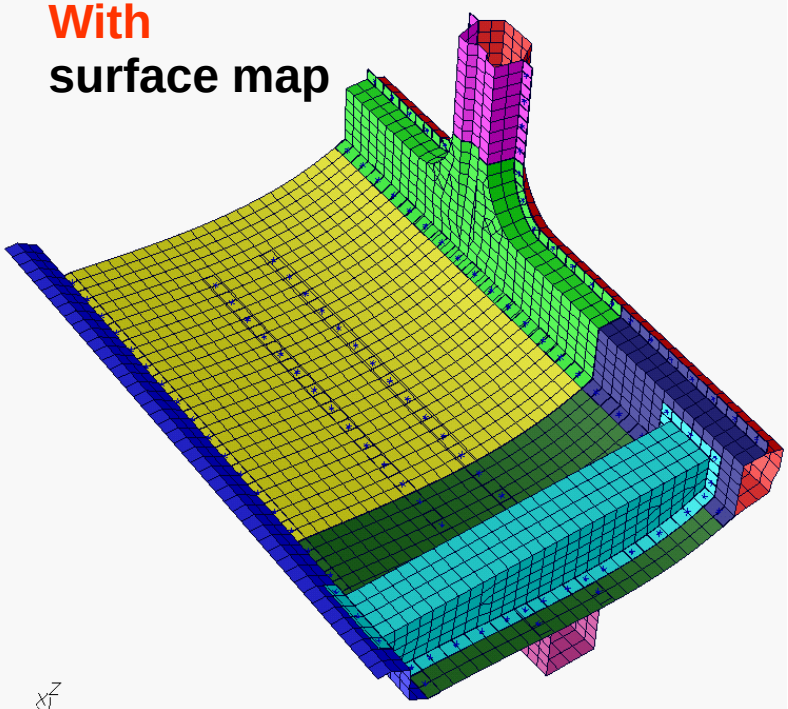
Without
surface map



Following information is lost:

- **Multi-flange assignment**
- **Joining assignment**

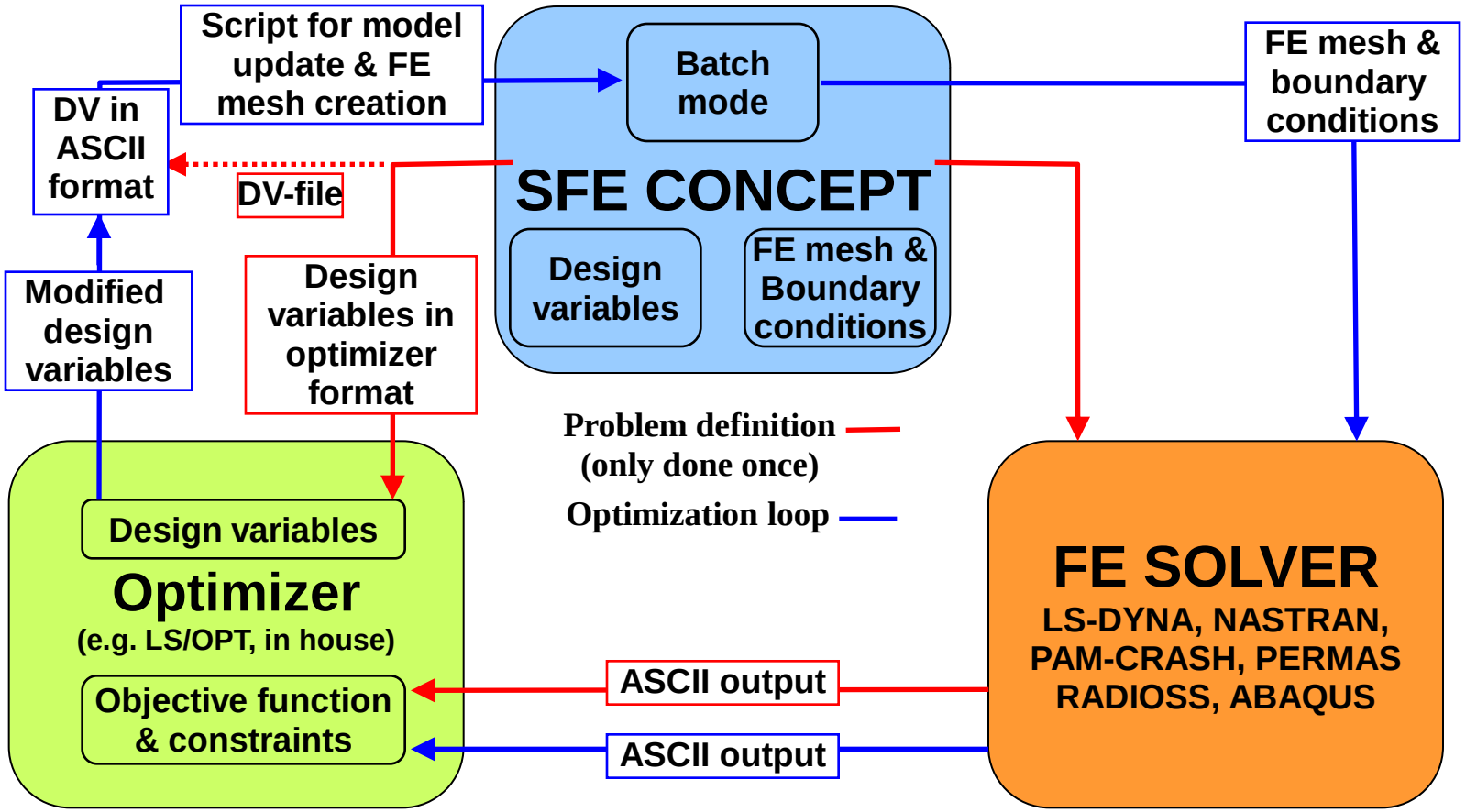
With
surface map



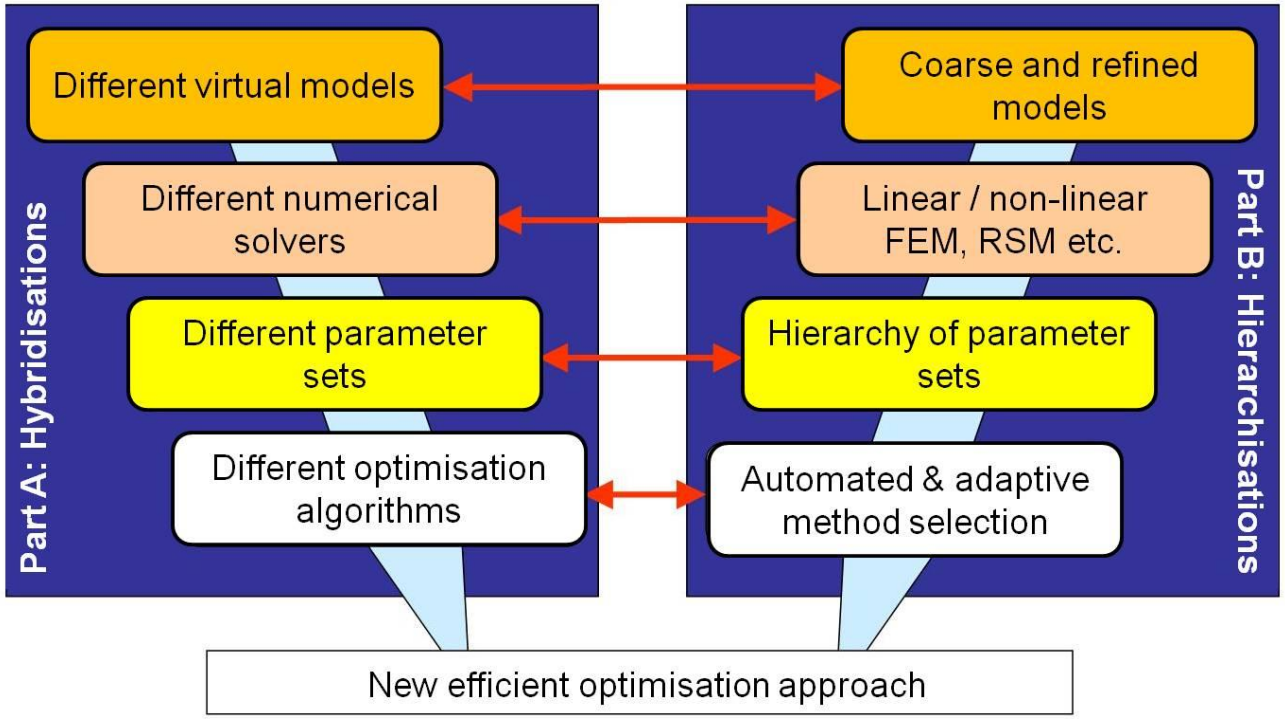
Automatically done:

- **Reparametrising the map-targets**
- **Identifying the flanges/joining**

Combined Shape and Topology Optimization

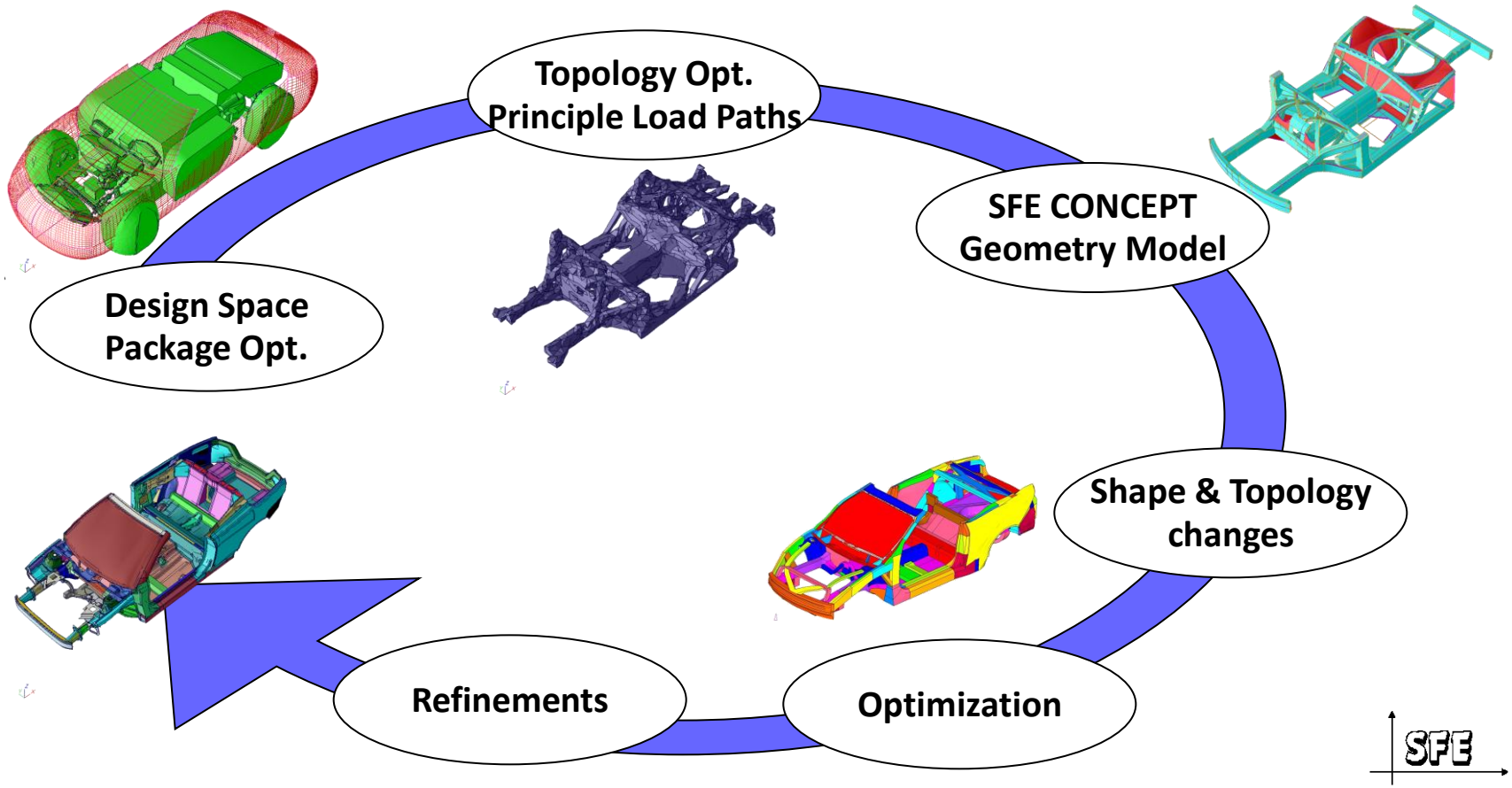


Algorithmic Aspects



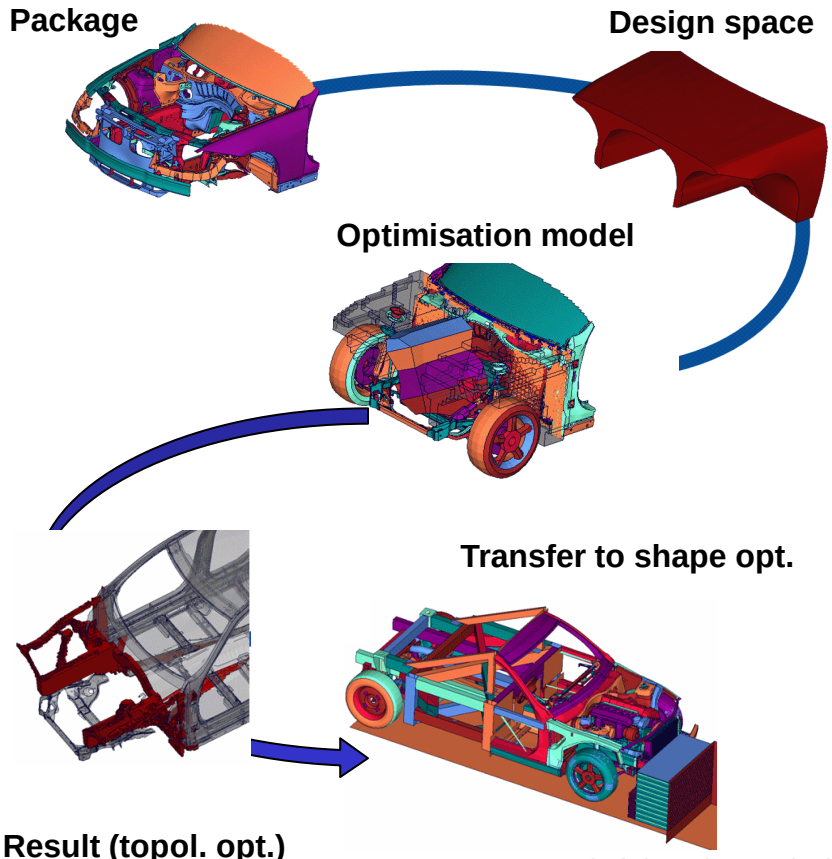
Hybrid and hierarchical methods for multi-level optimization

Combined Shape and Topology Optimization



Topology Optimization for Crash (ESLM)

- **Equivalent static load method (ESLM)** and standard topology optimization (linear FEM).
- Equivalent loads are defined for different time steps based on energy considerations.
- Result is embedded in an overall loop “topology – shape – size” optimization.
- Result corresponds well to reference designs
- New design alternatives can be identified



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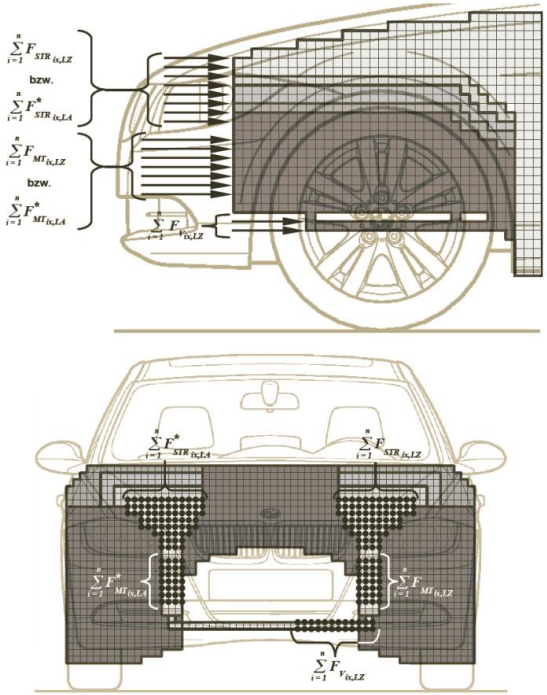
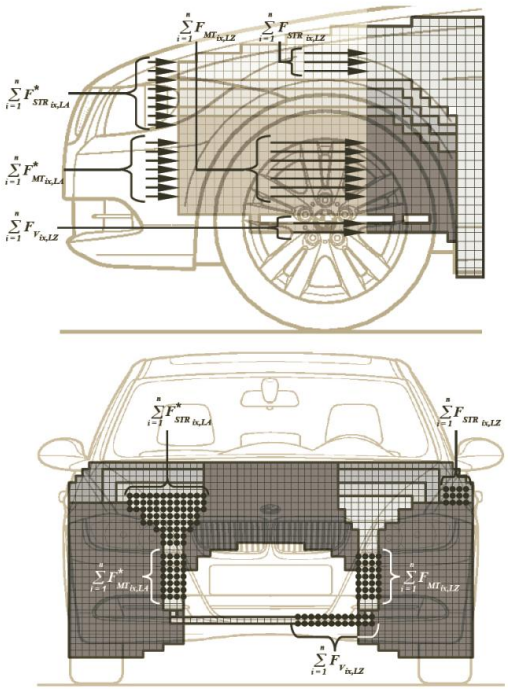
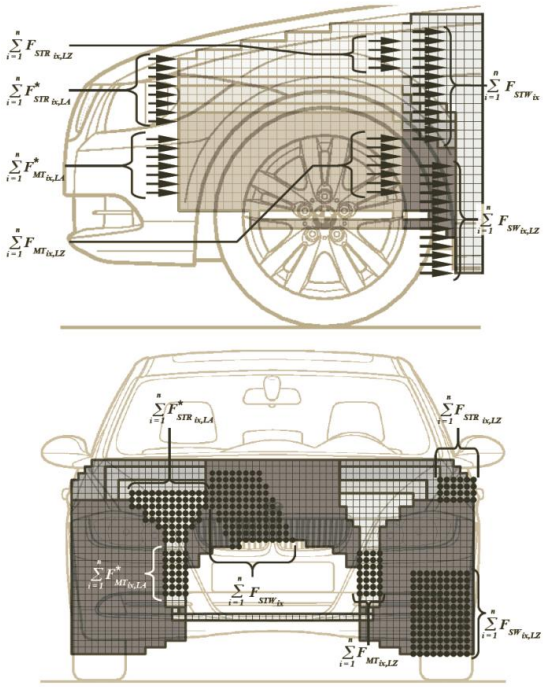
Topology Optimization for Crash (ESLM)



First load phase



Second load case



Third load case

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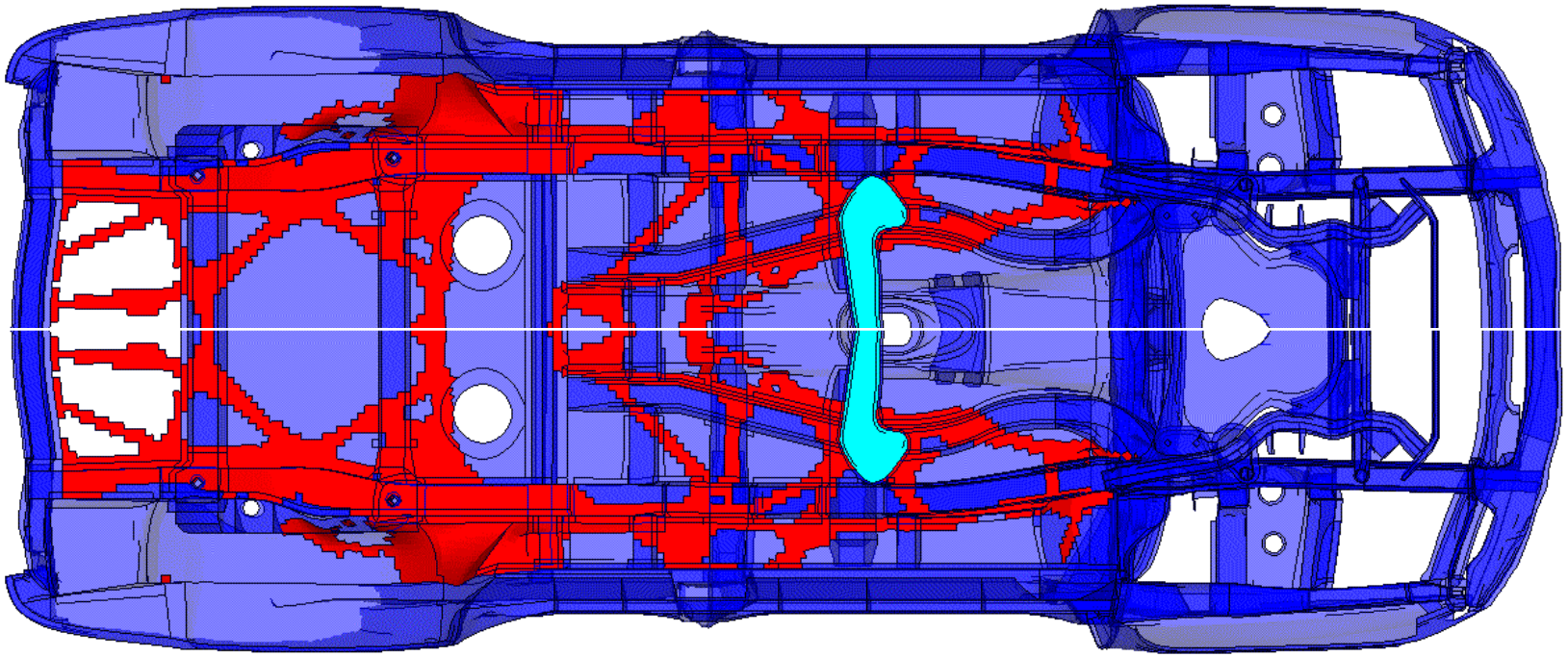
Topology Optimization for Crash (ESLM)



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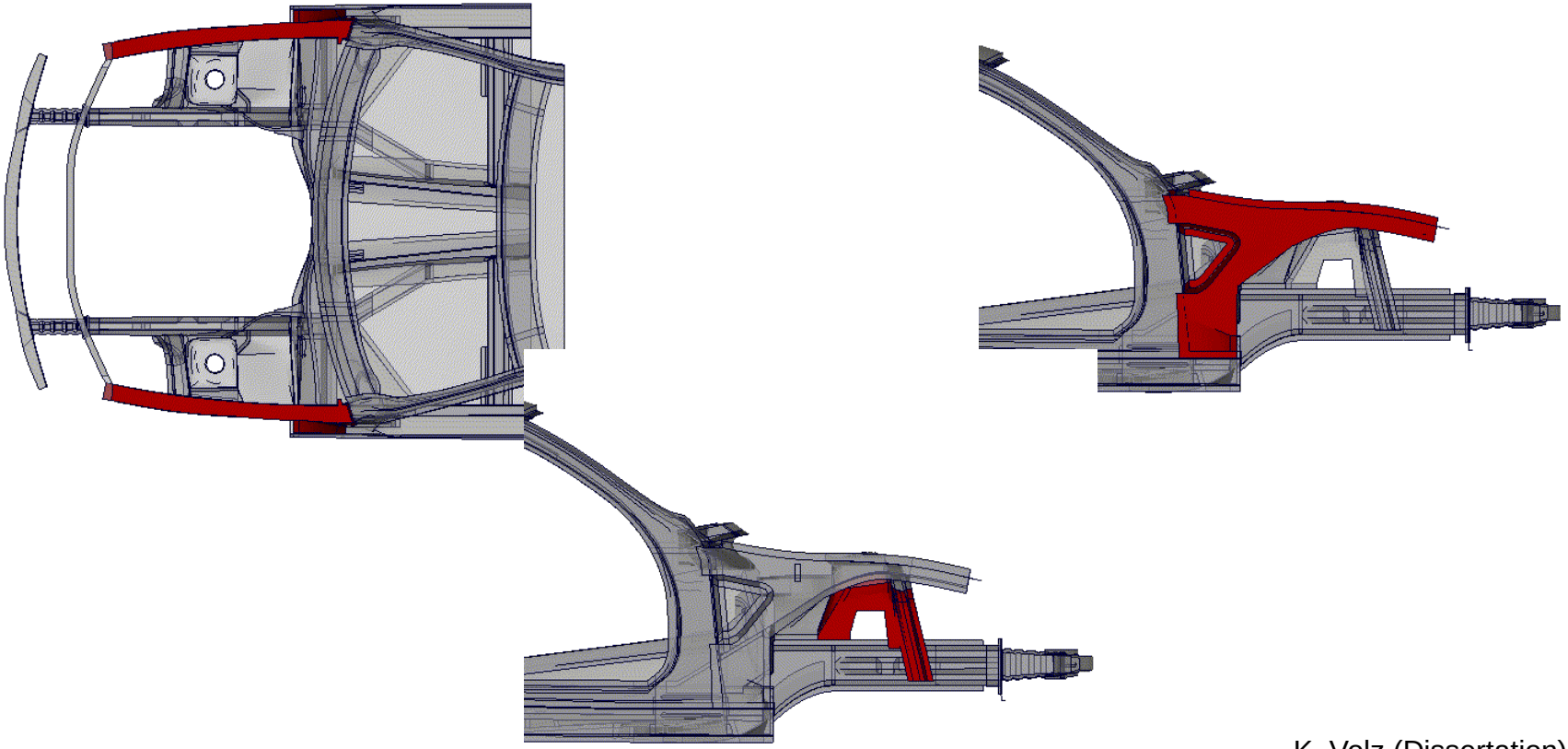
Combined Shape & Topology Opt. (SFE CONCEPT)



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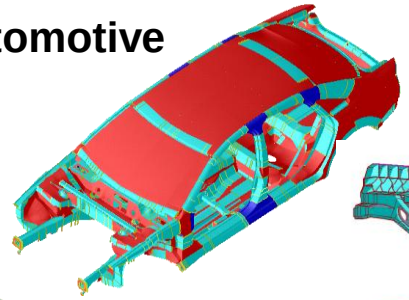
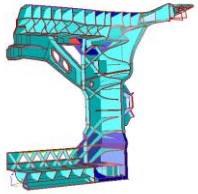
Conclusions

1. **New approaches for topology optimizaton (crash):**
   - Equivalent Static Load Method (ESLM)
   - Hybrid Cellular Automata (HCA)
   - Graph-based method
2. **New approaches for shape optimization (crash)**
   - Implicit parameterization (SFE CONCEPT)
   - Direct parameterization (CAD-based)
   - Morphing, etc.
3. **Combined package / material / structure (shape & topology) optimization required.**

End.

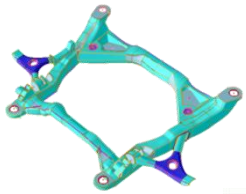
Automotive



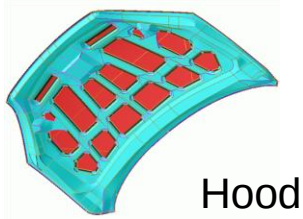


Front door

Radiator support

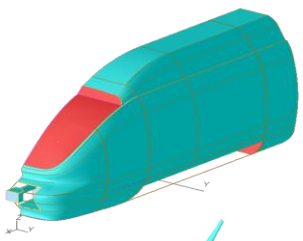


Lift gate

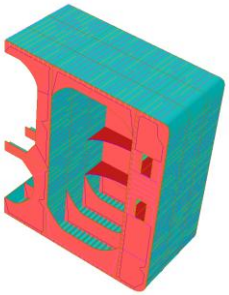


Front sub-frame

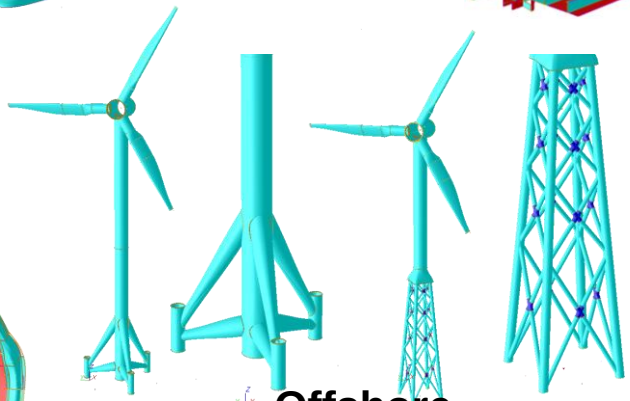
Hood



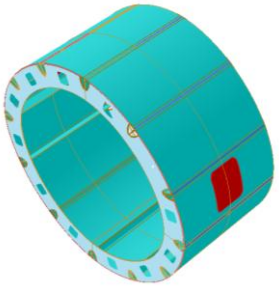
Trains

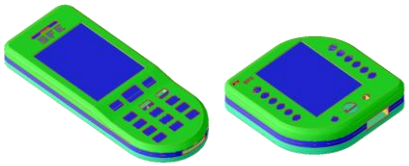


Shipping

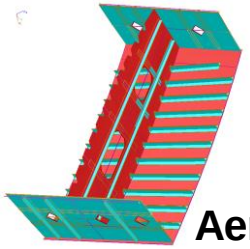


Offshore





White goods



Aerospace

SFE GmbH

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