Topology optimization of crash structures – creativity versus computer-based algorithms

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1 The research project CRASH-TOPO

The development of crash-loaded structures is still ambitious, especially if topology and shape variations have to be taken into account [1]. The research project CRASH-TOPO „Methodical and Software-Technical Implementation of Topology Optimization for Crash-loaded Vehicle Structures“ founded by the German Ministry of Education and Research (BMBF) work in this area. Research partners are the Automotive Simulation Center Stuttgart e.V. (asc(s), the DYNAmore GmbH, the SFE GmbH and the Hamburg University of Applied Sciences. Associated partners are Daimler, Opel, Porsche and the Goethe-University Frankfurt.
The part of the Hamburg University of Applied Sciences is the development of the combined topology and shape optimization of profile structures (especially aluminium extrusion components) considering all relevant crash loads. We have an outer loop for the topology changes done by design rules and an inner loop for the shape variation done by mathematical optimization algorithms (using LS-OPT). The flexible description of the geometry is done by a mathematical graph together with the CAE software SFE CONCEPT. The crash simulation is done by LS-DYNA.

2 An application example

Figure 1 gives the arrangement of an application example (v_0 = 29 km/h). The structure is pushed by a rigid wall with a mass of 85 kg against the rigid pole. The goal is the minimization of the maximum reaction force in the rigid wall. The task is to optimize the rocker of a vehicle. The detailed specification list is summarized in table 1.

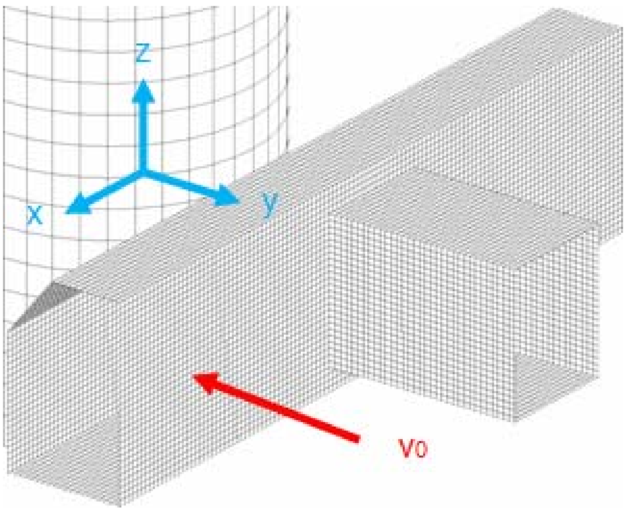


Fig. 1: Arrangement of an application example

Objective:	minimization of the maximum absolute value of the reaction force at the moved rigid wall
Design variables:	topology, shape and thickness of the rocker profile
Functional constraints:	mass of the structure ≤ 2.801 kg
	intrusion in the rocker ≤ 70 mm
Manufacture constraints:	1.6mm ≤ wall thickness ≤ 3.5 mm
	angle between two walls ≥ 15°
	distance between two walls ≥ 10 mm

Tab. 1: Specification list of the rocker optimization

3 Results of the automatic optimization

The details of the graph and heuristic based topology optimization method are given in [2,3,4]. The topology changes are done by heuristics. These topology design heuristics are:

- delete unnecessary walls
- support fast deforming walls
- remove small chambers
- balance energy density
- scale wall thicknesses

Figures 2 to 6 show the history of the automatic optimization loop. The left structure in the single figures is the initial design of the specific iteration, the middle structure is the design after activation of the topology design heuristic and the right structure is the design after the inner loop shape optimization with LS-OPT.

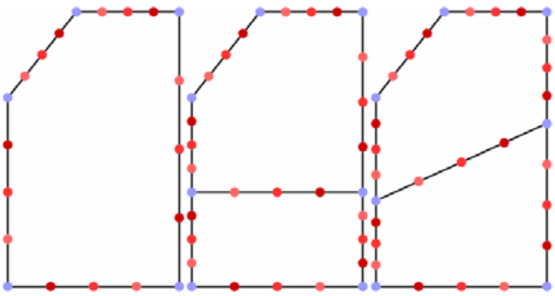


Fig.2: Iteration 1

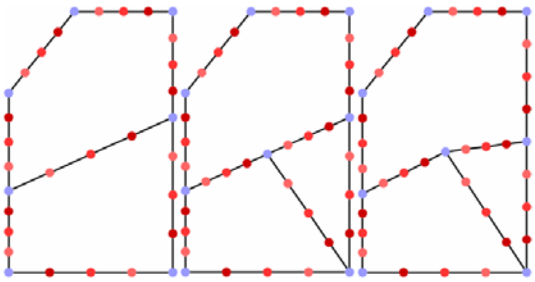


Fig.3: Iteration 2

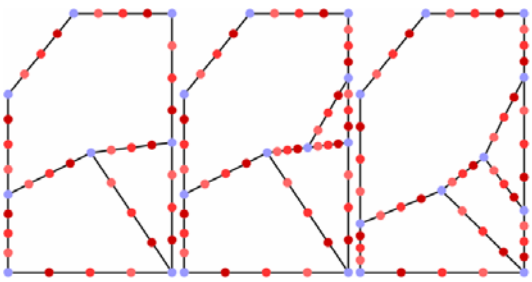


Fig.4: Iteration 3

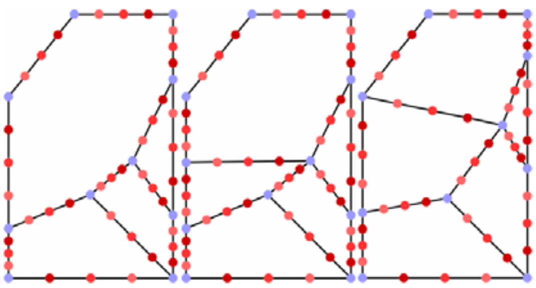


Fig.5: Iteration 4

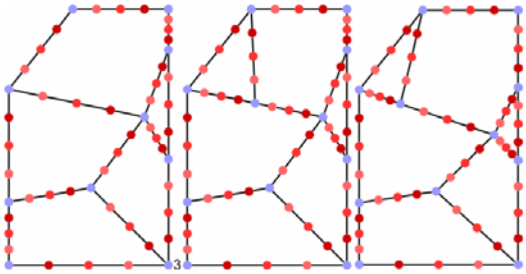
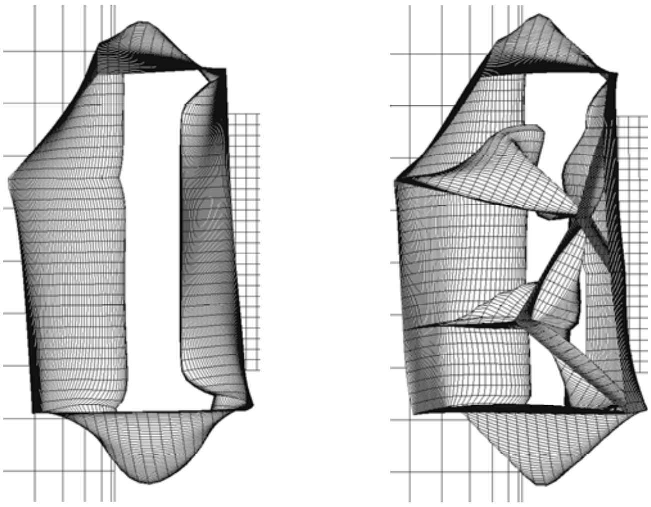


Fig.6: Iteration 5

Figure 7 shows the deformation plots of the initial design (empty profile) and the optimal design. Figure 8 shows the reaction force over the time. The maximal force of the optimal structure is 43.4 kN.



(a) (b)

Fig. 7: Graph description of the optimal structure (a), the deformation plots(b,c)

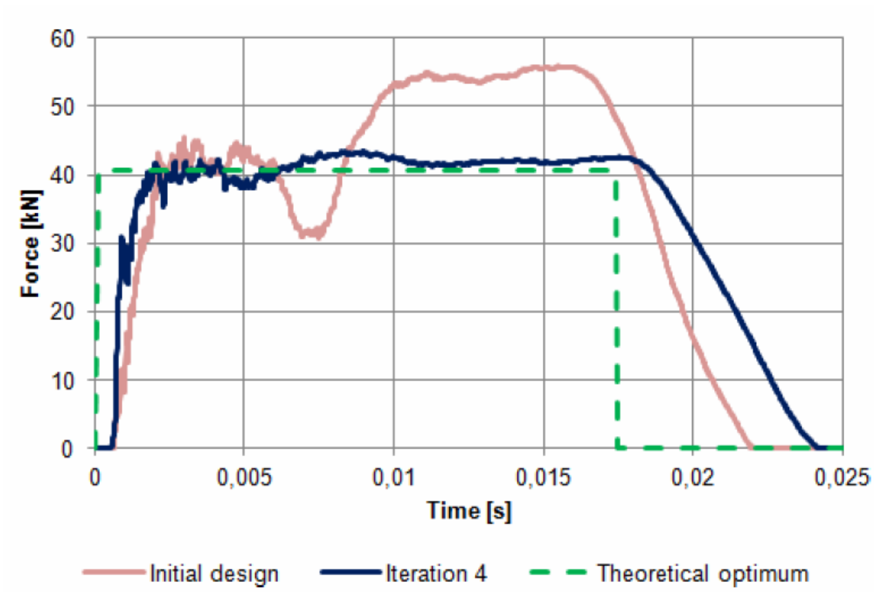
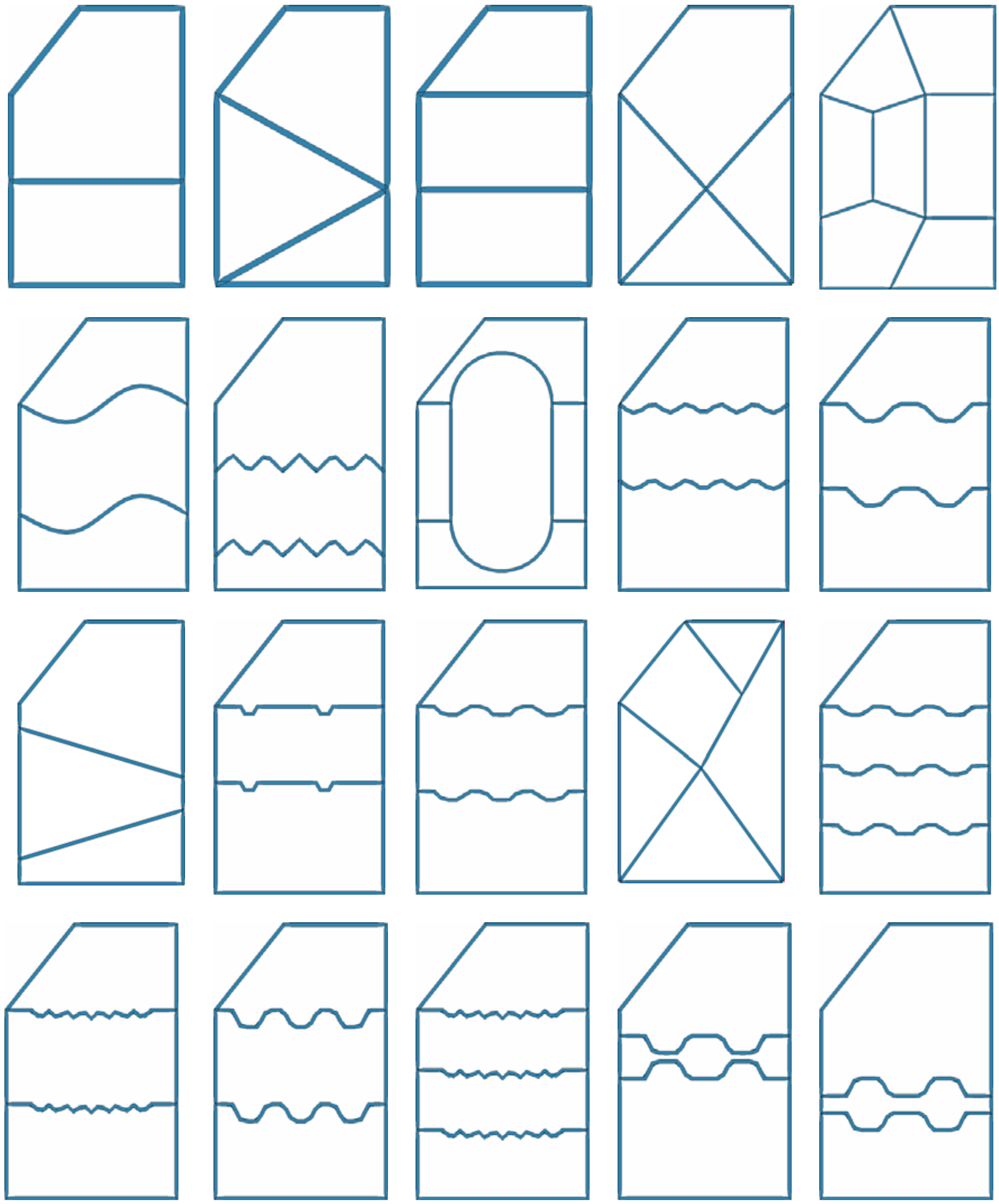


Fig. 8: Reaction force over the time of the result of the automatic optimization

4 Results of intuitive solutions

The problem is to find a global optimum for such complicated tasks. The question is: Is it possible to find similar or better results by intuitive approaches?
In figure 9 to 12 are the designed profiles of the student groups [5]. The students used CATIA, PATRAN, HyperMesh and LS-DYNA. The single working groups followed different approaches for the structural improvements. Beside the intuitive approach of creating and changing of the designs, the groups generated strategies like the following: In case of a good profile: 1) Analysis of the buckling mode, 2) small modification, 3) wall thickness variation. Table 2 and figures 13 and 14 summarize the results.



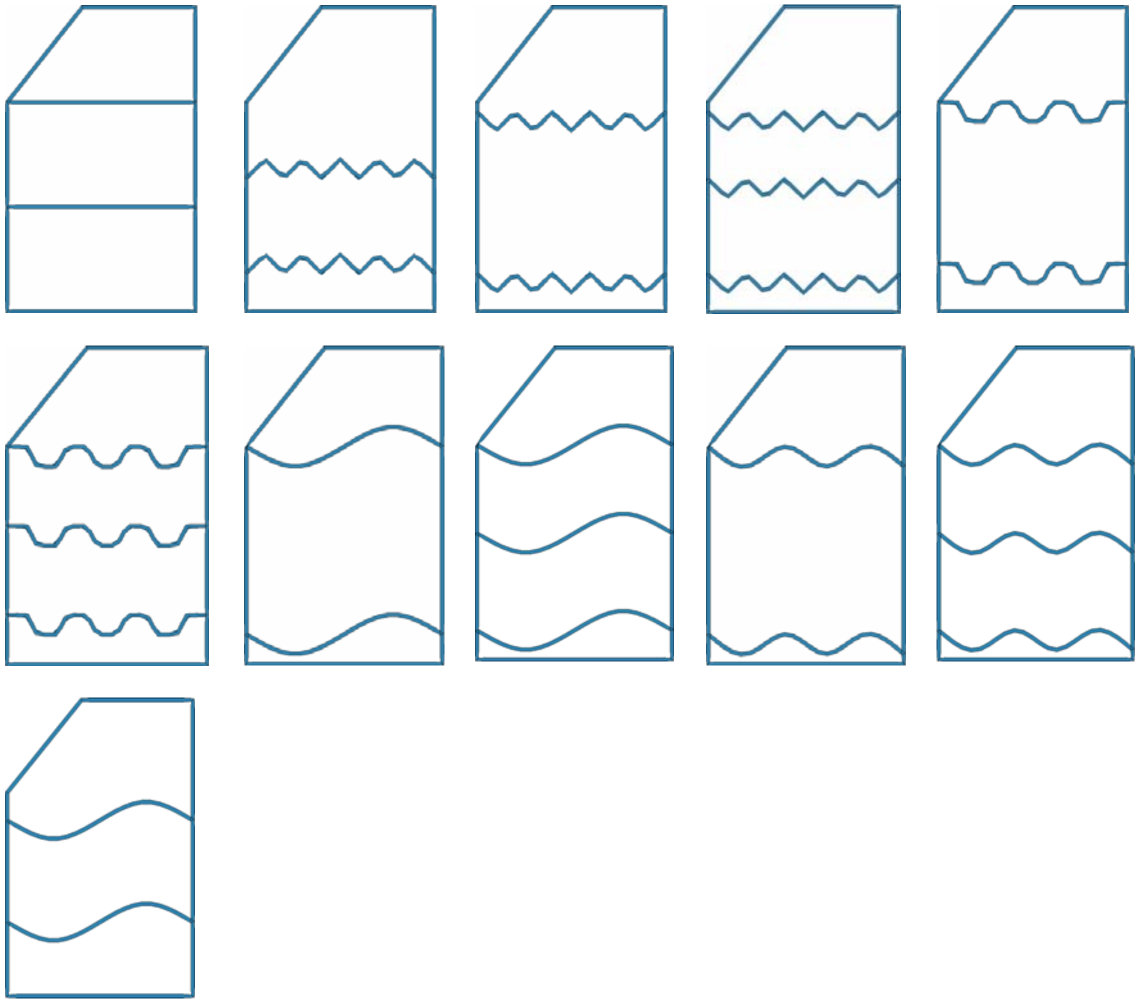
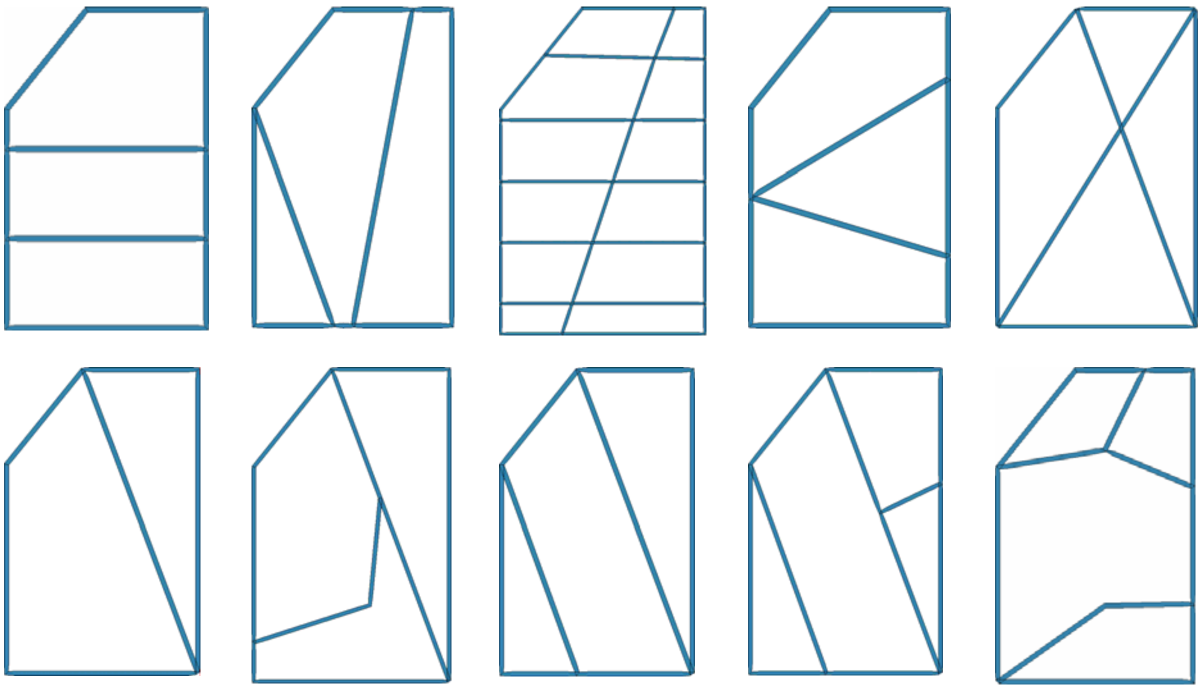


Fig. 9: Rocker profile designs of the student working group R1



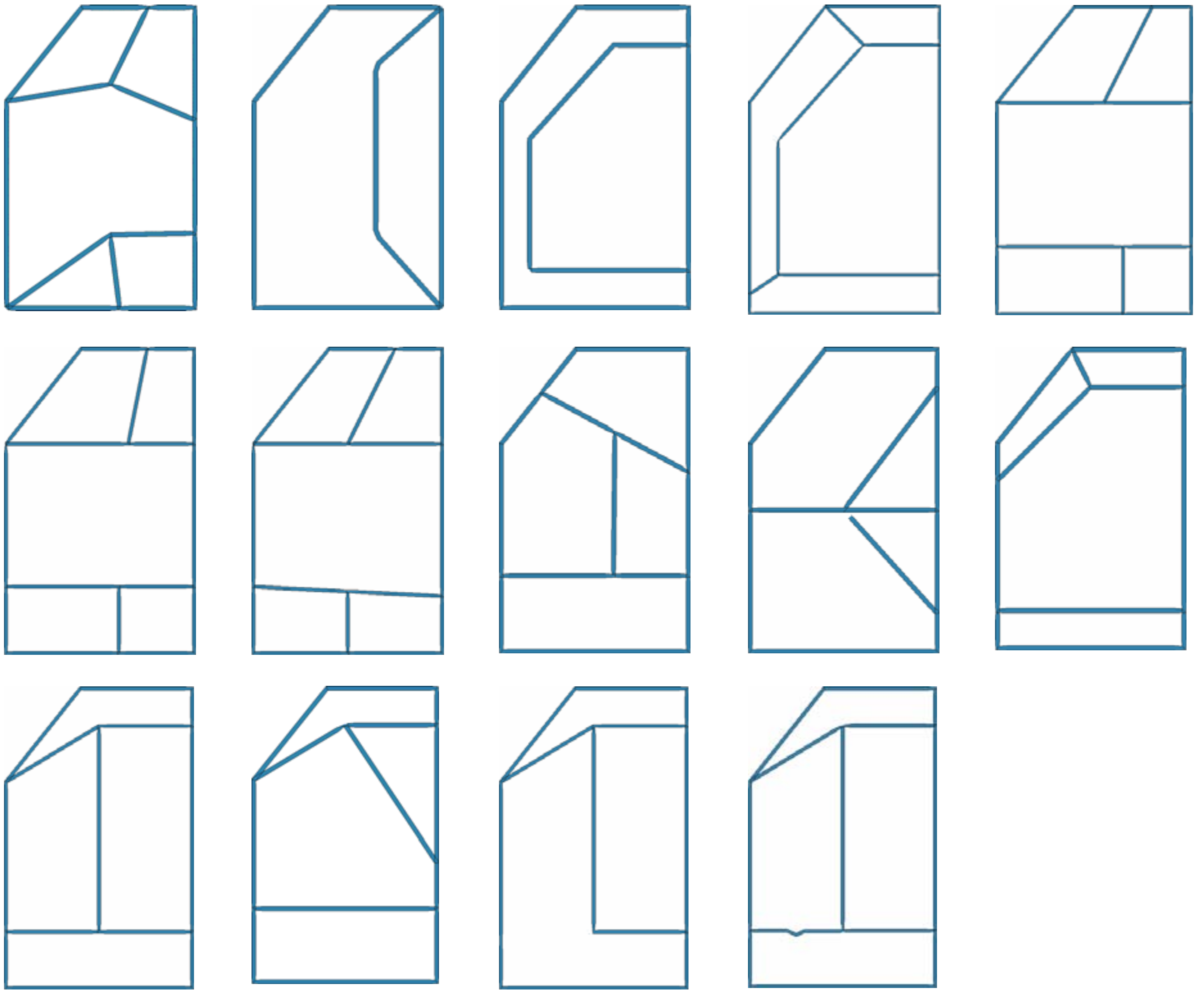
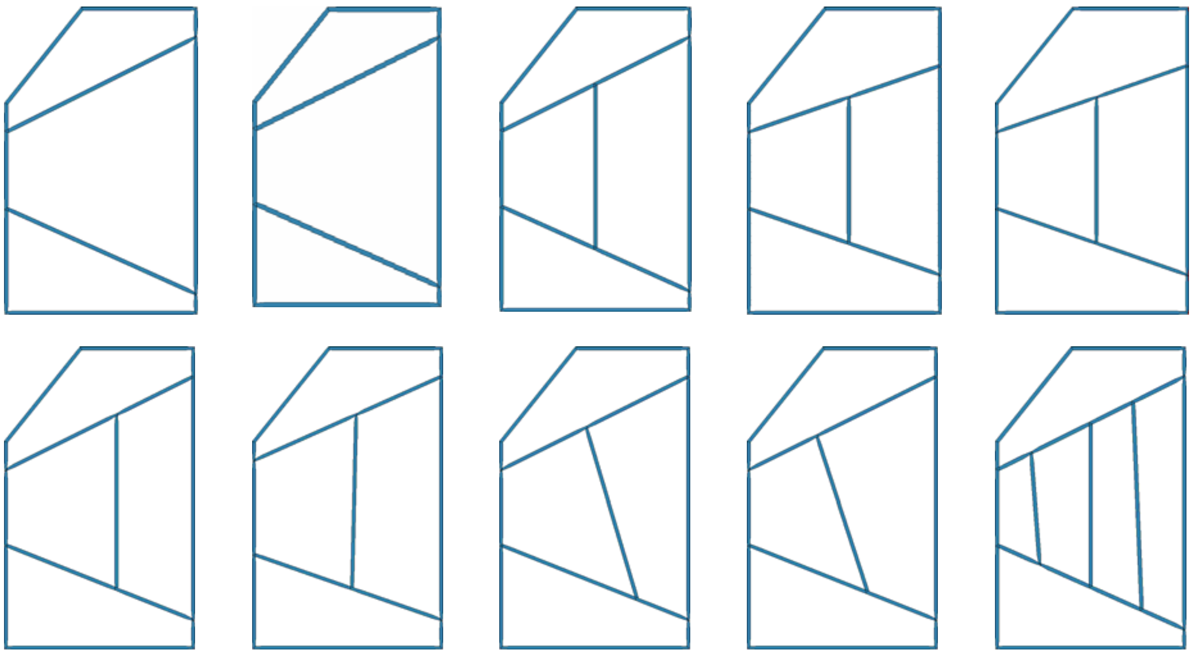


Fig. 10: Rocker profile designs of the student working group R2



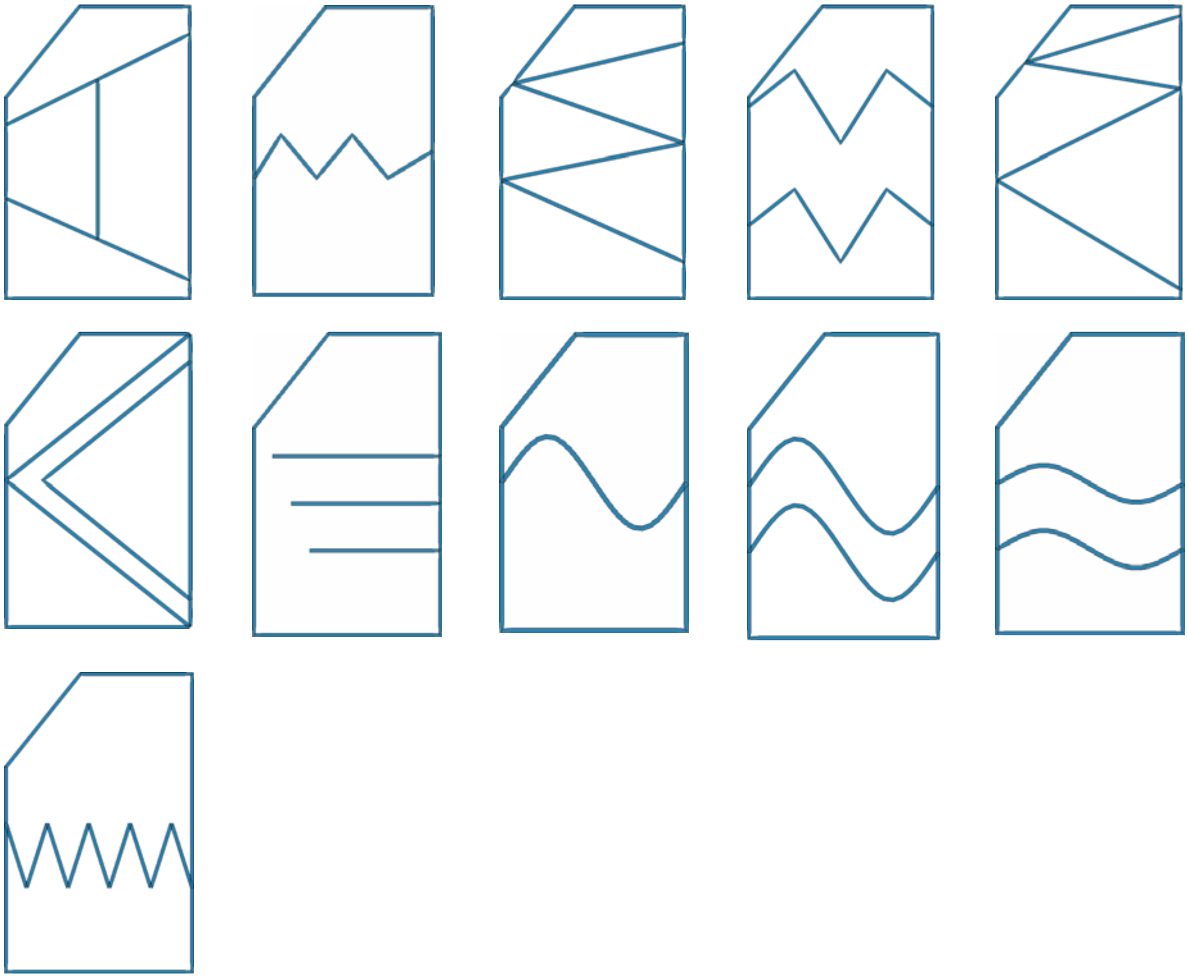


Fig. 11: Rocker profile designs of the student working group R3

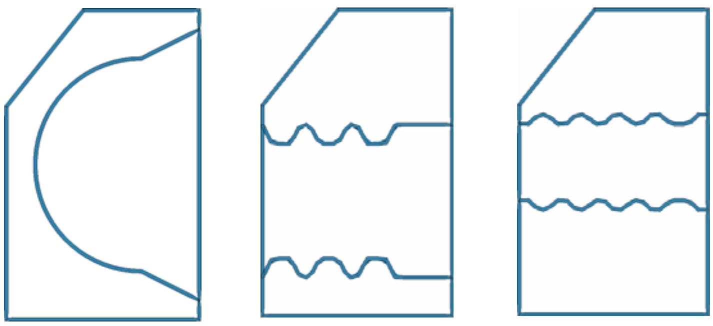


Fig. 12: Rocker profile designs of the student working group R4

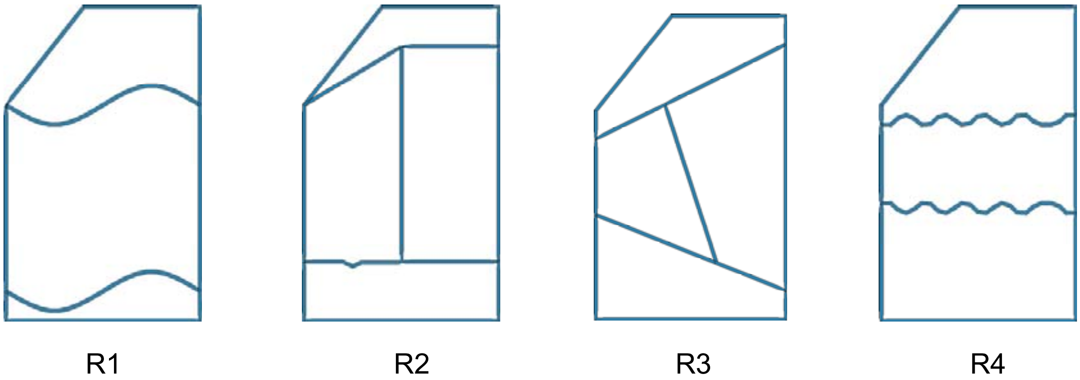


Fig. 13: Best results of four students groups

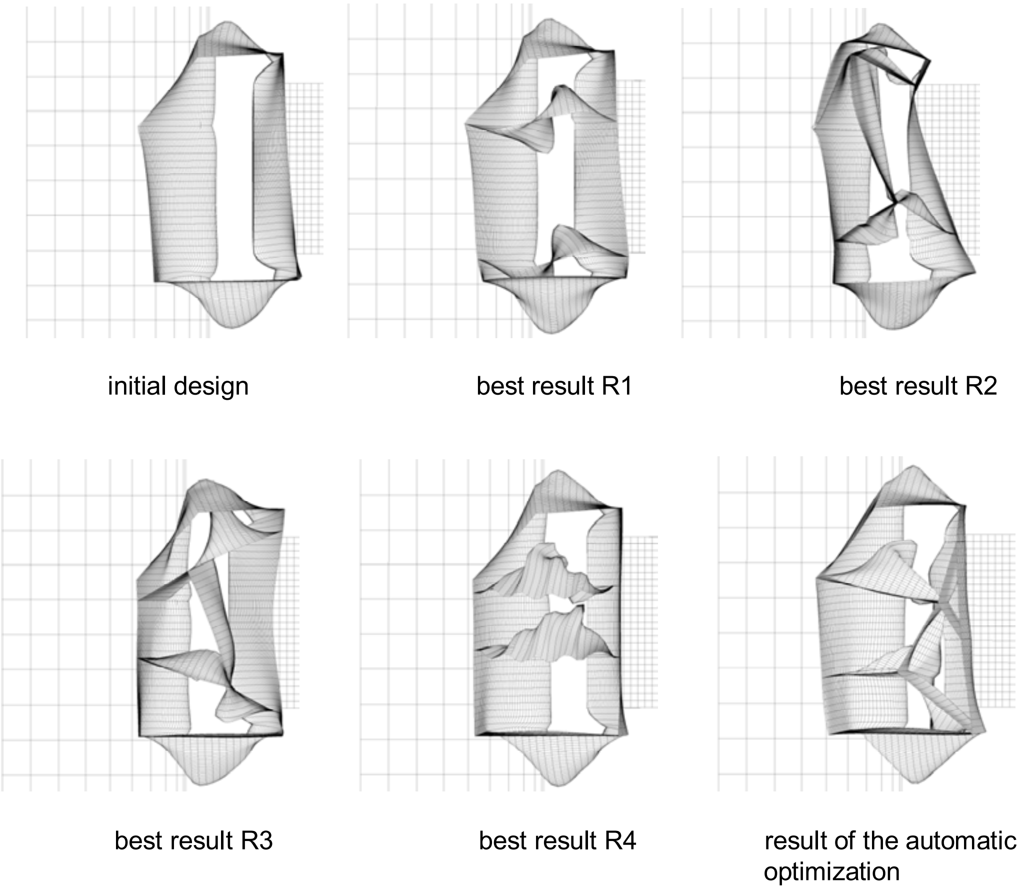


Fig. 14: Deformation plots of the designs

	max. RW force [kN]	mass [kg]	intrusion [mm]	wall thickness [mm]
Initial design	55.82	2.80	69.03	3.50
R 1	44.76	2.51	69.79	2.18
R 2	44.65	2.47	68.73	1.79
R 3	44.30	2.36	69.99	1.82
R 4	45.97	2.34	69.77	2.00
Optimizer	43.42	2.29	69.95	1.63

Tab. 2: Comparison of the different results

The results of the student groups are not as good as the results of the mathematical optimization, but nearby.

5 Acknowledgements

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6 Literature

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