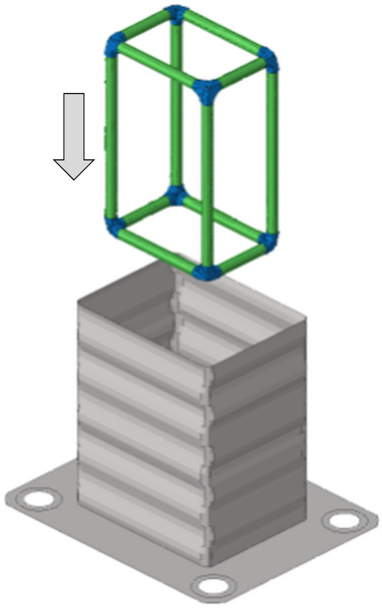
Topology optimization of inlay structures for crashboxes



14. Freiberger Crashworkshop
28. and 29.09.2023

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BERGISCHE UNIVERSITÄT WUPPERTAL

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Notice:
Florian Beyer gave a similar presentation on the World Congress on Structural and Multidisciplinary Optimization

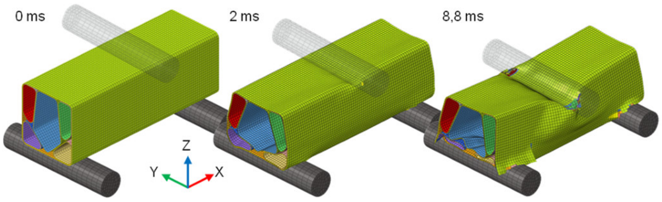
WCSMO-15 Cork
5-9 June 2023

Activities on the Graph and Heuristic based Topology Optimization (GHT)

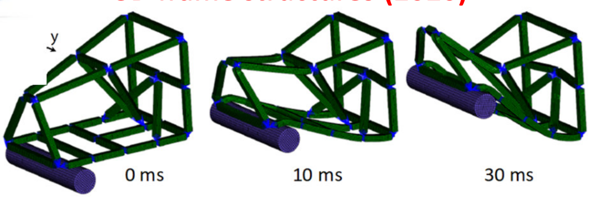
Aluminum extrusion profiles (2015)

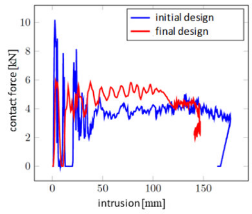
VW id.4
rocker

Composites profiles (2019)



3D frame structures (2020)





Roll formed steel and aluminum profiles (2024)

3D-graph description – from graph to FE-model

Model generated in an automated way by using shell-elements for the simulation

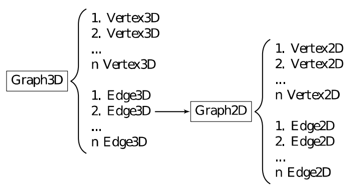
Syntax example: ASCII

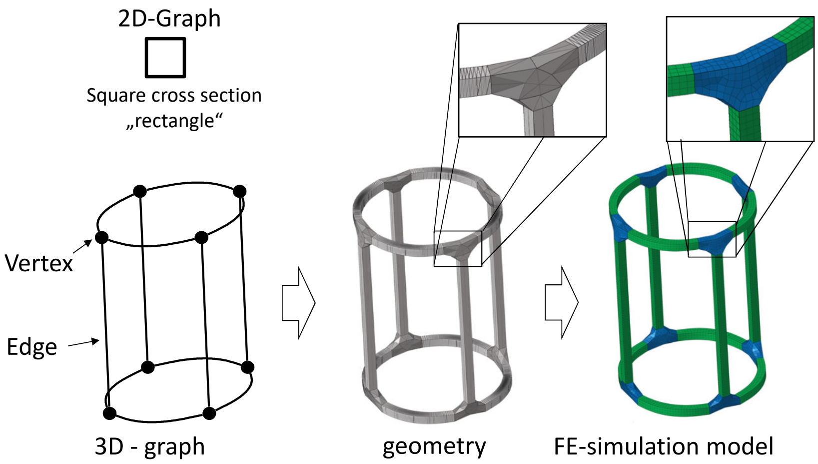
GRAPH; 1; TYPE (3DGRID); NAME (Box); SOURCE (Cross-section)*

VERTEX; 3; TYPE (LINK); COORDINATES (0, 50, 150)

EDGE; 1; VERTICES (1, 2); TYPE (ExtrudedProfile, rectangle); LENGTH(120, 120); ORIENTATIONPOINT (0, 1, 0)

**TYPE(2DExtrusion), 2D-graph*





3D-graph description – NURBS

- Spline definitions are implemented in geometry description
- Can be used as a starting design line and could be automatically split for connecting new edges

Keyword example: ASCII

```
NURBS(1, 0, 10, 0.5, 2)
NURBS(2, 0, -10, 0.33, 2, 0, 10, 0.66, 3)
NURBS(3, 0, 10, 0.25, 2, 0, -10, 0.50, 3, 0, 10, 0.75, 3)
```

Syntax example: ASCII

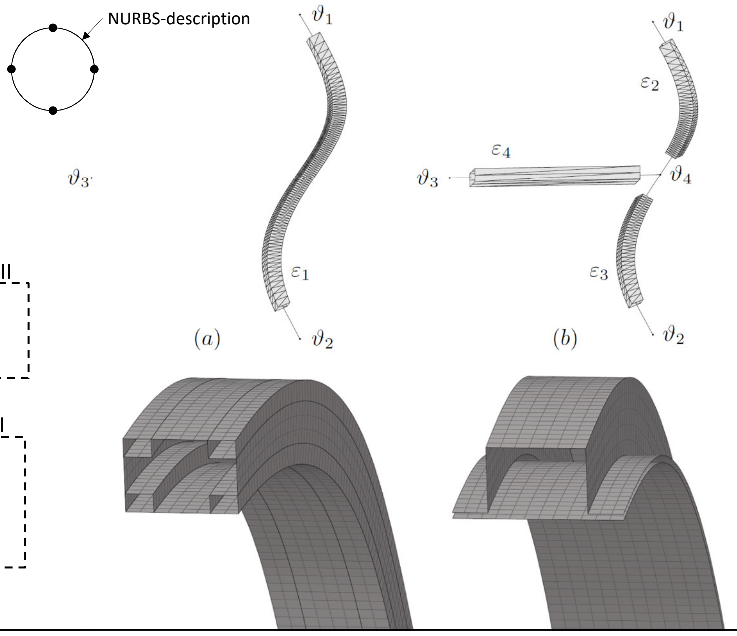
```
GRAPH; 1; TYPE (3DGRID*); NAME (Box); SOURCE (Cross-section)

VERTEX; 3; TYPE (LINK); COORDINATES (0, 50, 150)

EDGE; 1; VERTICES (1, 2); TYPE (ExtrudedProfile, profile1);
LENGTH(120, 120); ORIENTATIONPOINT (0, 1, 0);
NURBS(2, 0, -10, 0.33, 2, 0, 10, 0.66, 3)
```

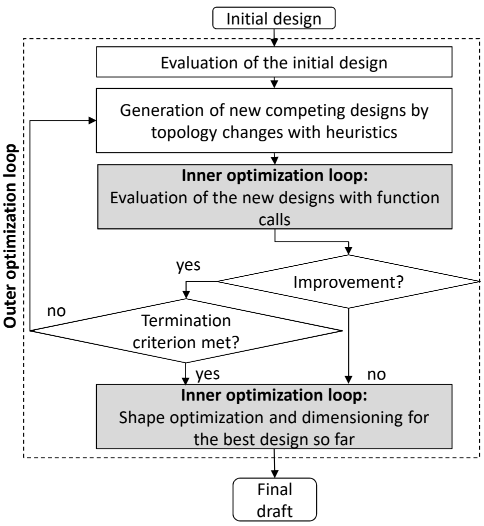
*TYPE(2DExtrusion) for 2D-graph

(For different cross sections)



Optimization process & overview of the heuristics

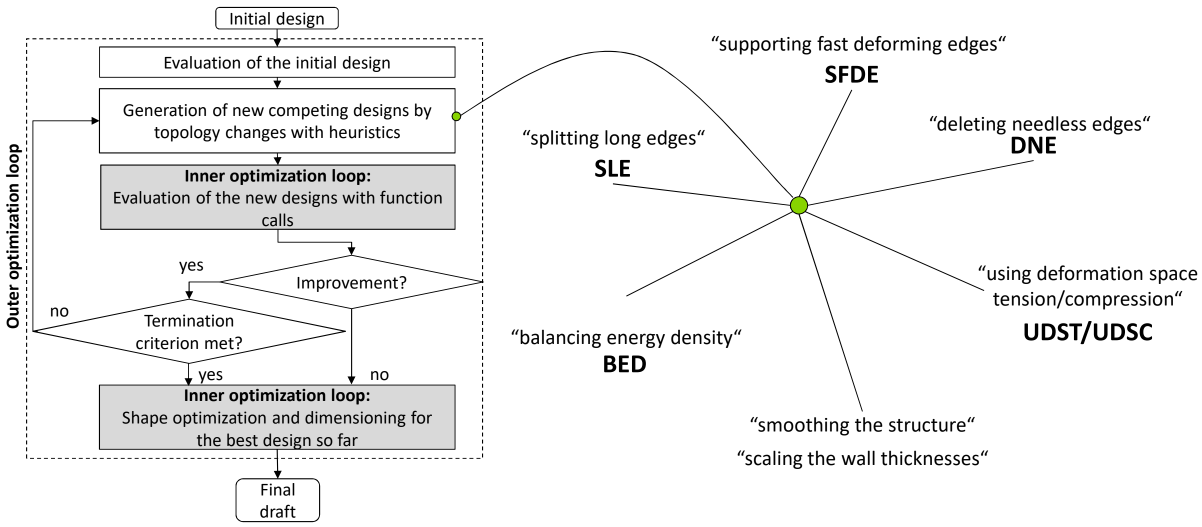
Selective(picking of the best) method for optimization



- Possible optimization objectives:
  - minimize the intrusion ("gain stiffness")
  - minimize the mass ("light weight, by fulfill targets")
  - minimize the contact force ("get higher energy absorption")
- Inner loop is using a Response Surface Method from LS-OPT
  - strategy can easily changed in DOE or evolutionary algorithms
- Outer loop is using ruled based heuristics for changing the structure from a mechanical point of view
- The process can fulfill a large number of requirements:
  - large displacements, nonlinear material behavior, failure, geometric nonlinearity, contact problems, different objectives, discretization in time (explicit)
    -> to optimize crashworthiness structure

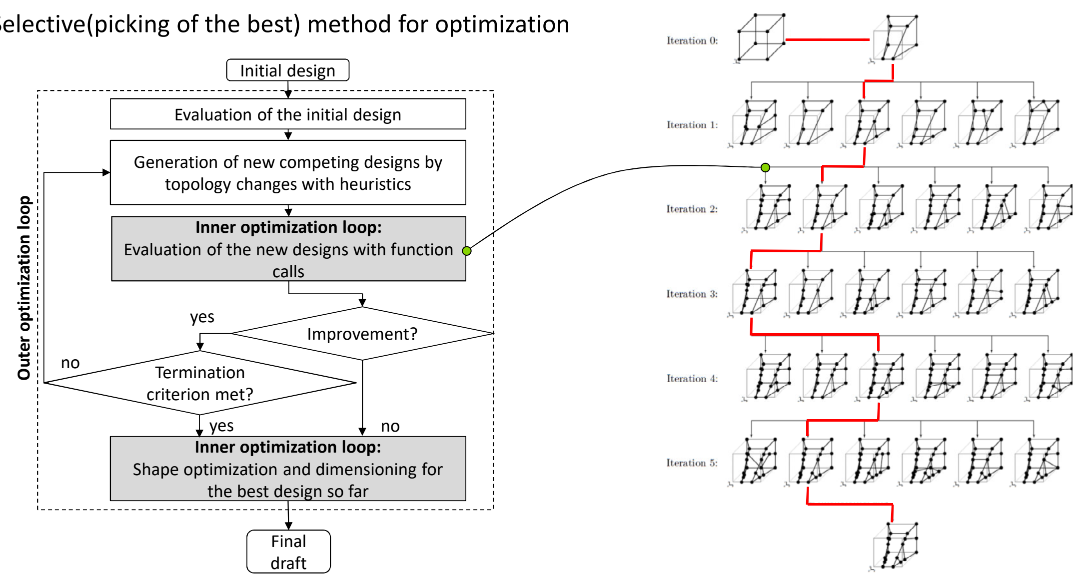
Optimization process & overview of the heuristics

Active and passive heuristics



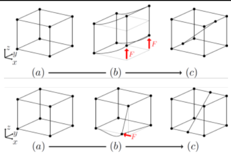
Optimization process & overview of the heuristics

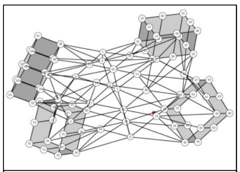
Selective(picking of the best) method for optimization

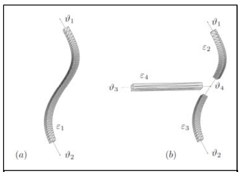


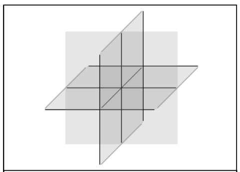
Useful functions and modules for geometry generation

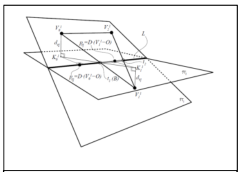
Functions to support the optimization process, includes partial modularized structure

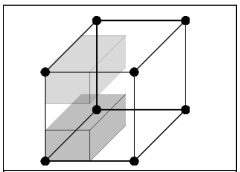

Heuristics for topological manipulation

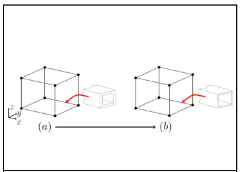

Generic and flexible connection nodes (no lib)

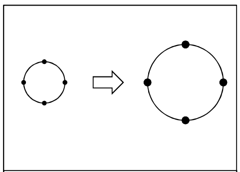

NURBS for the description of curves


Geometric restrictions: Symmetry, angles, lengths, …


Complex penetration testing

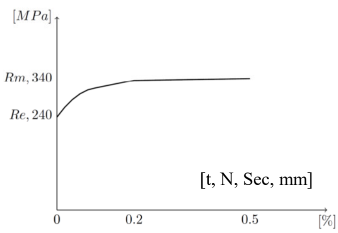

Shape optimization

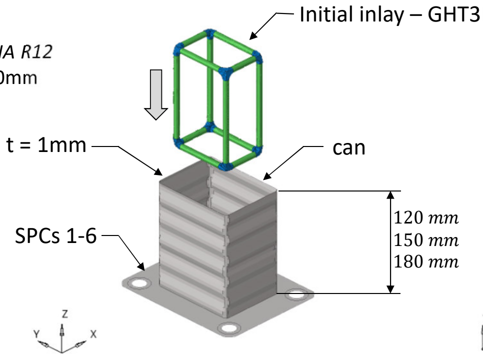

Size optimization

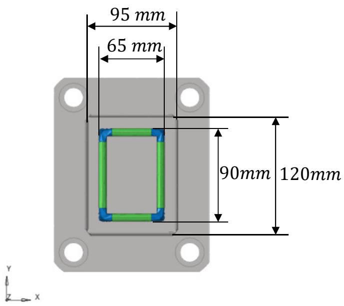

Scaling cross sections

Optimization task and load case – creation inlay structures for crashboxes

- Minimizing the contact force
- Inner loop: evaluation of the diameter
- DOE: with LS-OPT *SRSM/Space filling* + *LS-DYNA R12*
- Displacement constraint: $80\text{mm}/110mm/140\text{mm}$
- Symmetry constraints YZ-plane



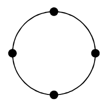




LS-DYNA material card: Aluminum, isotropic behavior with failure

```
*MAT_PIECEWISE_LINEAR_PLASTICITY
$#   mid          ro        e       pr     sigy    etan    fail    tdel
     10012.7000E-09   70000.0   0.33   240.0    0.0    0.50    0.0
$#     c       p      lcss    lcsr      vp   EPSTHIN  EPSMAJ  NUMINT
     0.0     0.0       0       0     0.0                         0.0
$#   eps1    eps2    eps3    eps4    eps5    eps6    eps7    eps8
      0.0    0.02    0.04    0.06    0.08     0.1     0.2     0.5
$#    es1     es2     es3     es4     es5     es6     es7     es8
    240.0   265.0   285.0   300.0   310.0   315.0   335.0   340.0
```

- Rigid wall: angle 10°, weight: $350kg$
- Wall thickness can: $1mm$
- Simulation time: $0.1sec.$
- Displacement is considered at rigid wall
- *SurfaceToSurface* Contact
- Body Z-Load $9.81m/s^2$
- no perturbation

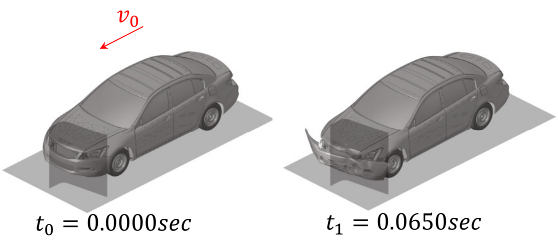


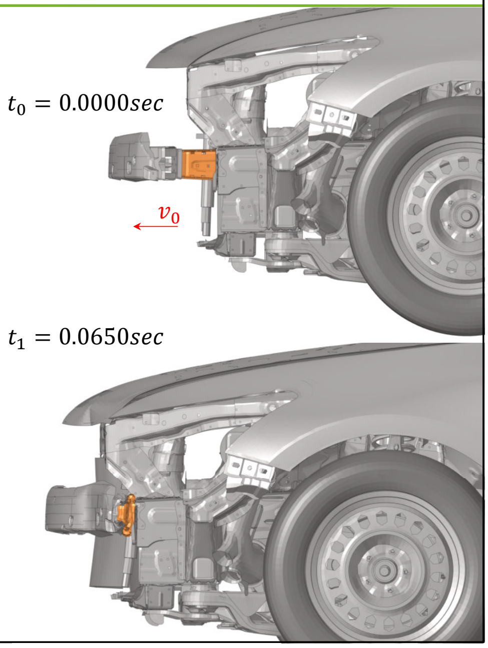
2D-graph: round, diameter = $2mm - 12mm$
wall thickness 40% from diameter length

Crash Scenario – Low Speed Crash 15 km/h

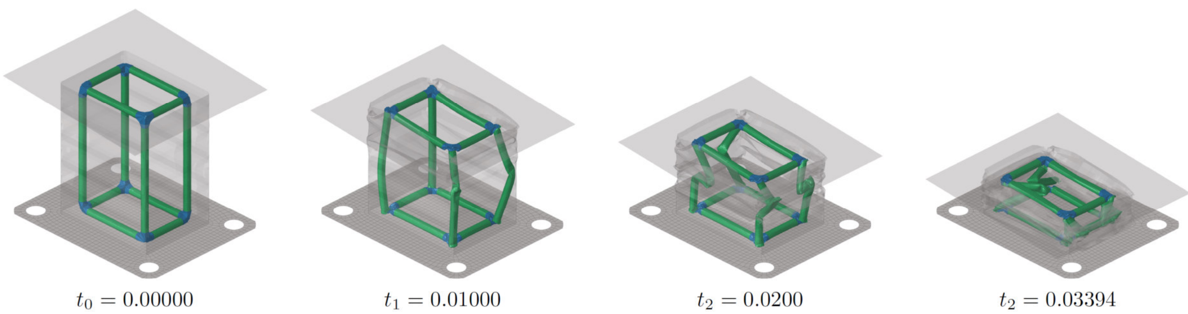
- Low Speed Crash *RCAR:* Vehicle $v_0 = 15km/h$
- Against a rigid barrier inclined by 10° and has an overlap of 40%
- Crash elements in the front area of the vehicle ensure that the energy is dissipated
- Protects parts from damage and enables more cost-effective repair

Vehicle: Honda Accord 2017 – LS-DYNA
Source: National Highway Traffic Safety Administration (NHTSA)
(Barrier is not included)

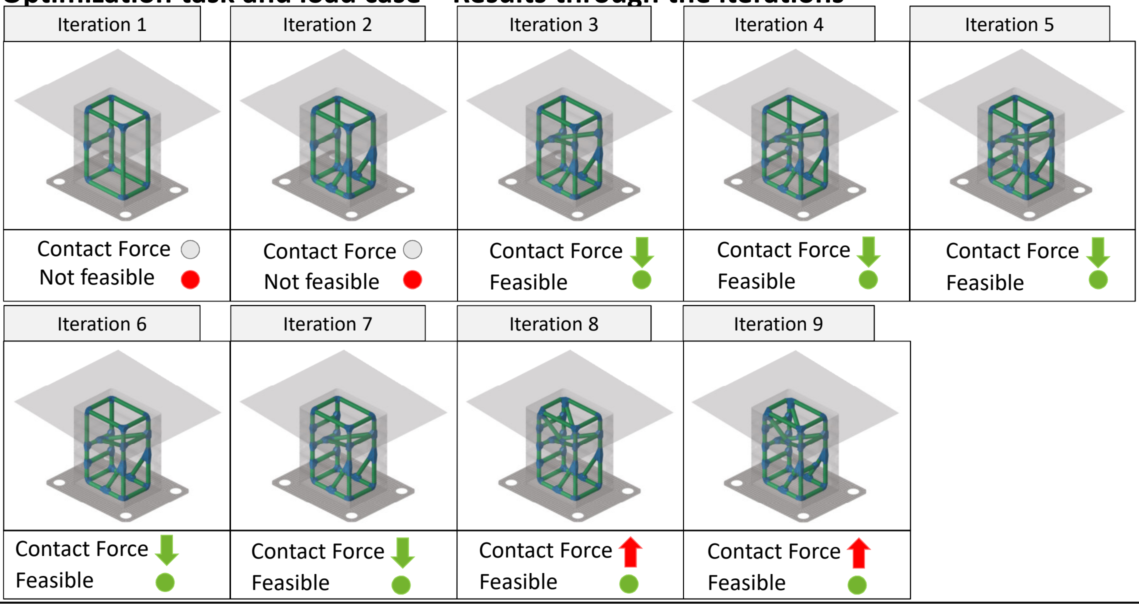




Deformation behavior of the initial design

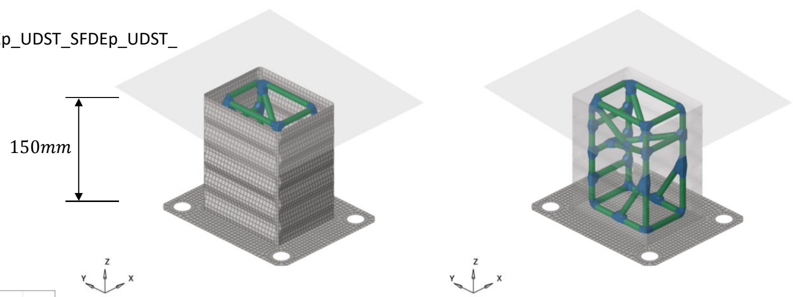


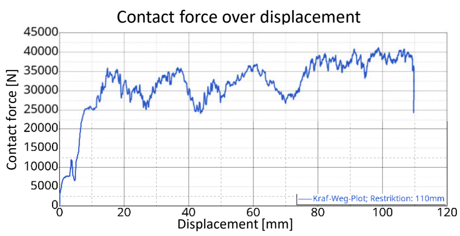
Optimization task and load case – Results through the iterations



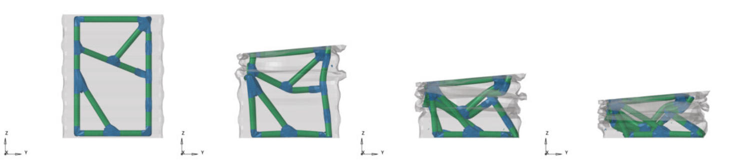
Optimization results: displacement constraint 110 mm; crashbox length 150 mm

- Iteration_7
- Design_1
- Heuristics are used:_H_SLE_BED_BED_SFDEp_UDST_SFDEp_UDST_
- Force peak : 41175.78 N
- Displacement : 109.78 mm / 110 mm
- Simulation time : *0.050933 sec*
- Diameter: 7.38 mm





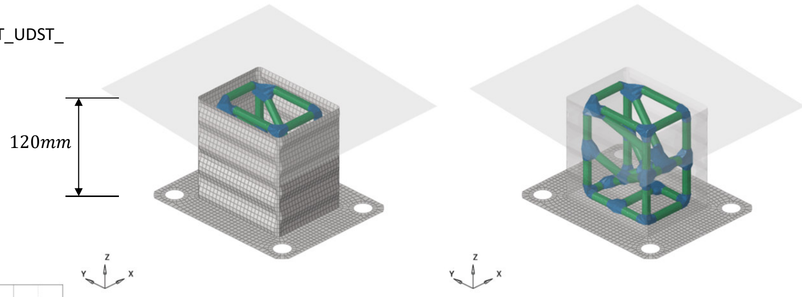
Frames YZ:

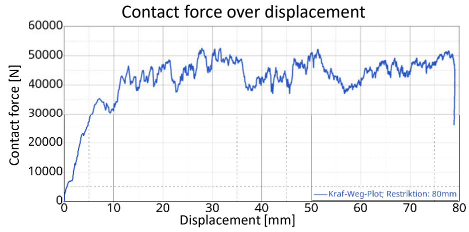


$t_0 = 0.00000sec$ $t_1 = 0.00095sec$ $t_2 = 0.00190sec$ $t_3 = 0.00285sec$

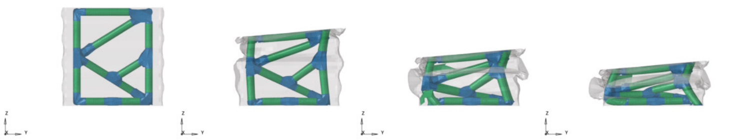
Optimization results: displacement constraint 80 mm; crashbox length 120 mm

- Iteration_5
- Design_3
- Heuristics are used:_H_BED_BED_SLE_UDST_UDST_
- Force peak: 52594.76 N
- Displacement: 79.10 mm / 80 mm
- Simulation time: *0.038032 sec*
- Diameter: 9.19 mm



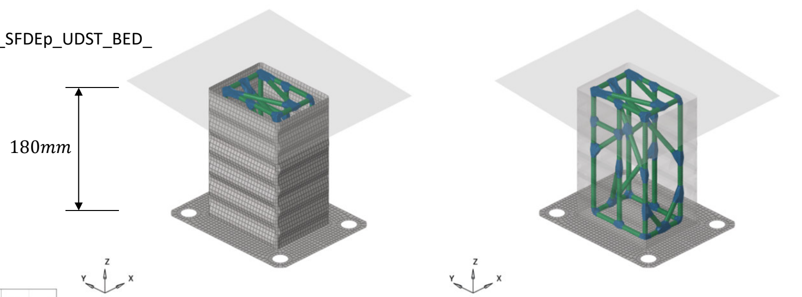


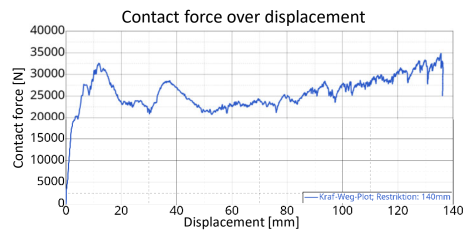
Frames YZ:



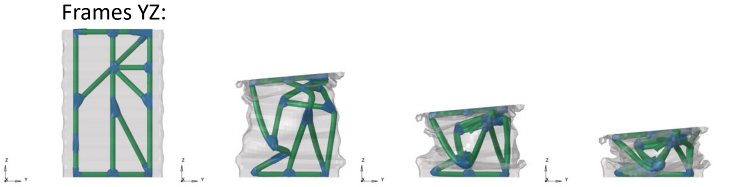
Optimization results: displacement constraint 140 mm; crashbox length 180 mm

- Iteration_7
- Design_2
- Heuristics are used:_H_BED_SLE_SLE_SFDE_SFDEp_UDST_BED_
- Force peak : 34878.60 N
- Displacement: 136.33 mm / 140 mm
- Simulation time : *0.062873 sec*
- Diameter: 6.14 mm



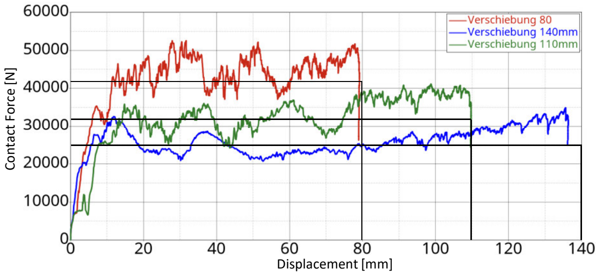


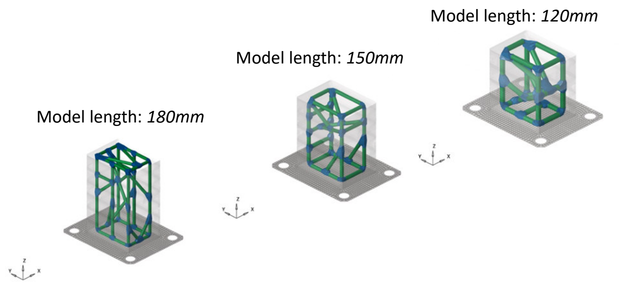
Frames YZ:



Optimization results – comparison of the different structures: displacement constraint 80mm, 110mm, 140mm

Comparison force-displacement plot and *Crush-Force-Efficiency-Indicator*





Model length	Mass wall	Velocity wall	Kinetic energy	Total mass	Mass inlay	Mass can	total internal energy	Internal energy inlay	Internal energy can	P_{max}	δ	EA	P_m	SEA	CFE
[mm]	[kg]	[m/s]	[J]	[g]	[g]	[g]	[J]	[J]	[J]	[N]	[m]	[J]	[N]	[J/g]	[-]
180	350,00	4,167	3038,68	383,80	173,50	210,30	3179,66	1277,17	1902,49	34878,60	0,136	3513,24	25832,65	9,15	0,74
150	350,00	4,167	3038,68	336,70	162,70	174,00	3032,98	1594,84	1438,14	41175,78	0,110	3476,81	31693,80	10,33	0,77
120	350,00	4,167	3038,68	358,40	217,70	138,60	2949,91	2024,57	925,34	52594,76	0,079	3329,23	42088,87	9,29	0,80

max Force peak – P_{max}; max Displacement – δ; internal energy – EA; mean Crush Load – P_m; Specific energy absorption – SEA; Crush-Force-Efficiency – CFE

- Adhesive between inlay structure and plate [#Sliding]
- Using the entire design space [#Interaction, #efficiency]
- Material model and material card: critical [#Isotropic, #Validity]
- 3D-printing boundary conditions are not considered [#Manufacturing #Manufacturing constraints]
- Structure is hollow [#deformation behavior, #Shell-elements]

Conclusion and further investigations

- inlay structures for different load cases and different design spaces for crashworthiness structures
- round profiles with shell elements are used in a hollow shape
  - → if solid elements in crash simulations are used, a work around of the optimization process would be necessary
- the used material model is not validated and a generic version
  - → material model can be changed easily
  - → in general, material models with failures can be considered
- an adhesive between inlay structure and the ground plate is required in this case
  - → could be a benefit for optimization process to get better results as well

References:

Ortmann, C., Schumacher, A. Graph and heuristic based topology optimization of crash loaded structures. Struct Multidisc Optim 47, 839–854 (2013). DOI: 10.1007/s00158-012-0872-7

Beyer, F., Schneider, D. & Schumacher, A. Finding three-dimensional layouts for crashworthiness load cases using the graph and heuristic based topology optimization. Struct Multidisc Optim 63, 59–73 (2021). DOI: 10.1007/s00158-020-02768-0