topology optimization with LS-TaSC and Genesis/ESL for crash-loading

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overview

- introduction
- HCA - method (LS-TaSC)
- ESL - method (Genesis/ESL)
- applications and remarks
- summary and outlook

KMU-innovative project (BMBF)

topic:

methodical and software-technical implementation of topology optimization for crash-stressed vehicle structures

sponsor:

Bundesministerium für Bildung und Forschung

project execution organization:

DLR

cooperation:

DYNAmore, Hochschule für Angewandte Wissenschaften Hamburg (University of Applied Science Hamburg), SFE, asc(s Automotive Simulation Center Stuttgart

associated partner:

Adam Opel AG, Daimler AG, Dr.-Ing. h.c. F. Porsche AG, Constellium / Alcan GmbH, Benteler Aluminum Systems Norway AS

process chain of cooperation partners:

1st step:
pre-optimization with LS-TaSC (HCA) / Genesis/ESL - DYNAmore

2nd step:
interpretation of topology as shell structure (SFE CONCEPT - SFE)

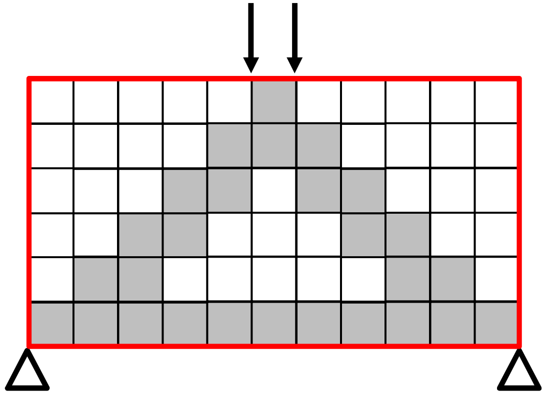
3rd step :
topology optimization of shell struct. via graph method (GRAMB, TOC) - HAW Hamburg

non-linear topology optimization

topology optimization

within design space:

complete freedom to find an optimal structural shape



design variables:

relative density within the finite elements

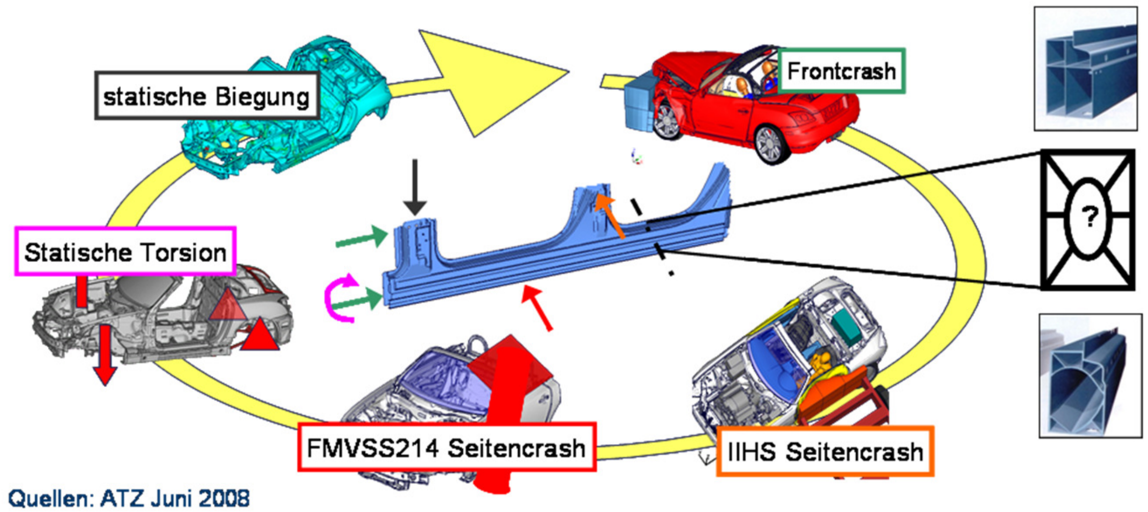
result:

pixelated material distribution

topology of the structure

state of art: *linear* topology optimization

new: topology optimization for crash-stressed vehicle structures



dynamic, contact, nonlinear material behavior, large deformations

two approaches:

- LS-TaSC: **H**ybrid **C**ellular **A**utomata Method (HCA)
- Genesis/ESL: **E**quivalent **S**tatic **L**oads Method

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LS-TaSC / HCA - method

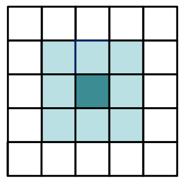
- **origin**: PhD-thesis Neal M. Patel:
  "Crashworthiness Design using Topology Optimization" University Notre Dame (Indiana, US)
- **heuristic method**
- **objective: homogenization of internal energy density:** $IED = \int_{\varepsilon=0}^{\varepsilon^{final}} \boldsymbol{\sigma}\, d\boldsymbol{\varepsilon}$

  ➡ density distribution ρ_{rel} is adapted, so that $\widetilde{IED} \approx const$ for given mass

  ➡ density ρ_{rel} is increased in the area of high $\widetilde{IED}$,
  density ρ_{rel} is reduced in the area of low $\widetilde{IED}$

- **smoothing of internal energy density** $\widetilde{IED}$

  typical neighborhood (Cellular Automata):

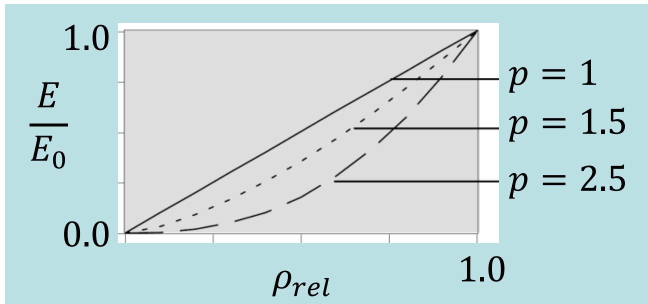
  

  8 neighbors (2D)
  26 neighbors (3D)

- **material parameterization with SIMP-model**

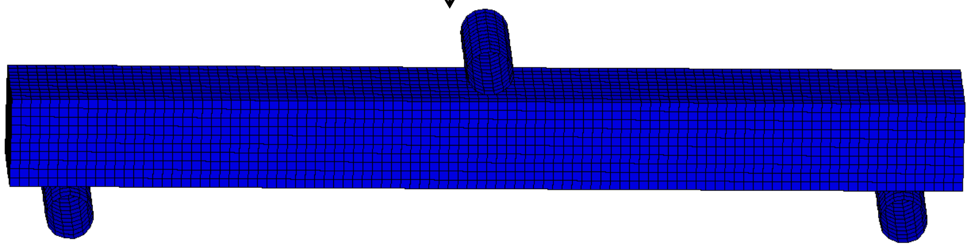
  e.g.: $E(x, \rho_{rel}) = (\rho_{rel}(x))^p \; E_0$

  ➡ obtain a 0.0-**or**-1.0 density distribution



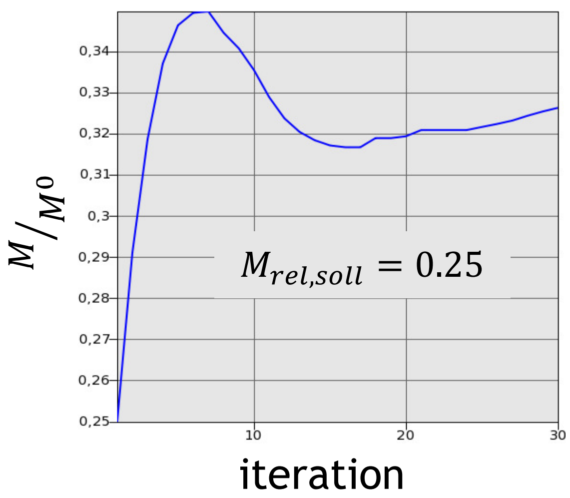
illustrating example LS-TaSC (HCA)

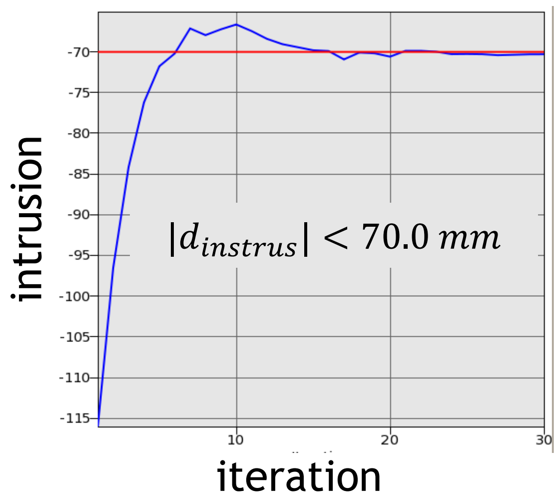
$v_0 = 10000\ ^{mm}/_{s}$

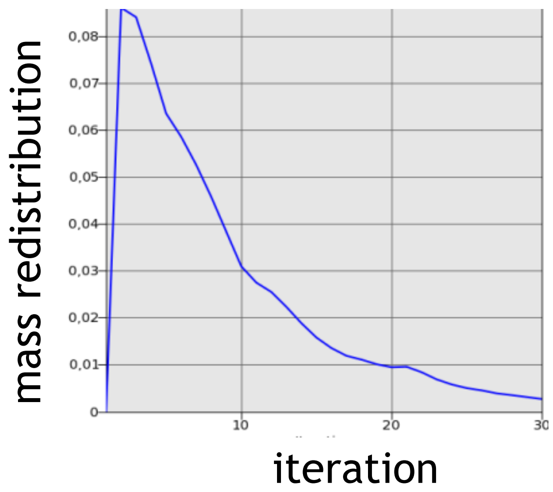


constraints: $M_{rel,expect} = 0.25$ $|d_{intrusion}| < 70.0\ mm$

➡ **mass constraint:** **displacement constraint:** **convergence:**







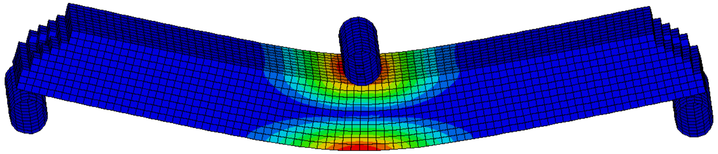
constraints: search for minimal mass, that fulfills displacement constraint

illustrating example LS-TaSC (HCA)

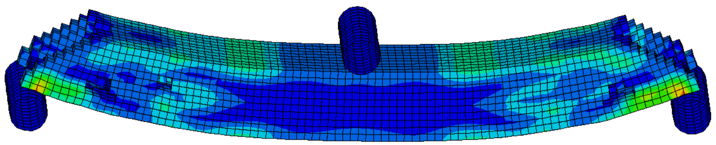
1st iteration: $\rho_{rel} = 0.25$ all over the design space

structural analysis: $IED\ [0, 22.0\ N/mm^2]$

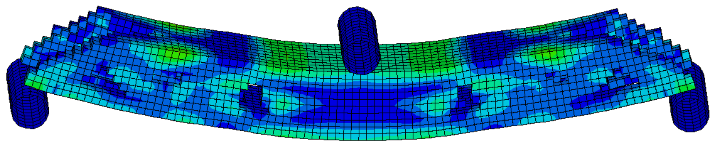
4th iteration:



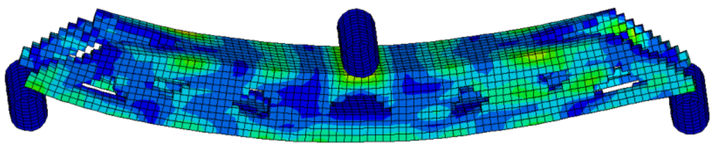
9th iteration:



15th iteration:

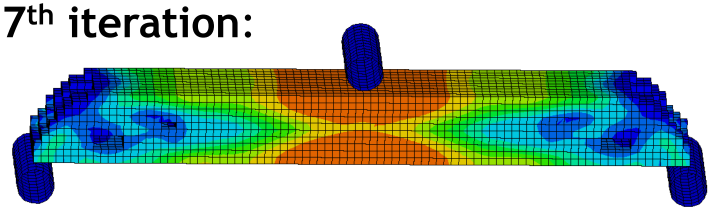


25th iteration:

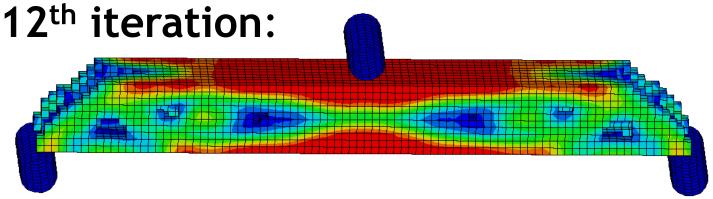


density update: $\rho_{rel}\ [0,1]$

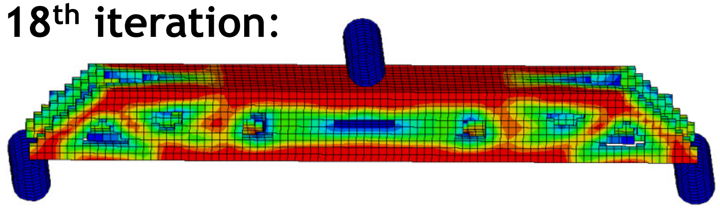
7th iteration:



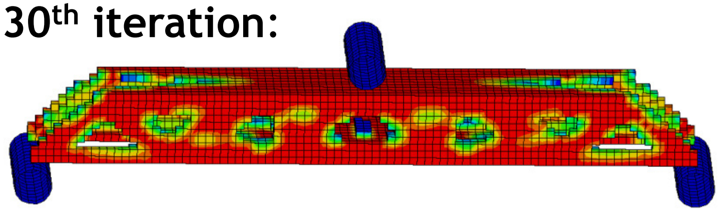
12th iteration:



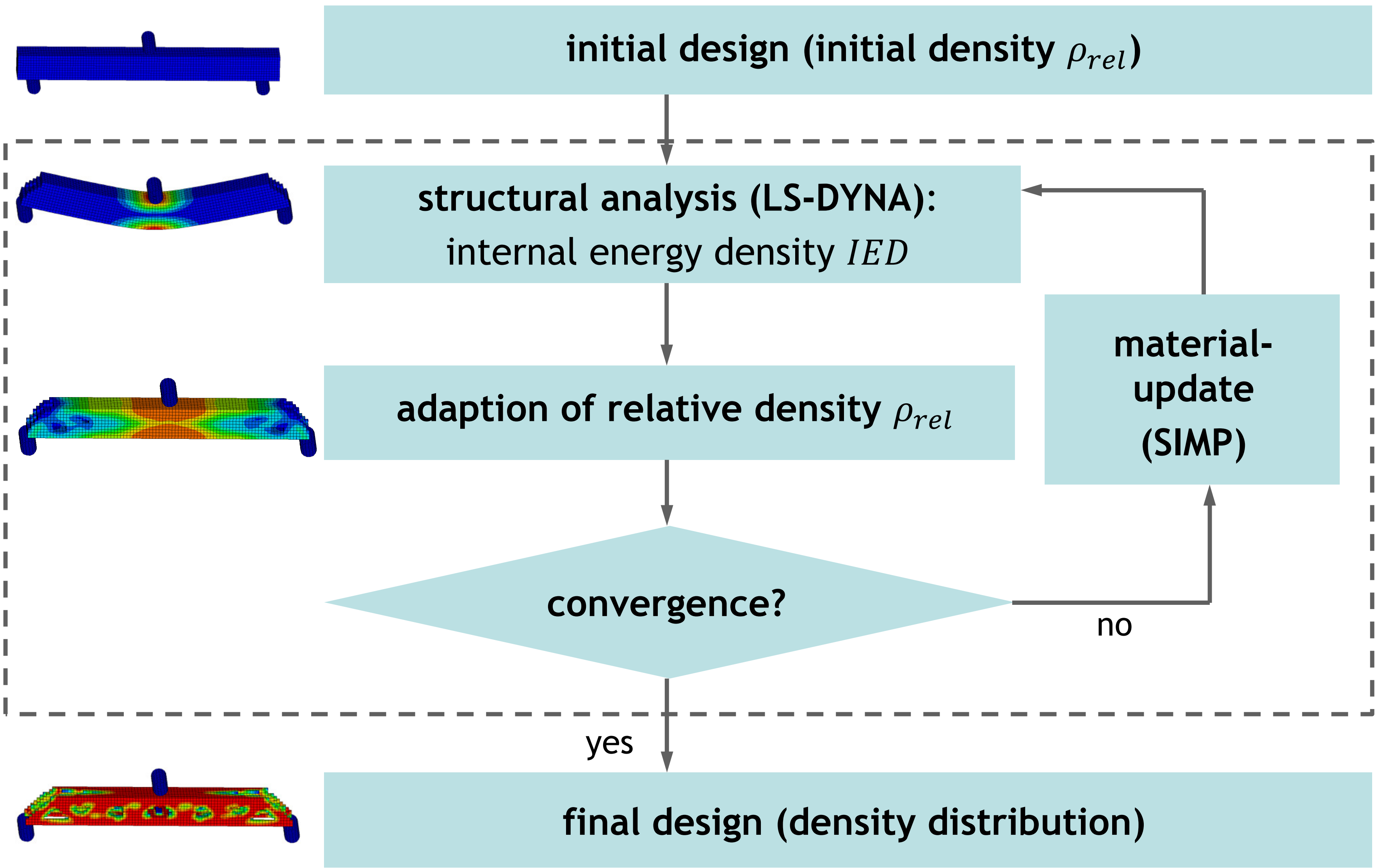
18th iteration:



30th iteration:



LS-TaSC / HCA- algorithm



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- **ESL - method (Genesis/ESL)**
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Genesis/ESL

- **origin:**

  Hanyang University, Korea:

  Shin MK, Park KJ, Park GJ (2007):" *Optimization of structures with nonlinear behavior using equivalent load*",Comp. Meth. Appl. Mech. Engrg.

- **idea:**

  break down the nonlinear dynamic optimization task into:

  nonlinear dynamic structural analysis → displacement field

  equivalent static loads for selected time steps (time discretization)

  linear static multi-loading optimization

  iterative process (convergence of objective and constraints fulfilled)

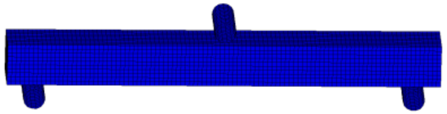
- **realization:**

  nonlinear dynamic FE-Solver: **LS-DYNA (others possible)**

  evaluation of the equivalent static loads: **Genesis/ESL**

  linear optimizer: **Genesis**

Genesis/ESL: algorithm

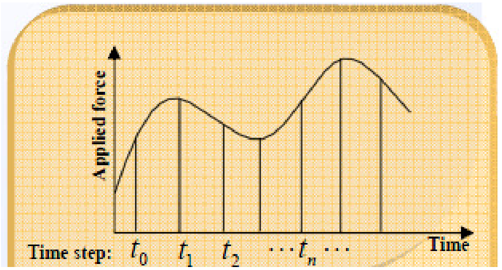


original design (topology)

structural analysis (LS-DYNA)

(nonlinear, dynamic)

→ deformations for time steps



equivalent static loads

for time steps

(time discretization)

optimal design?

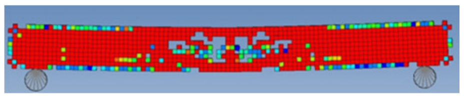
material-update (SIMP)

linear static multi-loading optimization with

equivalent static loads

(Genesis)

temporary state of optimized design



optimized design (topology)

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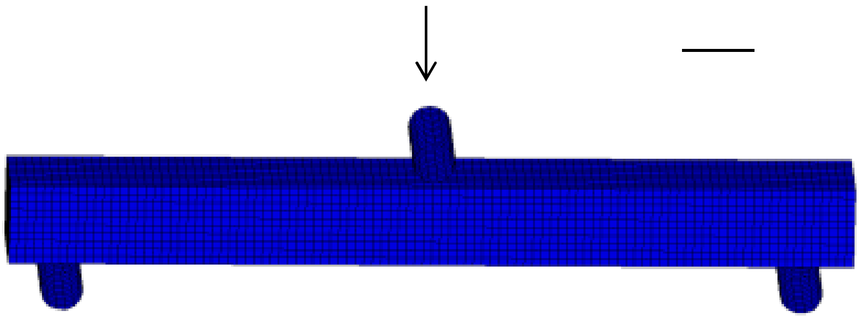
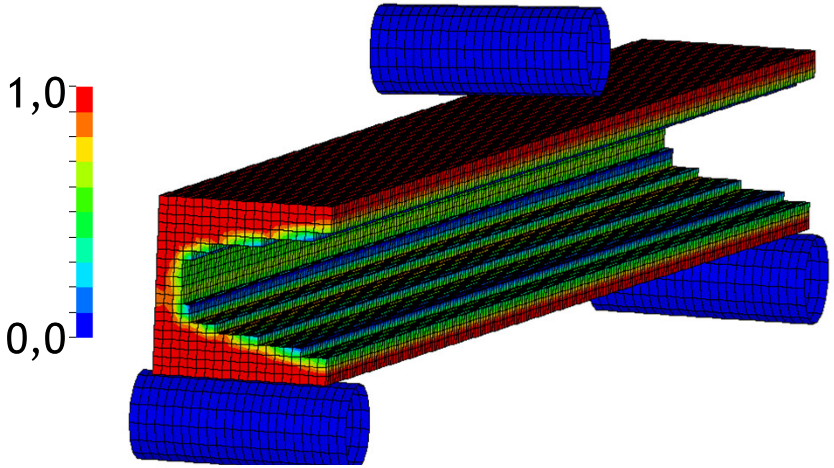
excentric impact LS-TaSC (HCA)

- **objective:** homogenization of internal energy density
- **constraints:** mass:
  displacement:
  extrusion

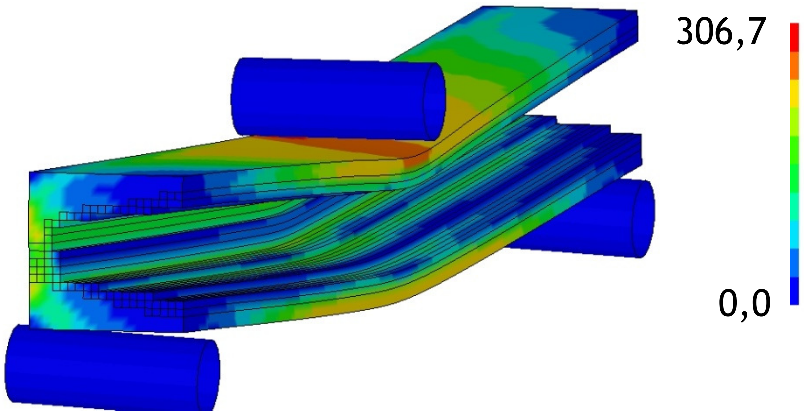
aluminum



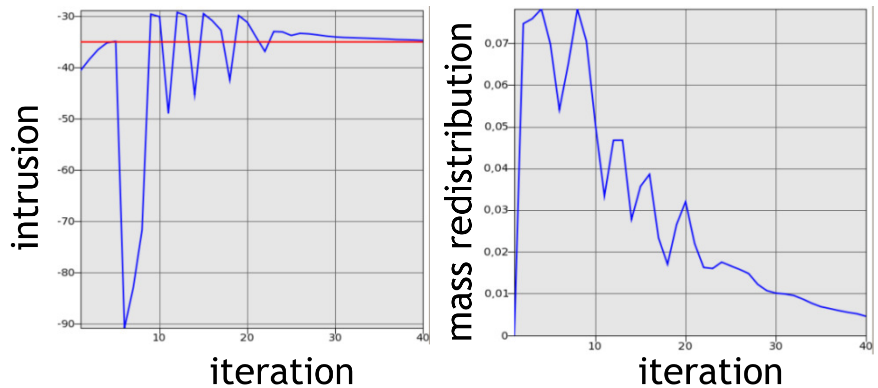
relative density



deformation, v.Mises stress, t= 0.012s



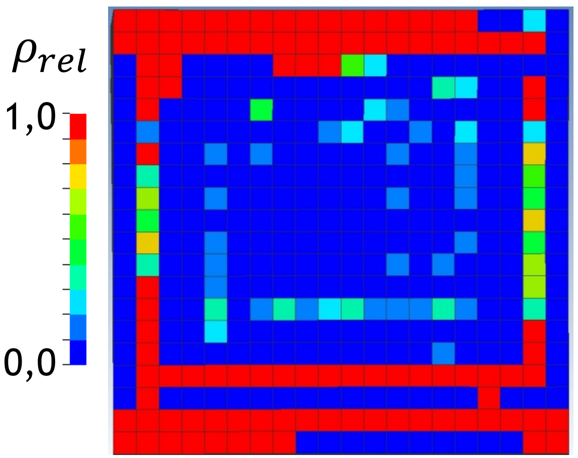
convergence



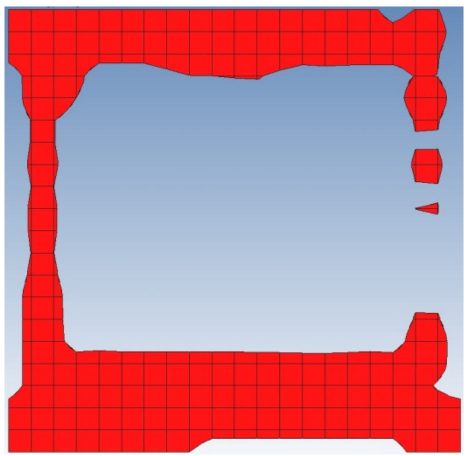
excentric impact Genesis/ESL

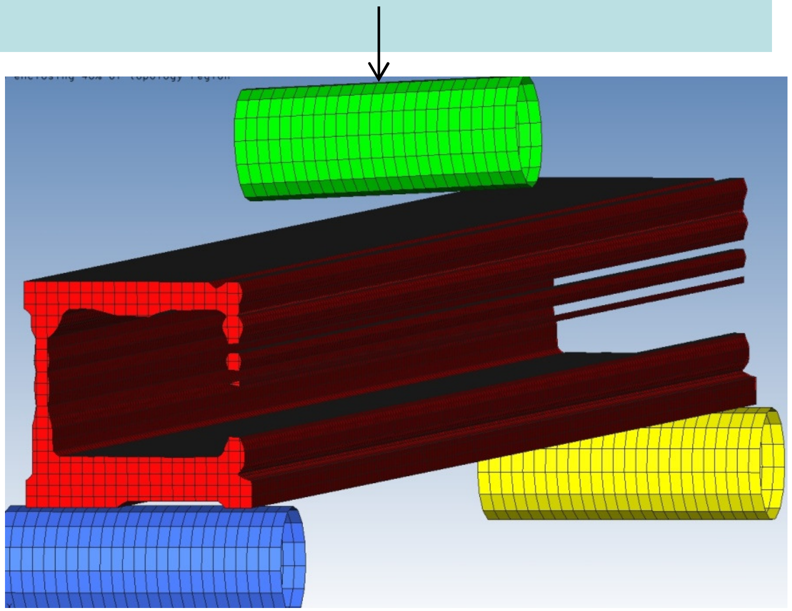
- **objective:** minimal internal energy
- **constraints:** mass: $M_{rel,soll} = 0.25$
  displacement: $|d_{ein}| < 35.0\ mm$
  extrusion

relative density



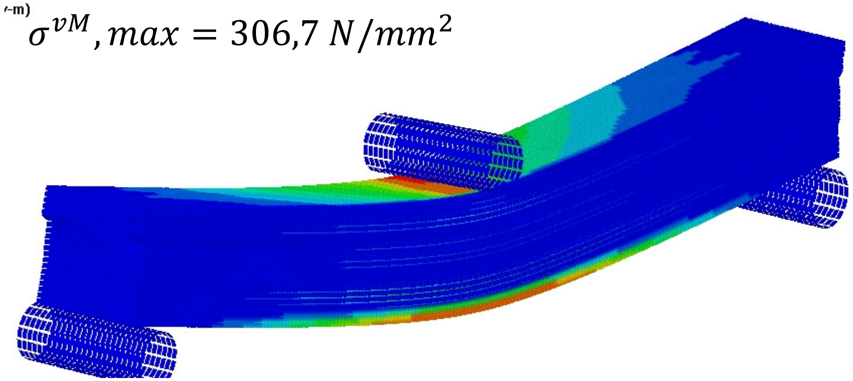
smoothed topology

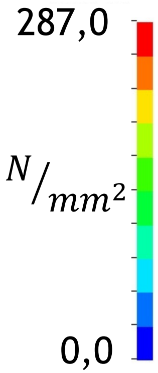




deformation, v.Mises stress, t= 0.012s

$\sigma^{vM}, max = 306,7\ N/mm^2$

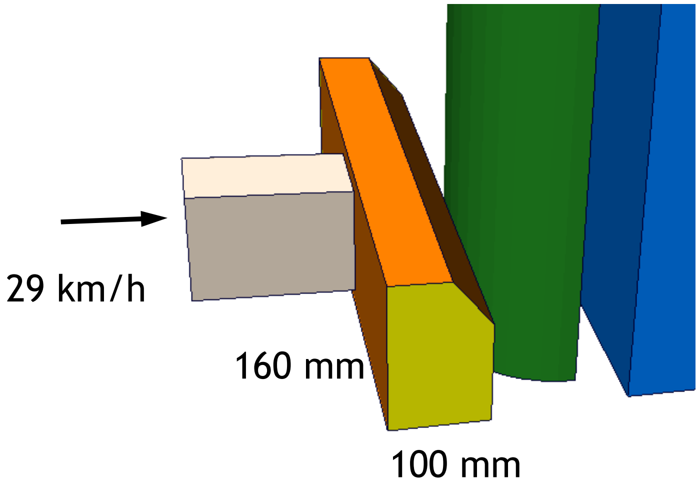




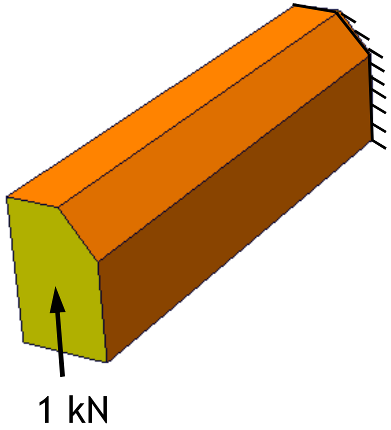
topology optimization of a door sill

- **part of a structure:** door sill (model in collaboration with project partners)
- **3 loading cases**:

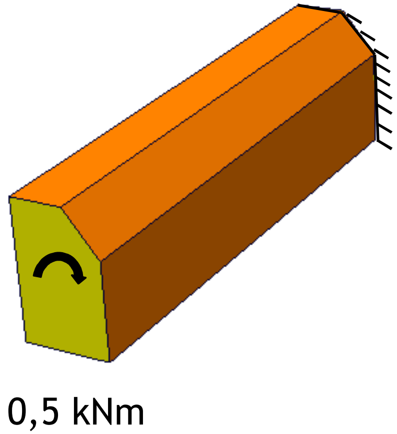
pole impact with 29 km/h



static bending



static torsion



- door sill material: aluminum, extrusion profile, boundary shape is given

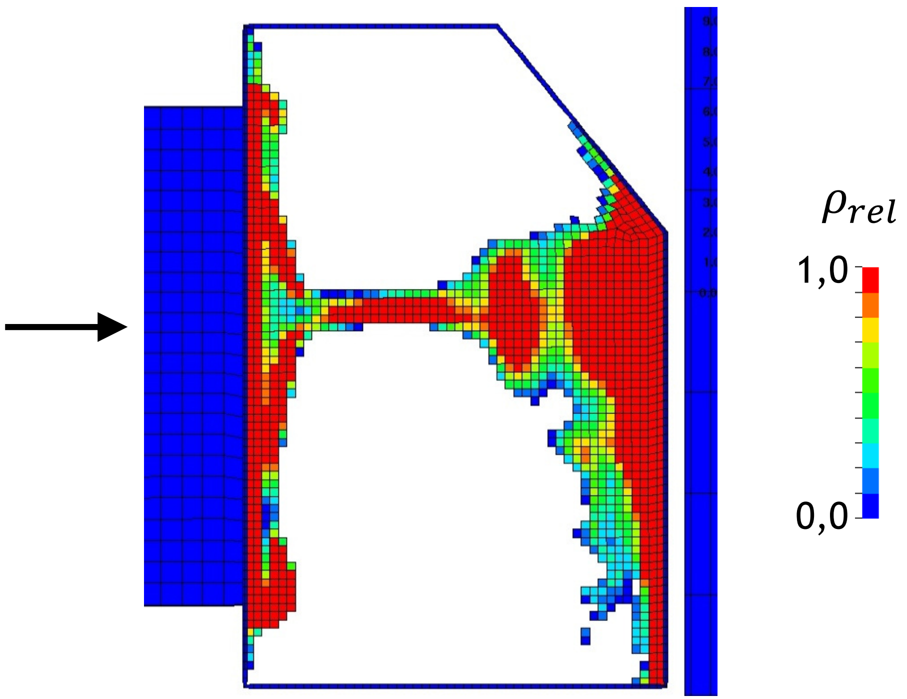
topology optimization of a door sill

LS-TaSC (HCA-method)

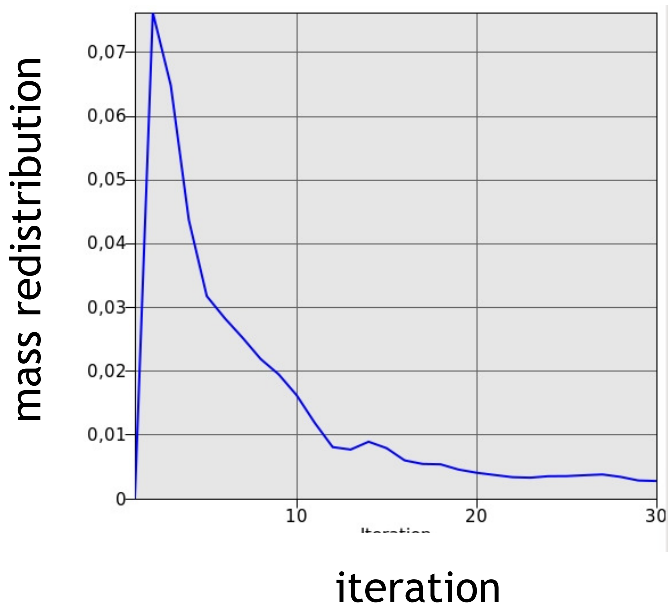
load case pole impact, shells with 1mm thickness on the boundary

- **objective:** homogenisation of internal energy density
- **constraints:** mass: $M_{rel,expect} = 0.25$
  extrusion

relative density



convergence



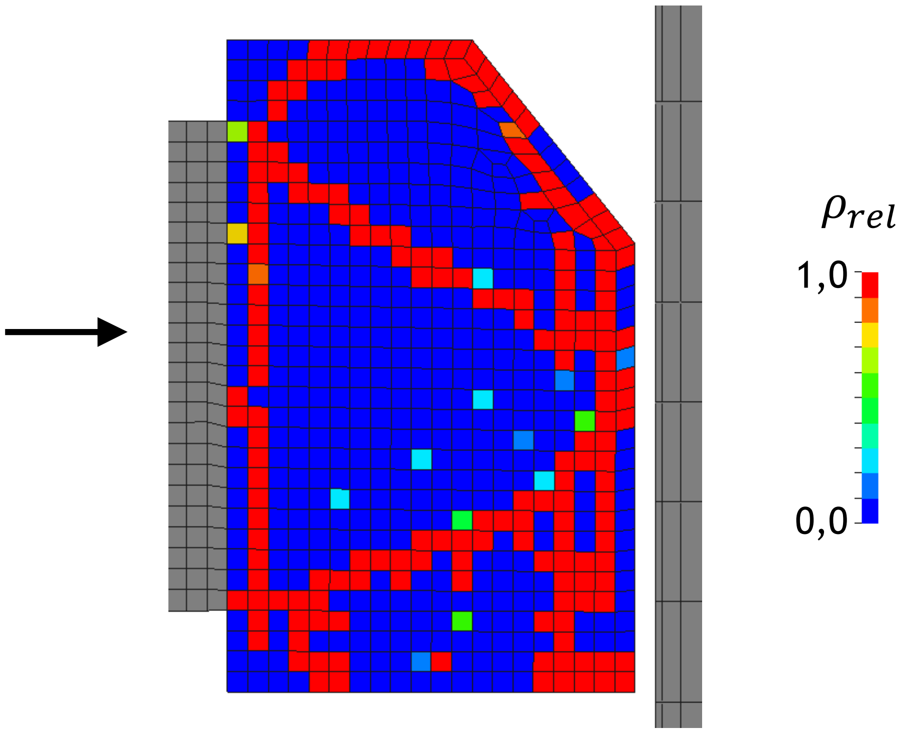
topology optimization of a door sill

Genesis/ESL

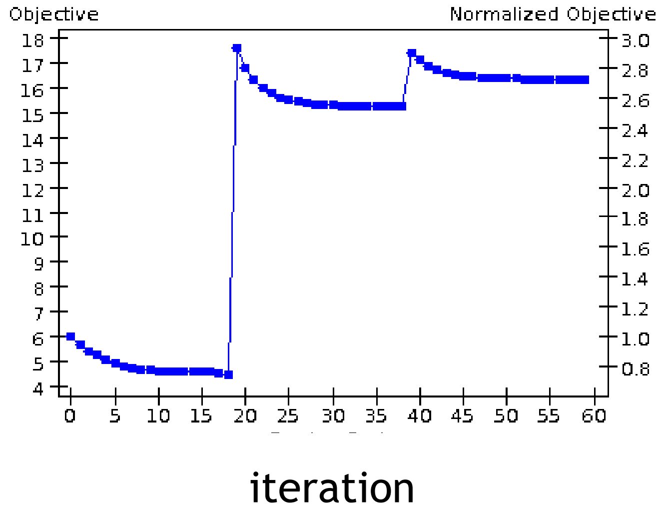
all 3 load cases, shells with 1mm thickness on the boundary

- **objective:** minimal internal energy
- **constraints:** mass: $M_{rel,expect} = 0.2$
  extrusion

relative density



convergence

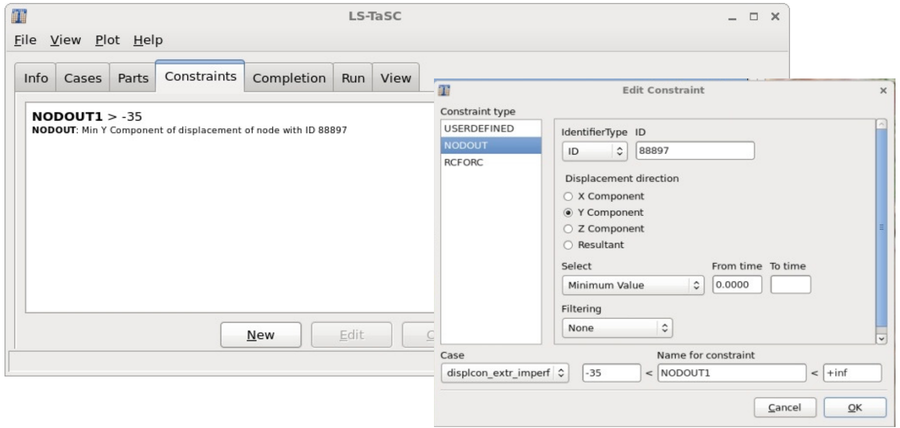


remarks to LS-TaSC (HCA)

- heuristic optimization method with obligatory objective:
  homogenization of IED. Does this objective fit?

- constraints:
  are introduced indirectly through adaption of mass constraint. I.e. the mass constraint cannot be fulfilled exactly for the case of further constraints.

- robust implementation, GUI is user friendly



- features of the actual version:
  - different constraints are possible (displacements, accelerations, forces)
  - nonlinear material behavior, large deformations
  - multiloading optimization, weighting of the load cases
  - manufacturing constraints as extrusion. Possible as well following curved lines, and with notches
  - alternative objective: homogenization of the von Mises stress
  - shell thickness optimization is possible as well

remarks to Genesis/ESL

- automatic process chain between LS-DYNA and Genesis, Genesis/ESL

- linear optimization includes an implicit analysis:
  - the related implicit Genesis-Nastran input file is automatically generated by Genesis
  - for some DYNA-Keywords this “translation” is not realized
  - ➢ workaround: Parser DYNA – Genesis-Nastran

- how far do simplifications of the method (linearization and multi loading instead of the dynamic process) reach?
  - check convergence (objective and constraints) with nonlinear dynamic analysis
  - store d3plot-files, d3hsp-files and the DYNA-input files of all ESL iterations

- check the Genesis-Nastran model: Deformation results due to equivalent static loads should agree with the deformation results of the LS-DYNA-analysis

- Genesis: well established software for linear optimization
  - gradient based optimization
  - ESL is not restricted to topology optimization. Shape optimization, sizing optimization, topometry optimization,… are possible as well.
  - numerous different objectives and constraints possible
  - multi-loading
  - fabrication constraints

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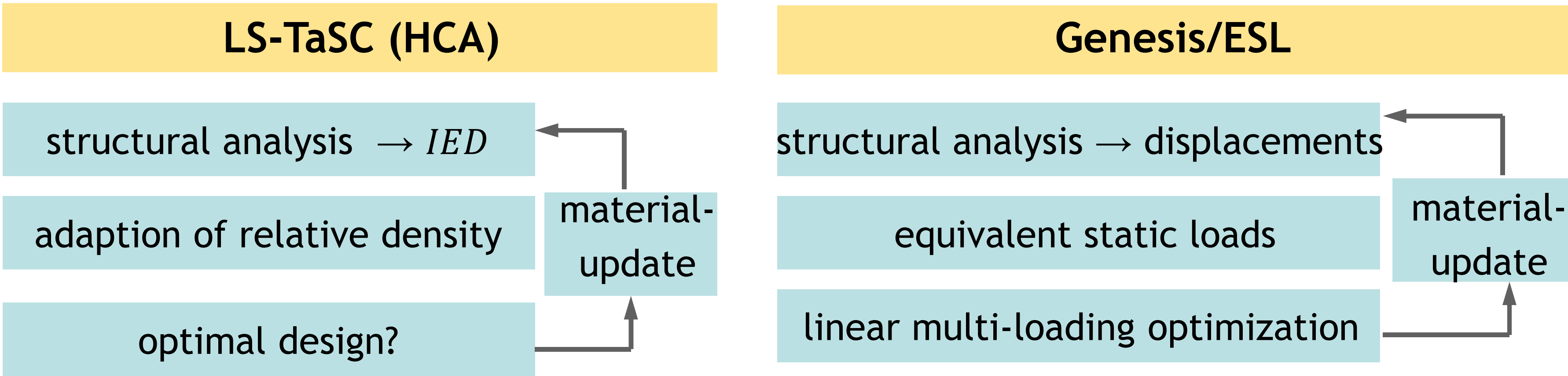
summary, comparison of the methods



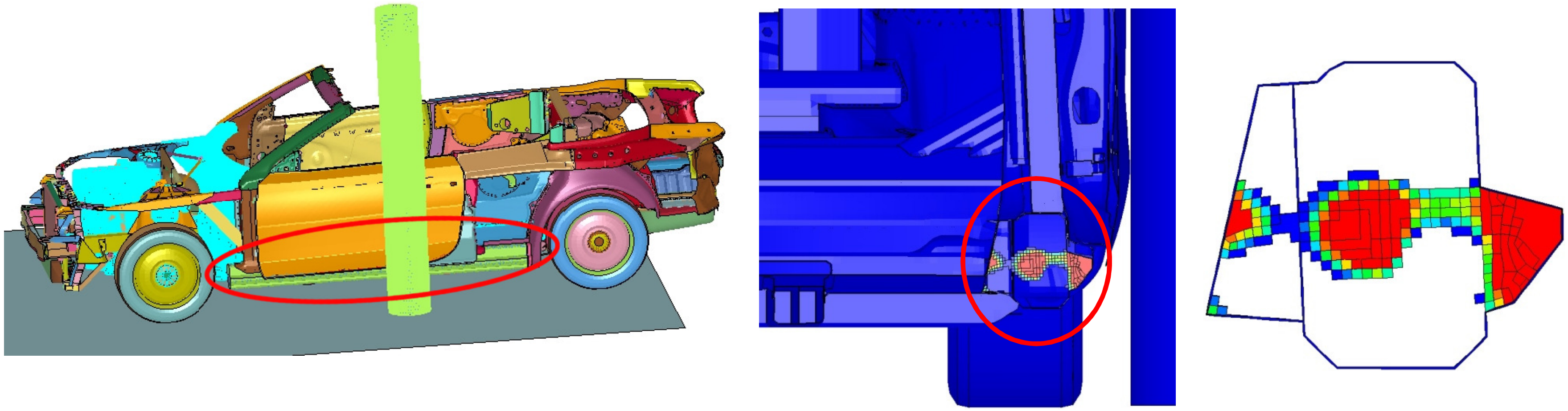
comparison of the methods:

- LS-TaSC and Genesis/ESL: reasonable optimization results for contact, dynamics, material and geometrical nonlinearity
- limit of HCA (LS-TaSC): objective determined, multiple constraints cannot be exactly fulfilled
- limit of ESL (Genesis/ESL): how far do the assumptions of linearization and multiple loadings instead of a dynamical process bear?

outlook

- **in context of the process chain of the KMU innovative project:**
  refinement of the pre-optimized topologies by project partners
  (interpretation of topology as shell structure, shape optimization)

- **application of LS-TaSC (HCA) and Genesis/ESL to realistic crash model**



- **topometry optimization of a hood for passenger safety (head impact) with Genesis/ESL**

- **topometry optimization of a occupant cabin under crash with Genesis/ESL**