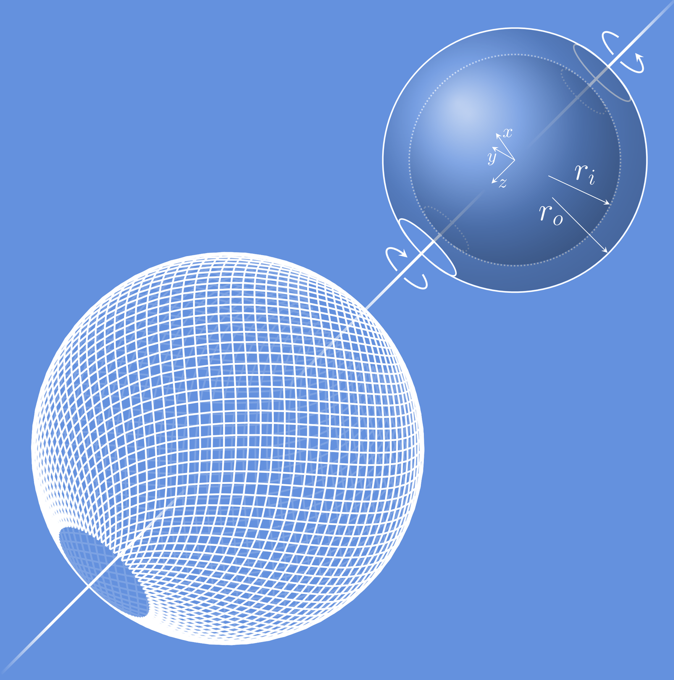

Topology Optimization of Truss Structures to Redesign Solid Components

Oliver Wege

Faculty of Mechanical and Process Engineering
University of Applied Sciences Düsseldorf · Germany

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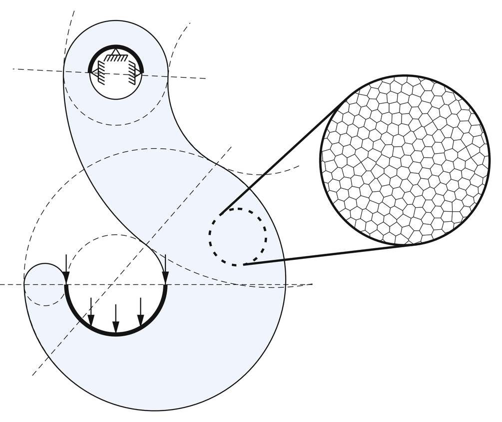
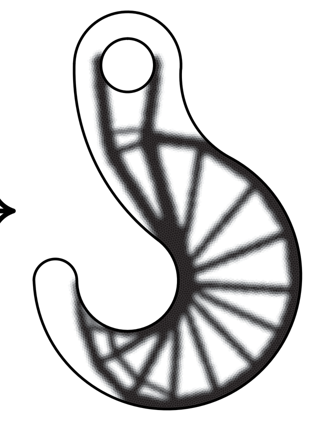
or get in touch via email at
oliver.wege@hs-duesseldorf.de

1 Motivation

Let's take a plane hook with a domain discretized by polygonal finite elements [5] →



And perform a topology optimization of the solid model (SIMP method) →



Note how the optimized structure appears more like a truss rather than a solid distribution of material? →

That's why this paper deals with the discretization and optimization of domains filled by truss elements

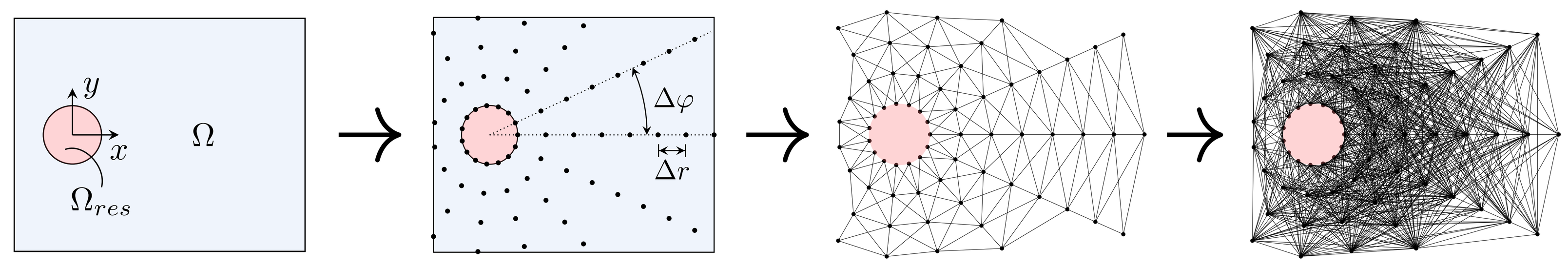
2 Finite Element Model

- Distribute a set of nodes $\mathcal{N}$ in the design domain Ω along Cartesian/polar axes
- Similar to [6], collect adjacent nodes in a connectivity matrix $\mathbf{C}^0$ to set up a base mesh and obtain structures of higher connectivity by

$$\mathbf{C}^{n_{lvl}} = \mathbf{C}^{n_{lvl}-1}\mathbf{C}^{n_{lvl}-1}$$

- The set of bars $\mathcal{B}$ is split into a physical (load carrying) set $\mathcal{B}_{phys}$ and a fictitious set $\mathcal{B}_{fict}$ containing all redundant elements as well as elements which are violating Ω_{res}

Read more about this fictitious domain approach e.g. in [4]



Domain geometry → Nodes $|\mathcal{N}| = 66$ → Base mesh $n_{lvl} = 0$ → Ground Structure $n_{lvl} = 2$

3 Optimization Algorithm

Weight optimization

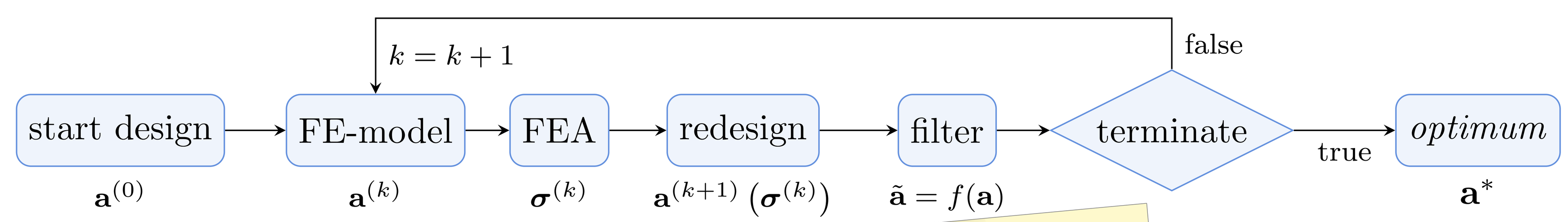
$$V^* = \min_{\mathbf{a}} V = \sum l_i a_i\,, \quad i \in \mathcal{B}_{phys}$$
$$\text{s.t.} \quad a^l < a_i \leq a^u$$
$$|\sigma_i| = \sigma^u$$

Aim for homogeneous stress distribution at the max. permissible amount

Redesign formula based on [1]

- Vary cross-sectional areas $\mathbf{a}$ based on the element's stress capacity
- Penalization of redundant elements with μ

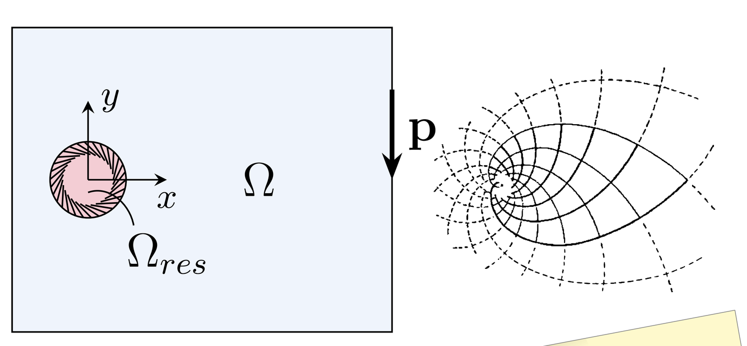
$$a_i^{(k+1)} = \begin{cases} \min\left(a_i^{(k)}\frac{\sigma_i^{(k)}}{\sigma^u},\ a^u\right) & ,\, a_i^{(k+1)} > a^l \\ \mu = 10^{-12} & ,\, a_i^{(k+1)} \leq a^l \end{cases} \qquad i \in \mathcal{B}$$



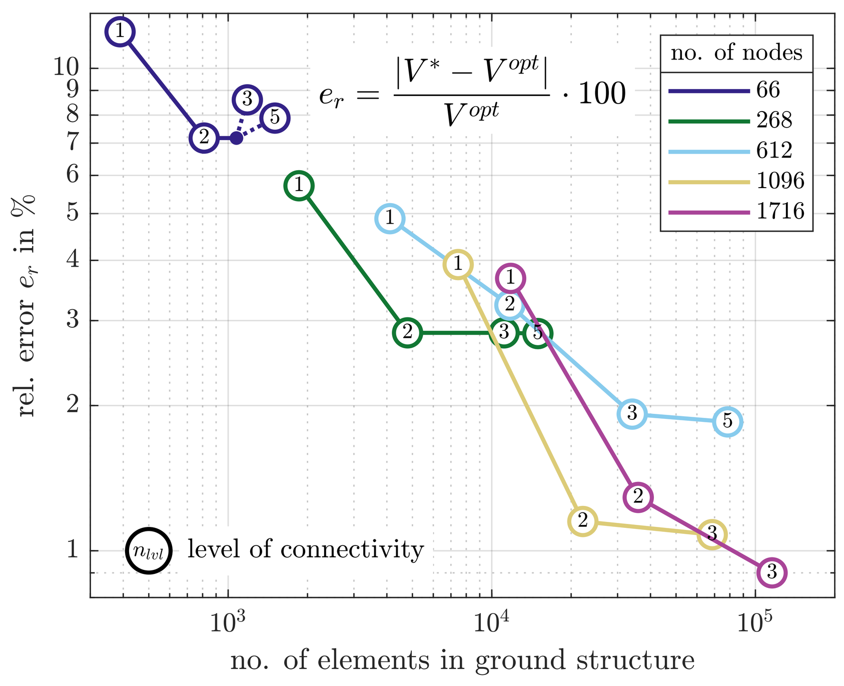
The Heaviside function is used for filtering to improve contouring and convergence [2]

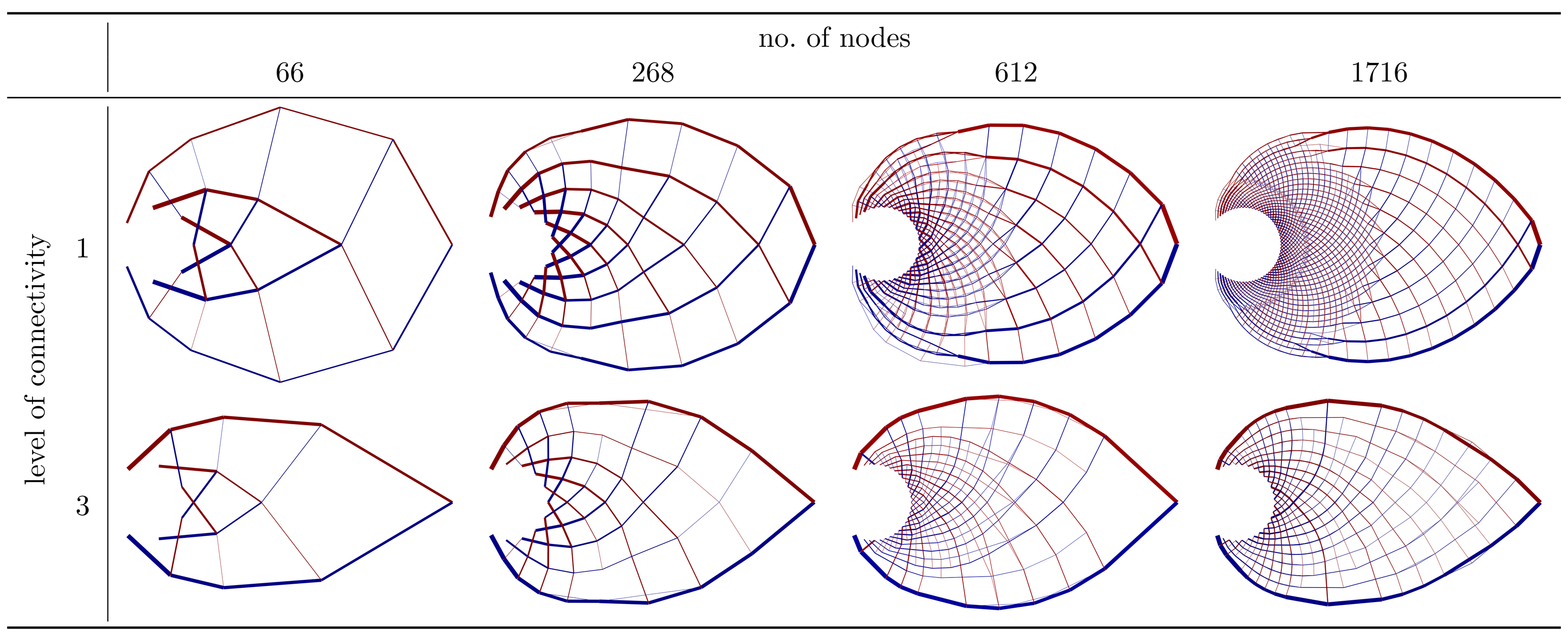
4 Verification

The optimality is evaluated based on MICHELL's optimal solution V^{opt} [3].



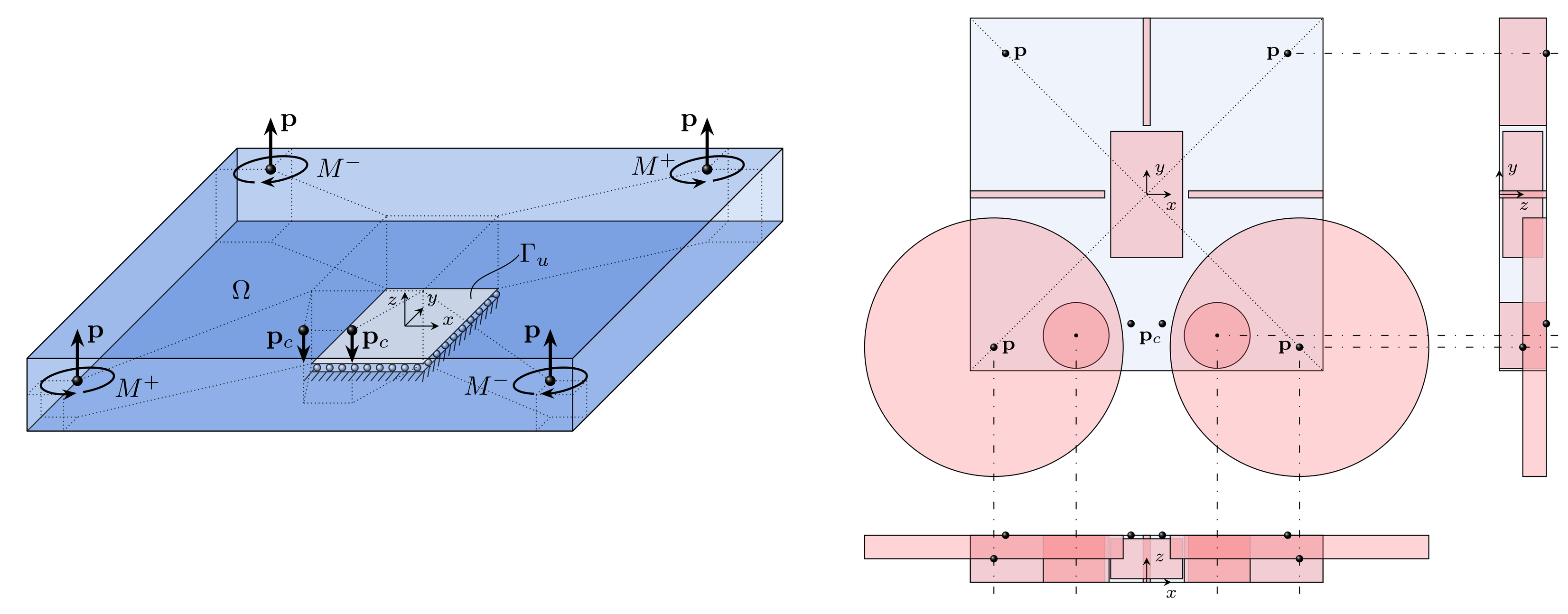
The original MICHELL structure [3] for visual comparison

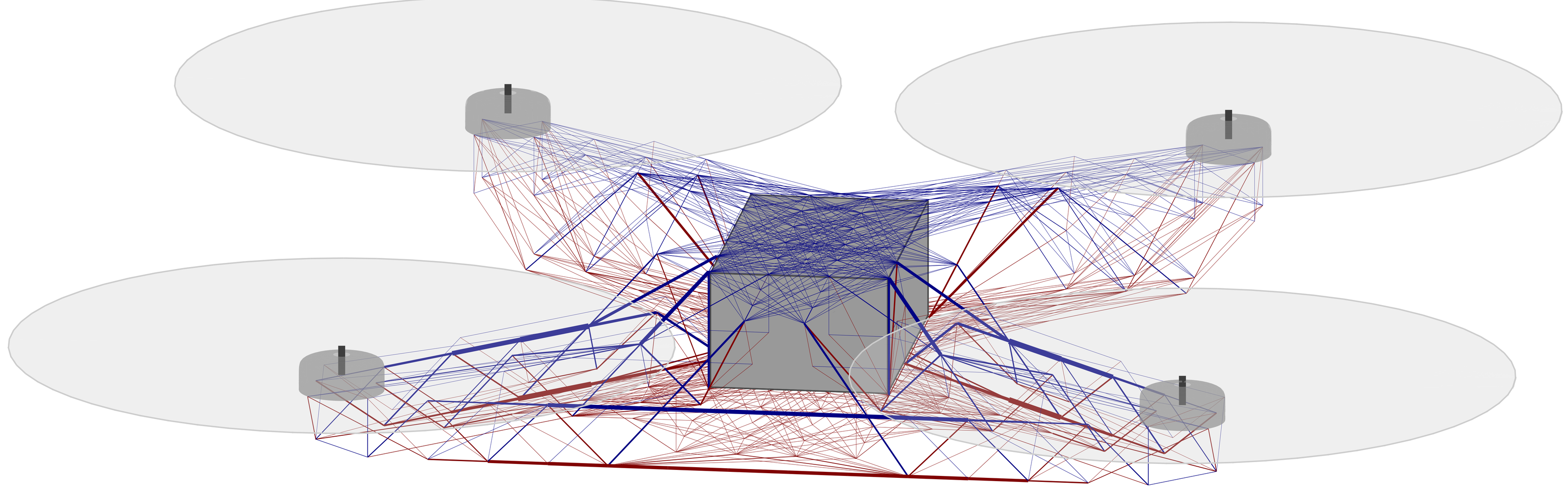




5 Demonstration

- Model of a drone frame
- Test on behavior with more complex geometry and boundary conditions





6 Conclusion

- Algorithm converges to MICHELL's optimal solution
- High computational effort for high optimality (up to several hours run time)
- Nevertheless errors $< 1\%$ obtained
- Contouring issues for densely filled ground structures
- Stress field-based pre-orientation of the ground structure could be helpful

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