Automated and Accurate Geometry Extraction and Shape Optimisation of 3D Topology Optimisation Results

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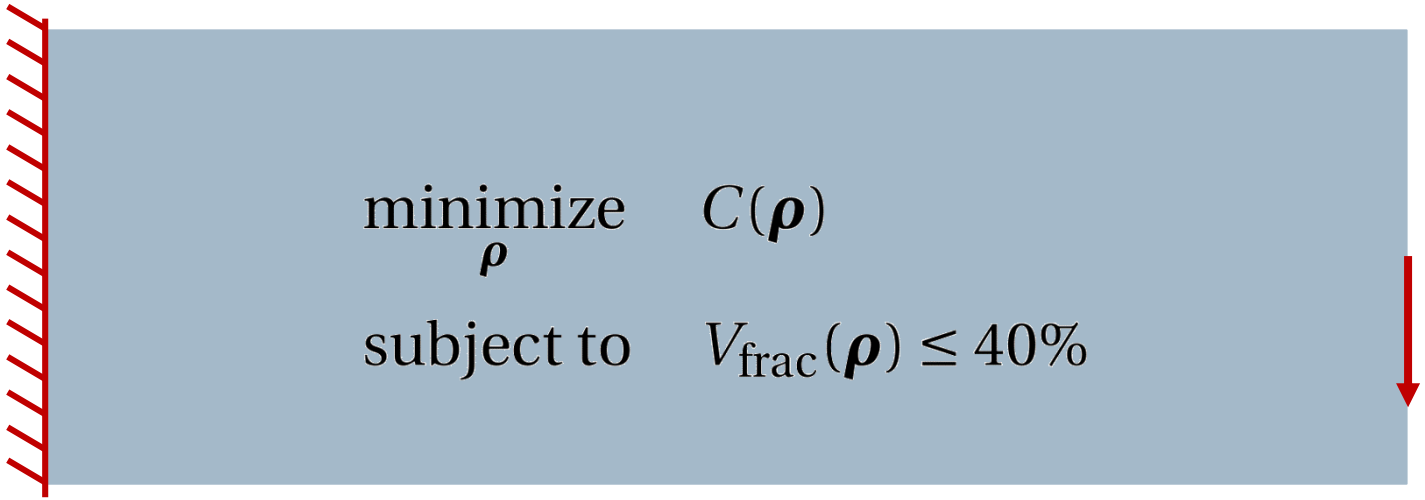
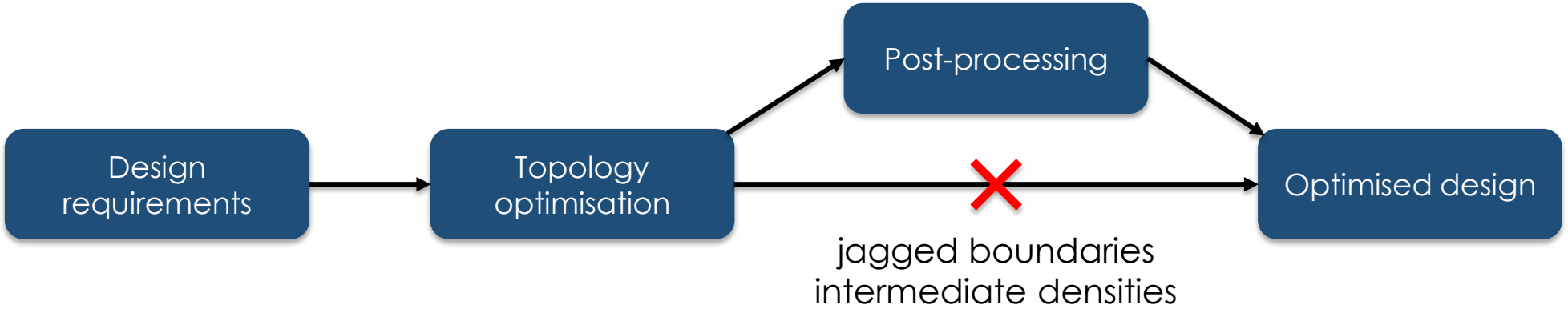
Introduction – Topology optimisation

- Design requirements
  - Boundary conditions
  - Variables: material placement
  - Objective: maximum stiffness (minimum compliance)
  - Constraint: limit amount of material used

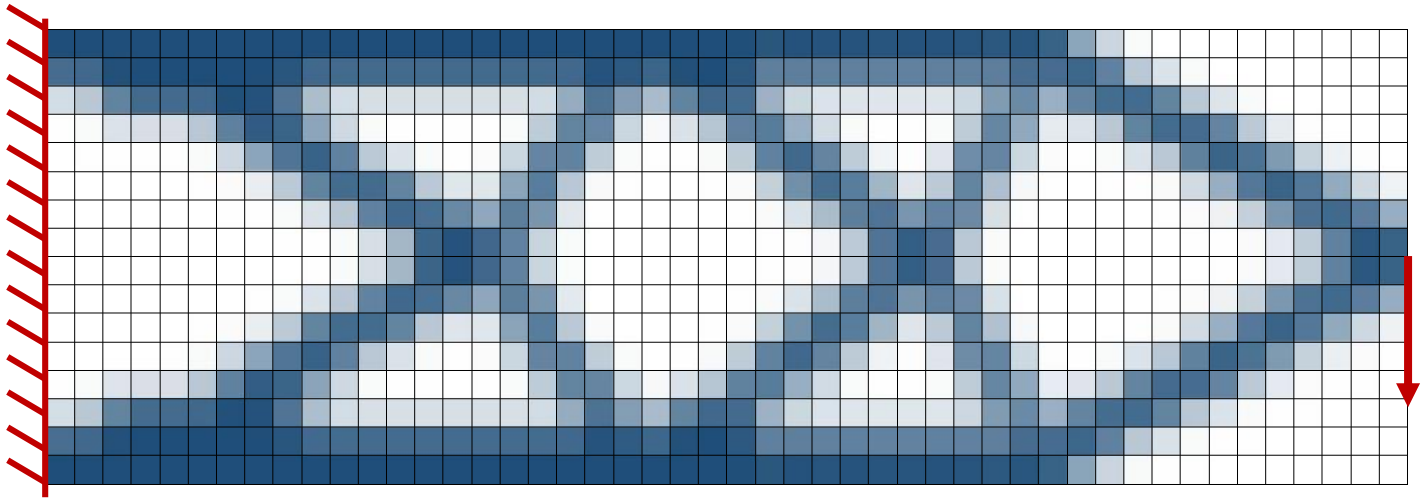


Introduction – Topology optimisation



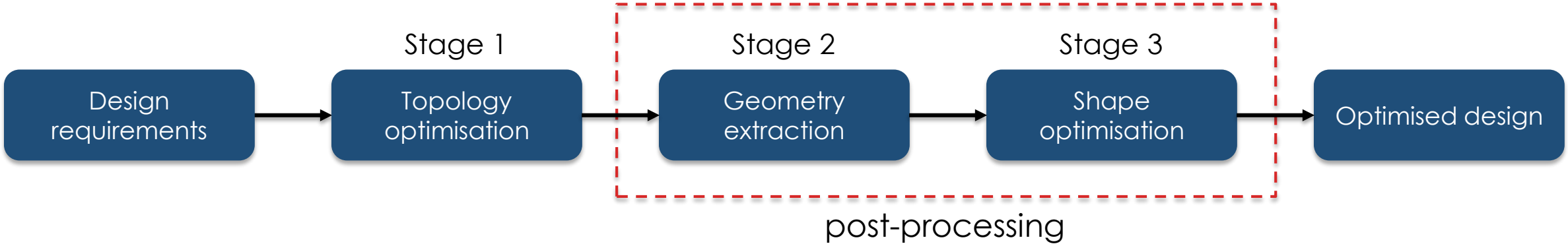
$$\min_{\rho_i} \quad C(\rho_i)$$

$$\text{s.t.} \quad V_{\text{frac}}(\rho_i) \leq 40\%$$



Introduction – Post-processing

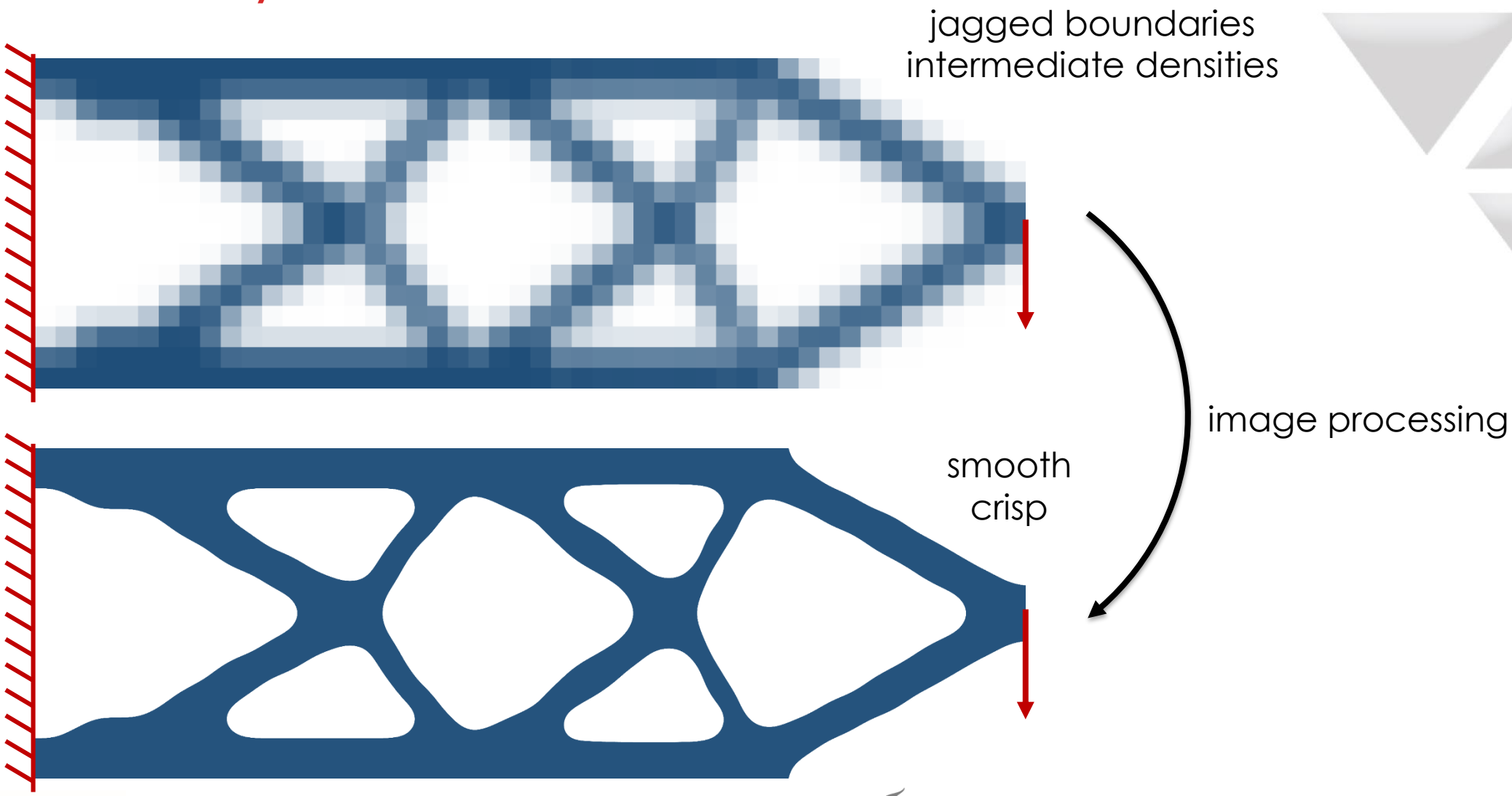
- Goals
  - Automatic
  - Accurate and optimised
  - 3D



Contents

- Structural design optimisation (2D)
  - Stage 1. Topology optimisation (TO)
  - Stage 2. Geometry extraction
  - Stage 3. Shape optimisation
- Case studies (3D)
- Performance
- Conclusions

Geometry extraction



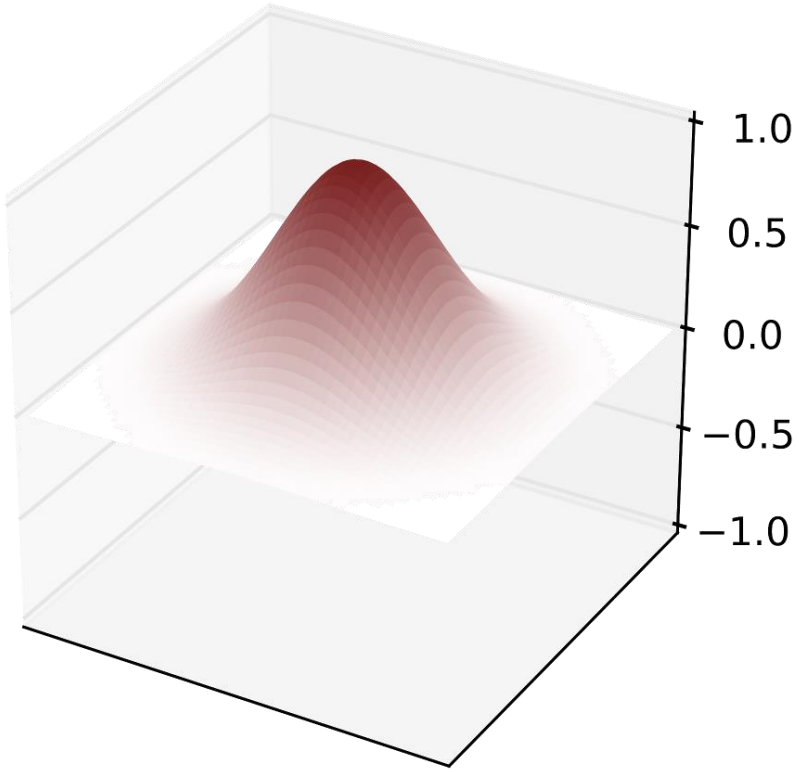
Level Set Function (LSF)

- Radial Basis Function (RBF):

$$N_i(x) = e^{-R_i(x)^2} \cdot w_i$$

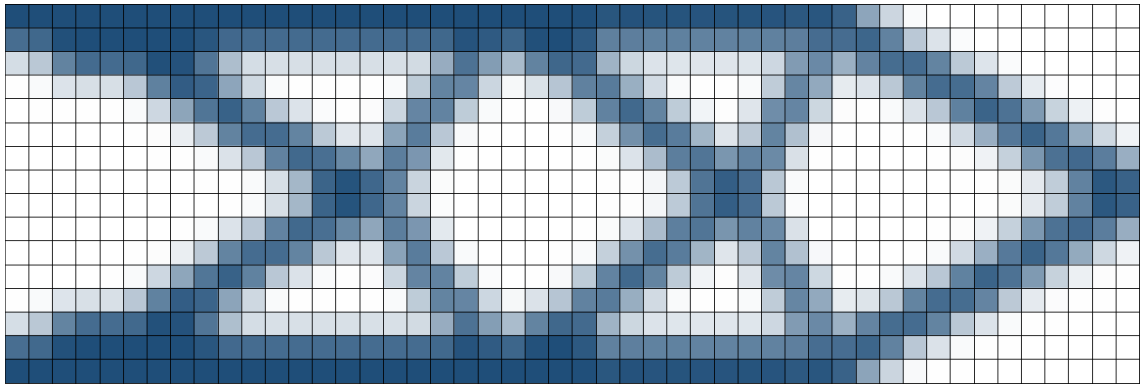
- Sum RBFs to Level Set Function (LSF):

$$\phi(\mathbf{x}, \mathbf{w}) = \sum_{i=1}^{n} e^{-R_i(x)^2} \cdot w_i$$

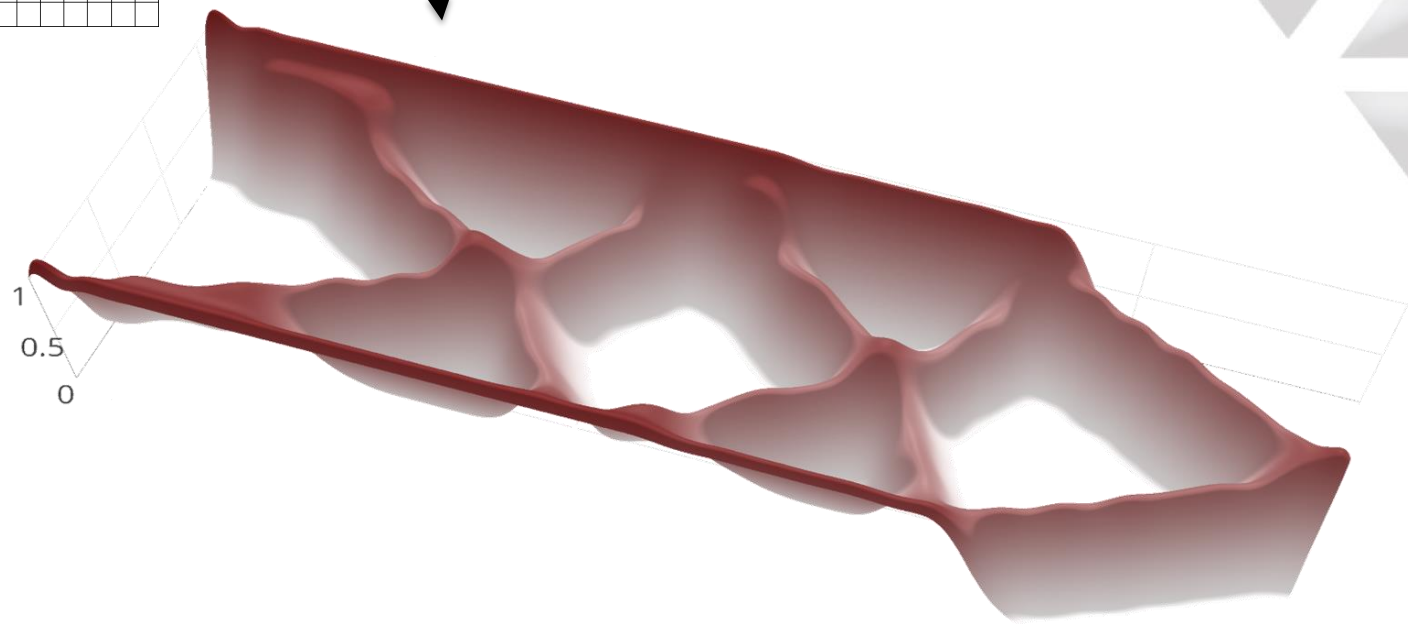


RBF with weight $w_i = 1.0$

Topology optimised result to LSF



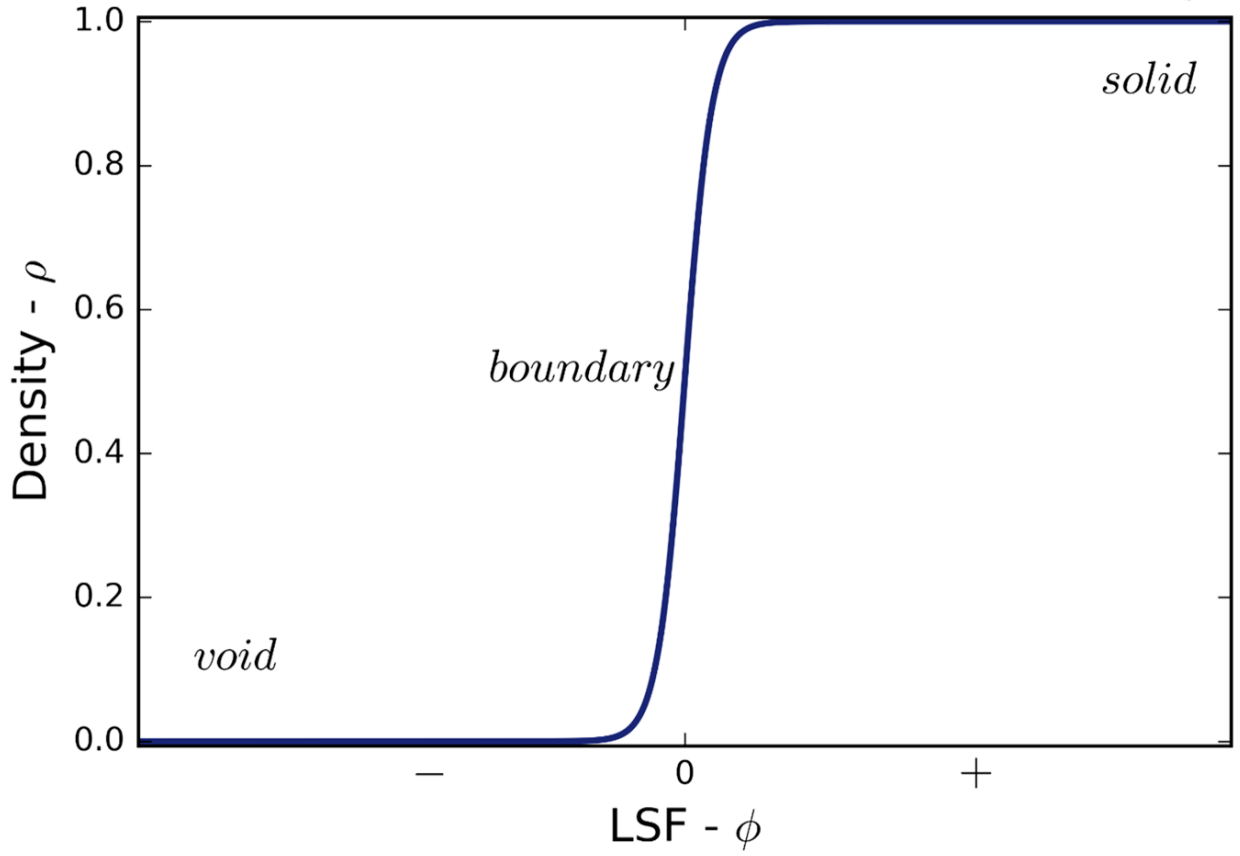
Solve set of linear equations



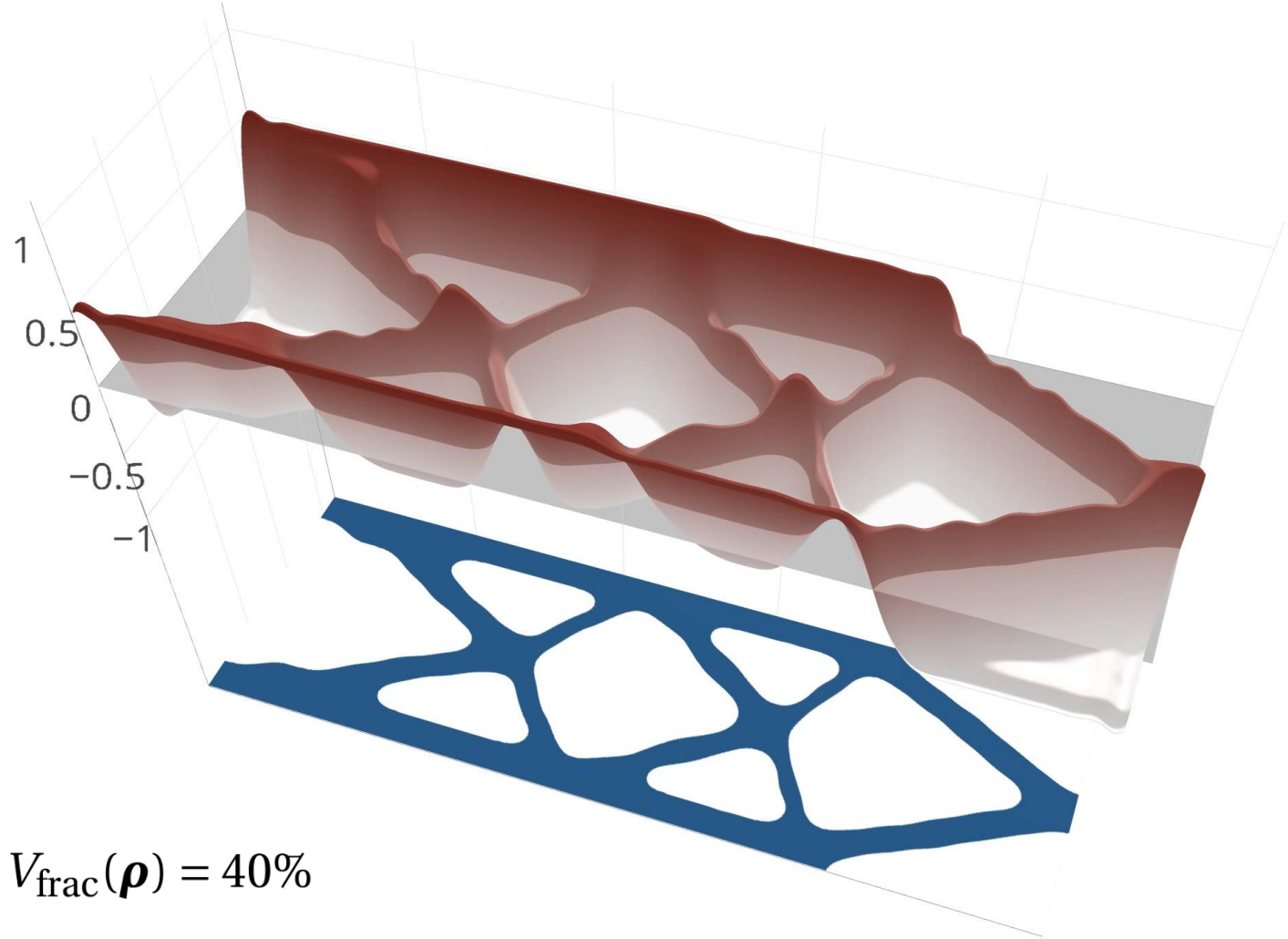
- RBF at every element
- LSF equals TO density value at every element centre location
- LSF is fully positive

LSF to smooth density field (1)

- $\hat{\rho} = \rho_0 + (1 - \rho_0) \cdot \left(\frac{1}{1 + e^{-\kappa\phi}} \right)$
- Heaviside function

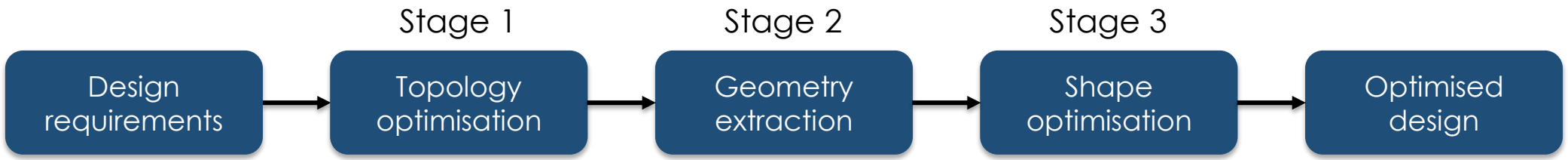


LSF to smooth density field (2)



$$V_{\text{frac}}(\boldsymbol{\rho}) = 40\%$$

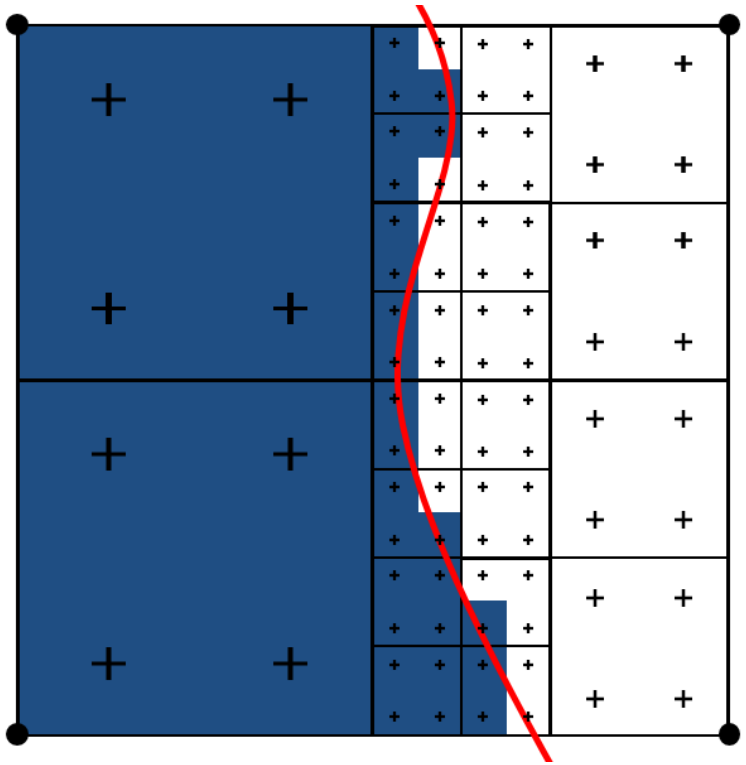
Shape optimisation

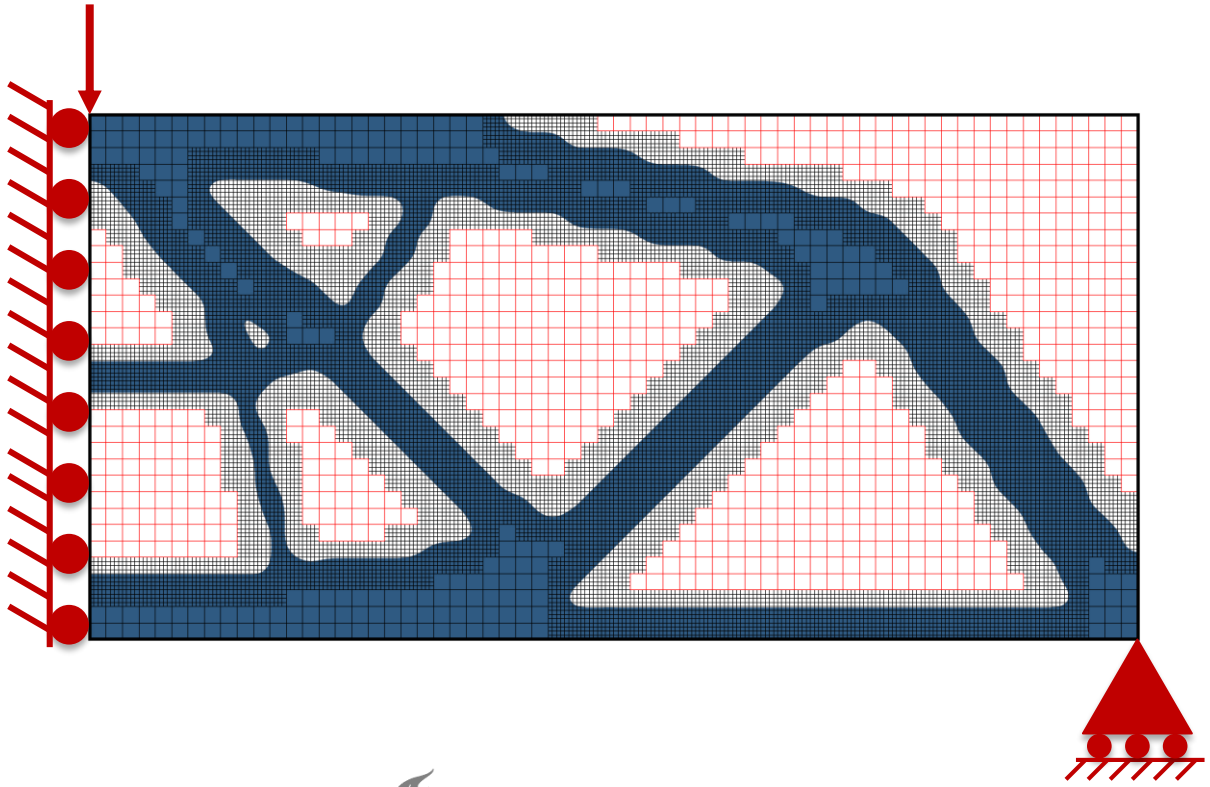


- Not an optimised design anymore
- Image interpretation – no mechanics
- Variables: weights w_i of Radial Basis Functions
- Two tools: structural analysis and sensitivity analysis

Structural analysis

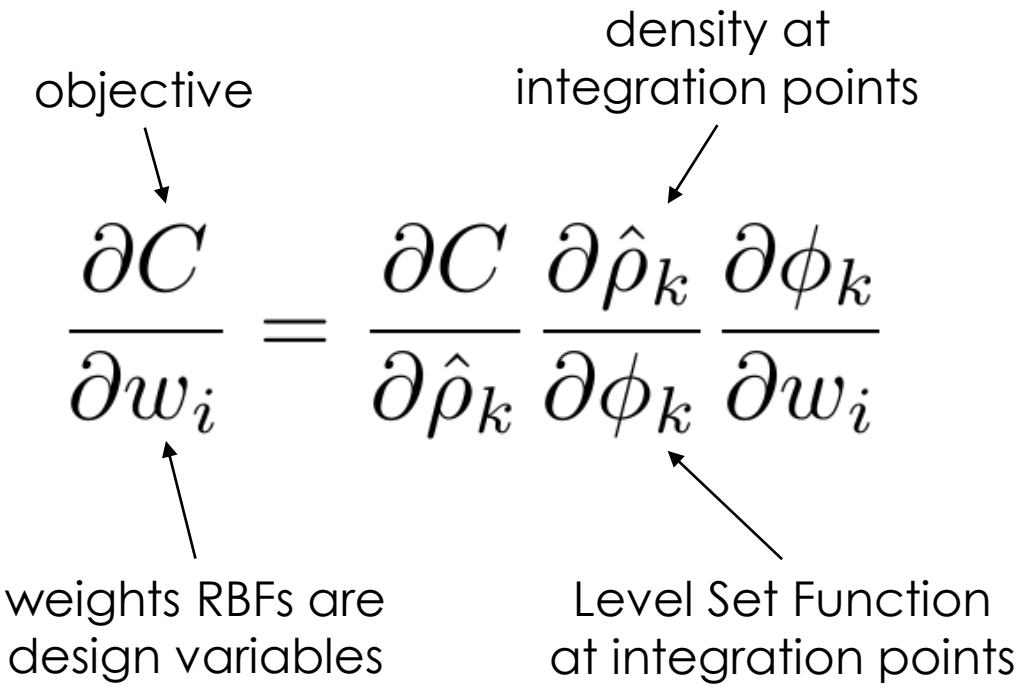
- Same mesh as topology optimisation
- *p*-FEM + quadtree integration = Finite Cell Method



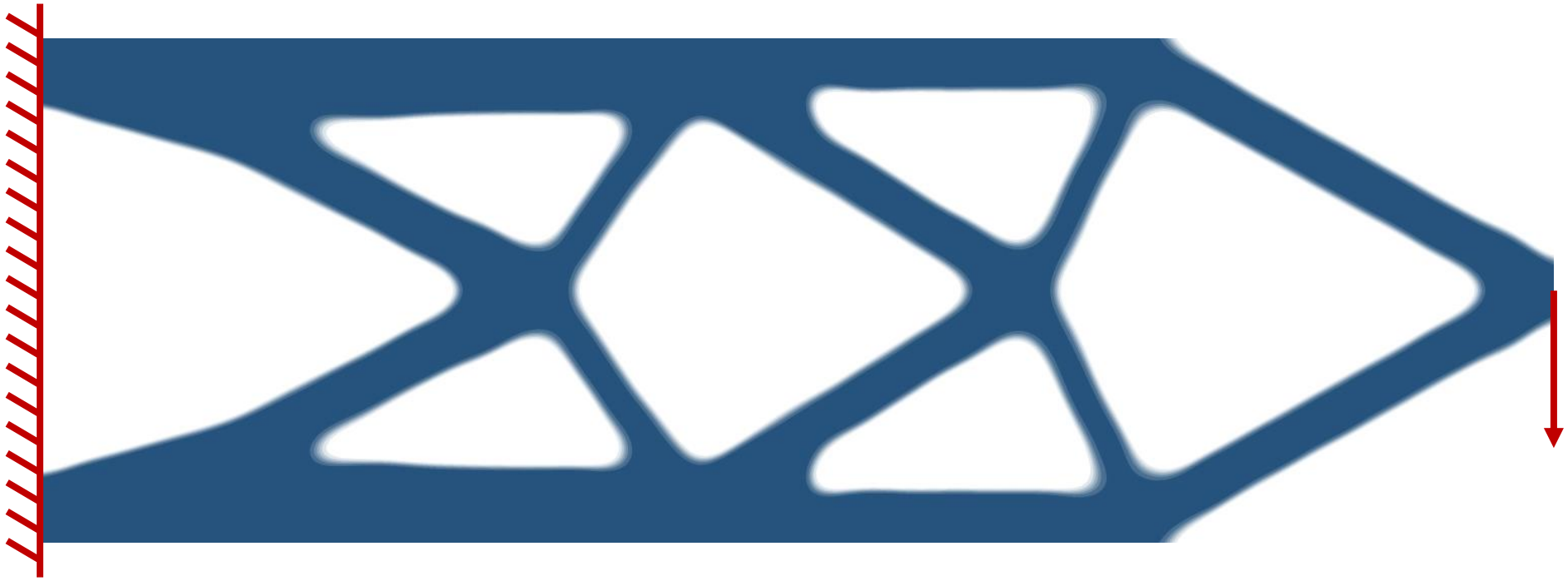


Sensitivity analysis

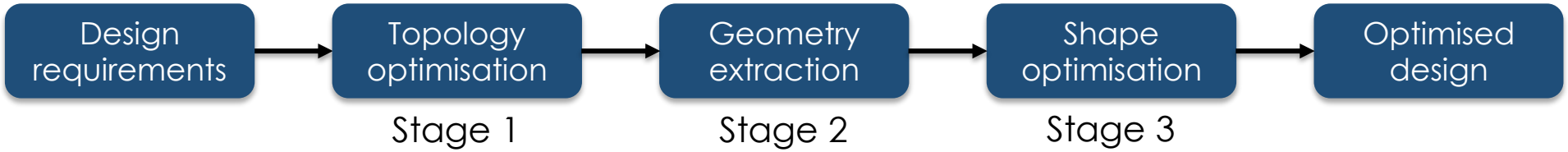
- Gradient-based optimisation

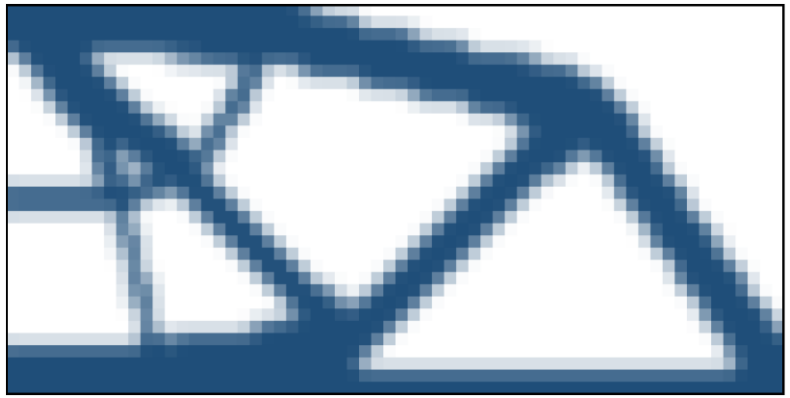


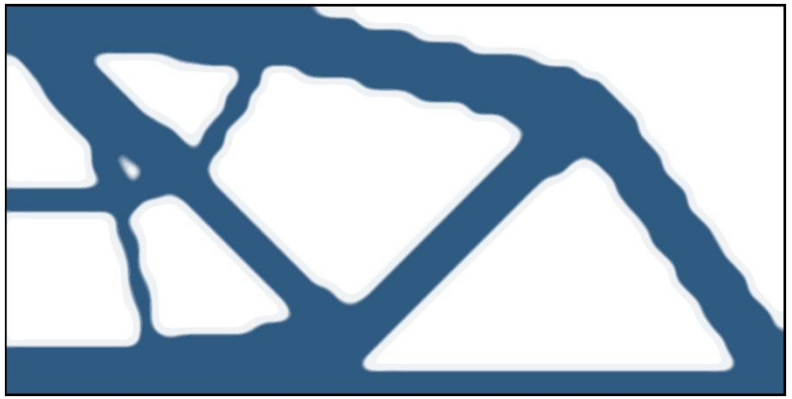
Shape optimisation

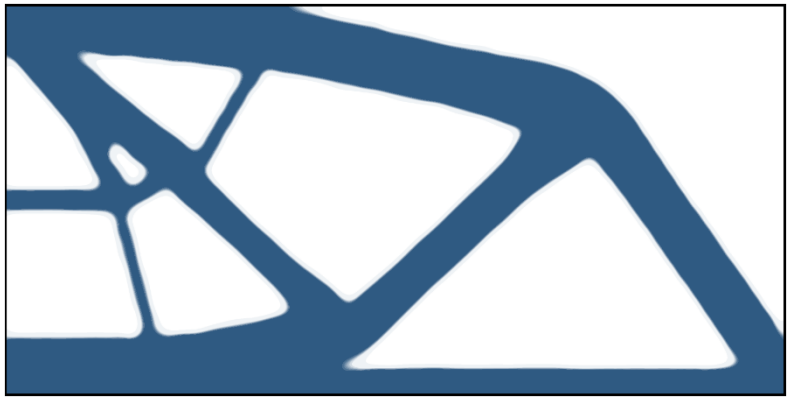


Summary three-staged procedure

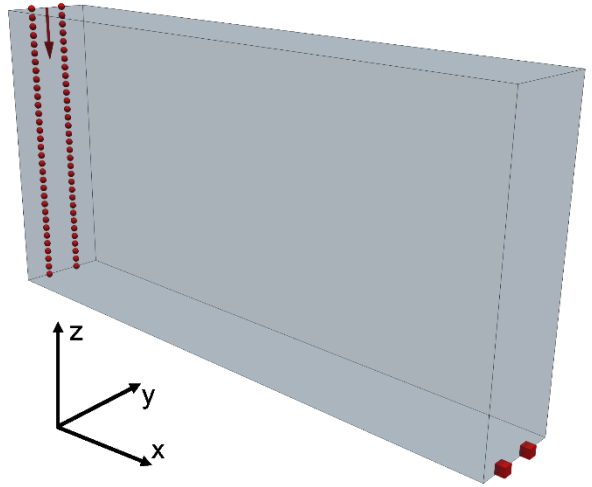


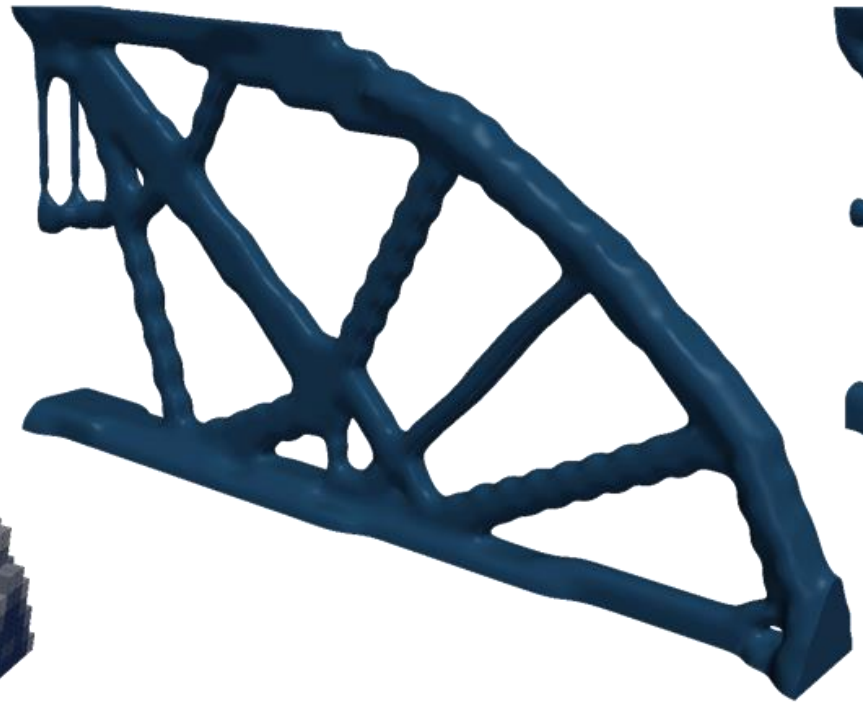


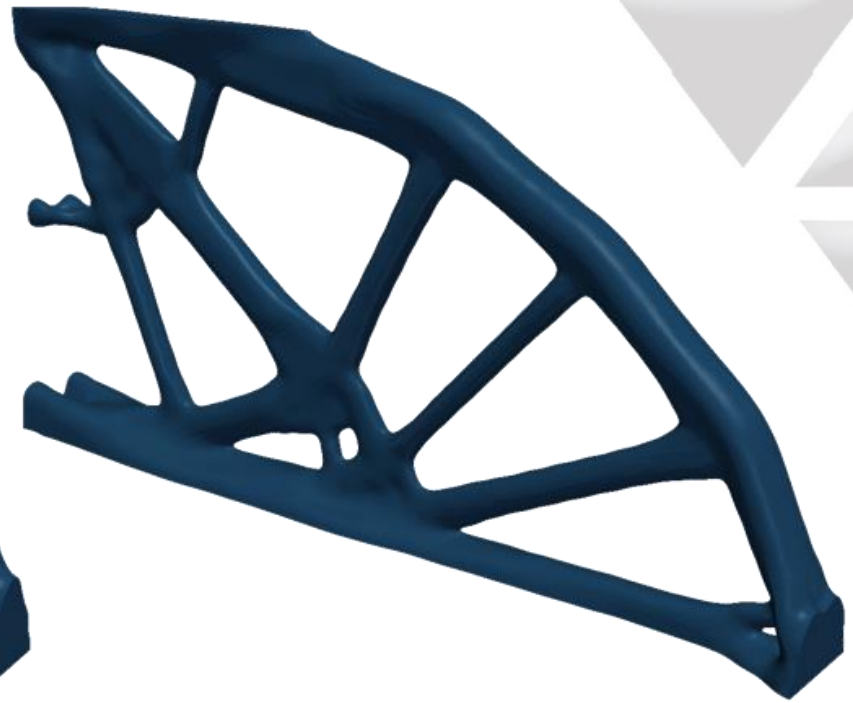




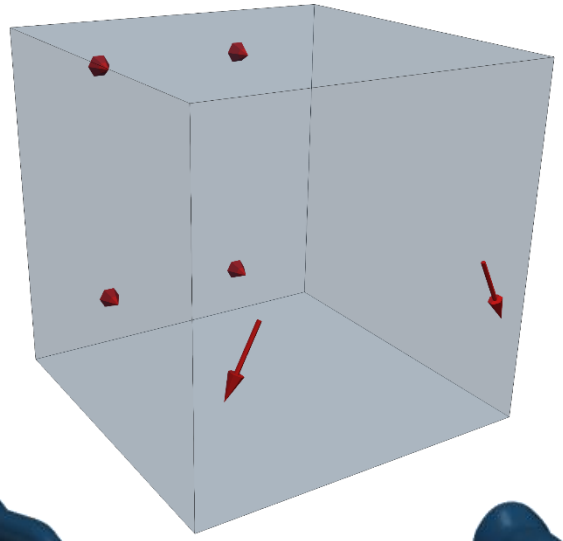
Case studies (1)

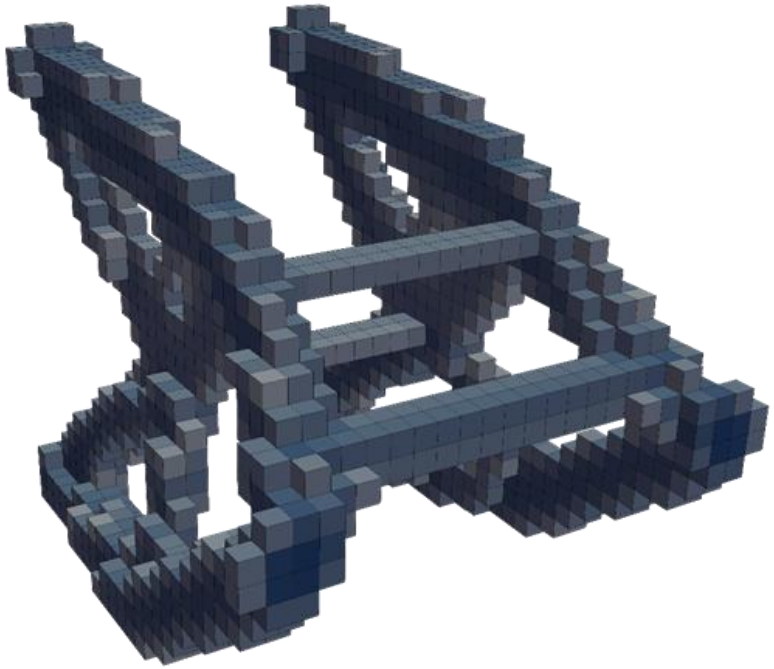


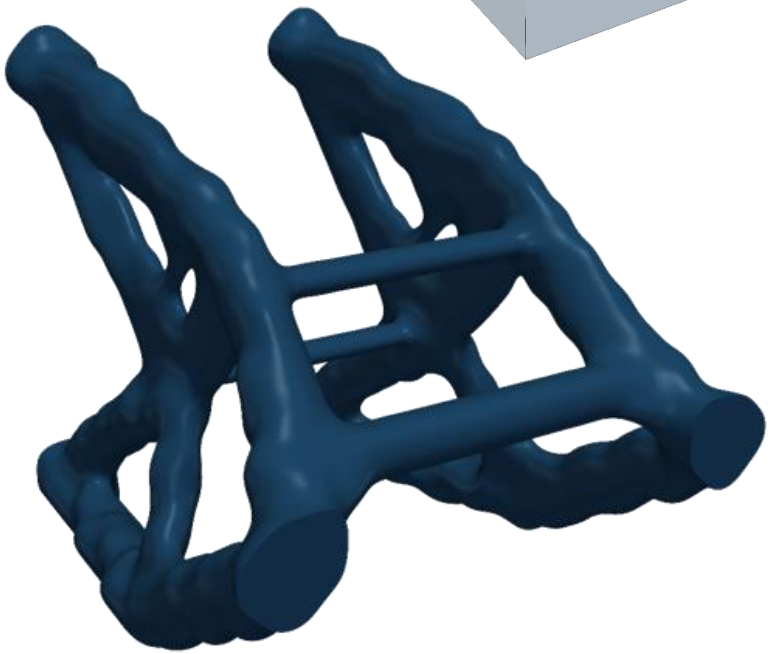


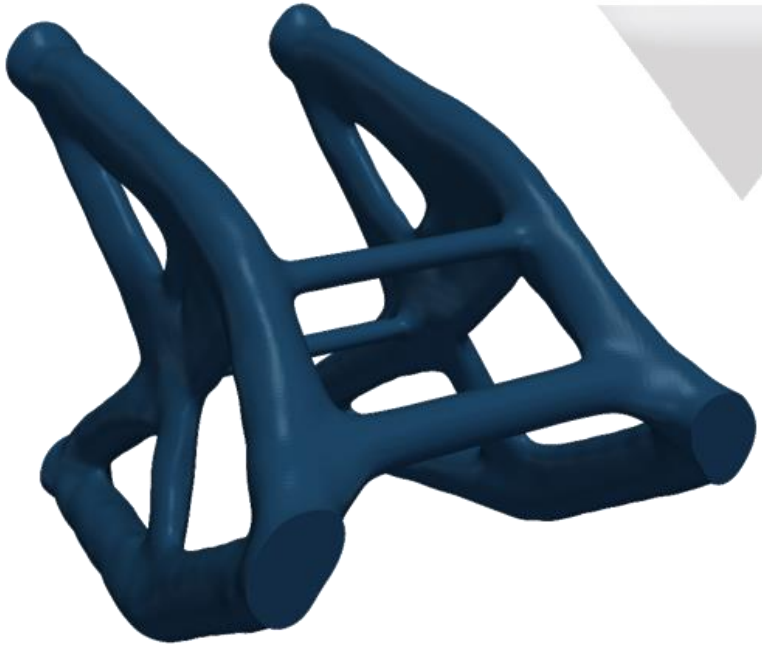


Case studies (2)









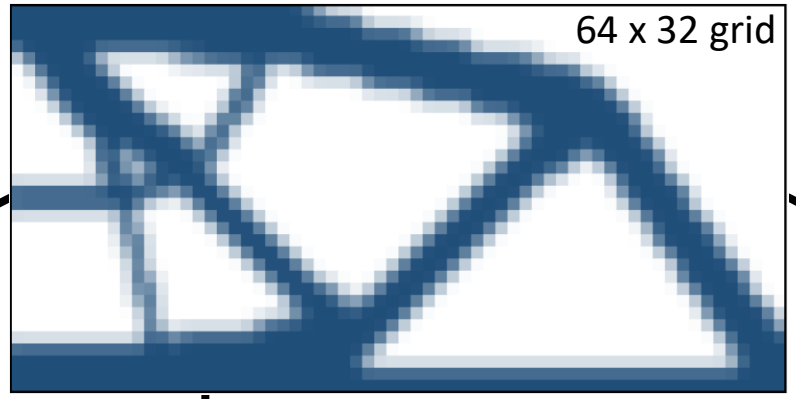
Performance – computation time (1)

- Post-processing takes more time on average
- Prototype Python implementation
- Similar quality using TO alone is less efficient

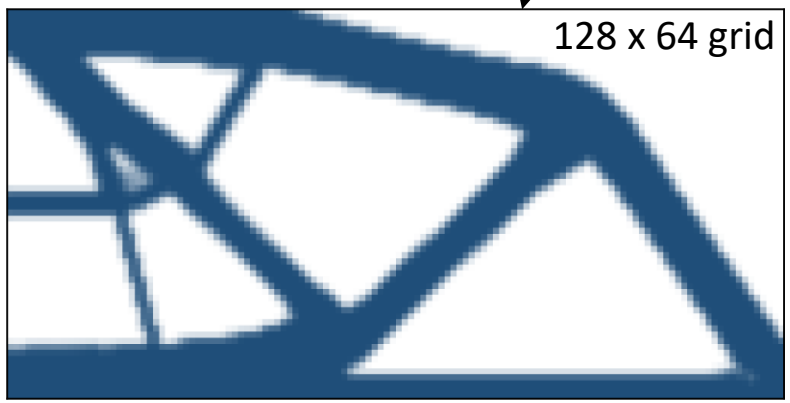
Computation times (s) for the case studies.

Case study	Grid size	Stage 1	Stage 2	Stage 3	Stage 2 + 3
2D MBB	64 x 32	20	1	22	53%
2D Cantilever	180 x 120	371	6	167	32%
3D MBB	64 x 10 x 32	1,203	53	3,108	72%
3D Cantilever	30 x 30 x 30	1,454	80	2,369	63%

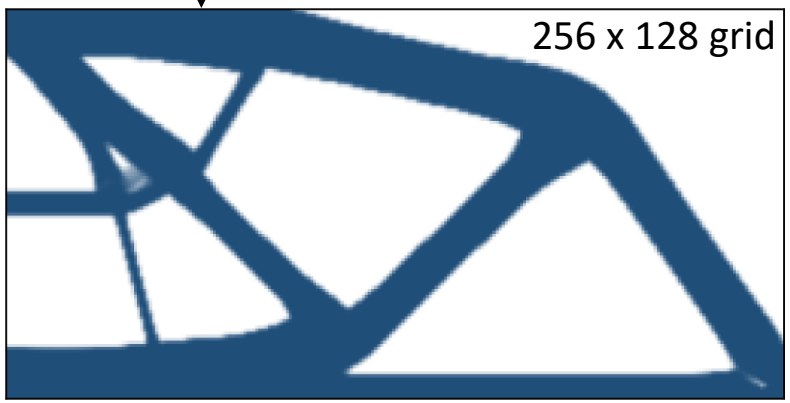
Performance computation time (2)



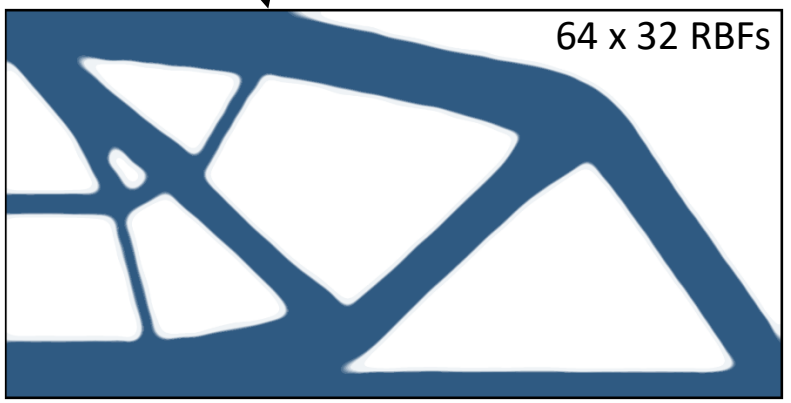
20 extra TO iterations
took 25 seconds



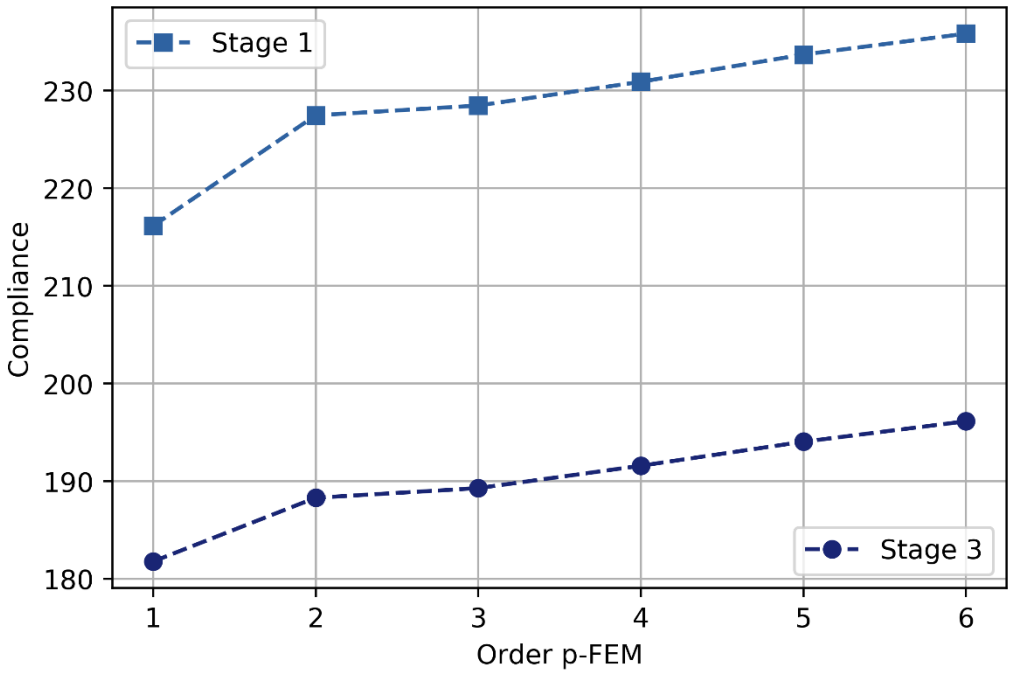
20 extra TO iterations
took 262 seconds

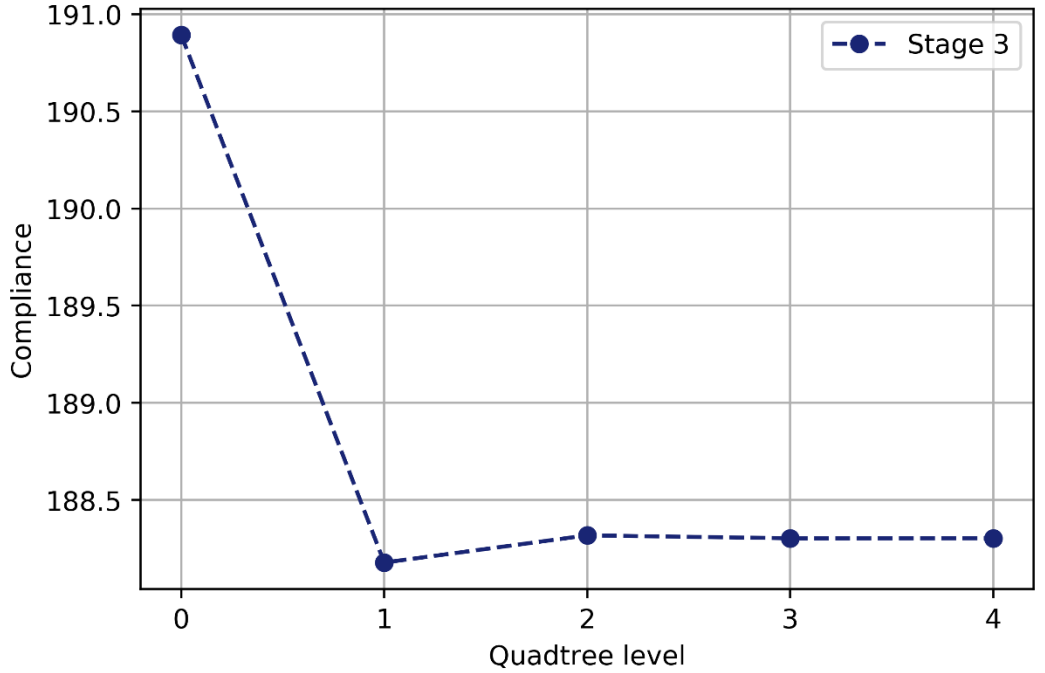


3-staged process
took 23 seconds

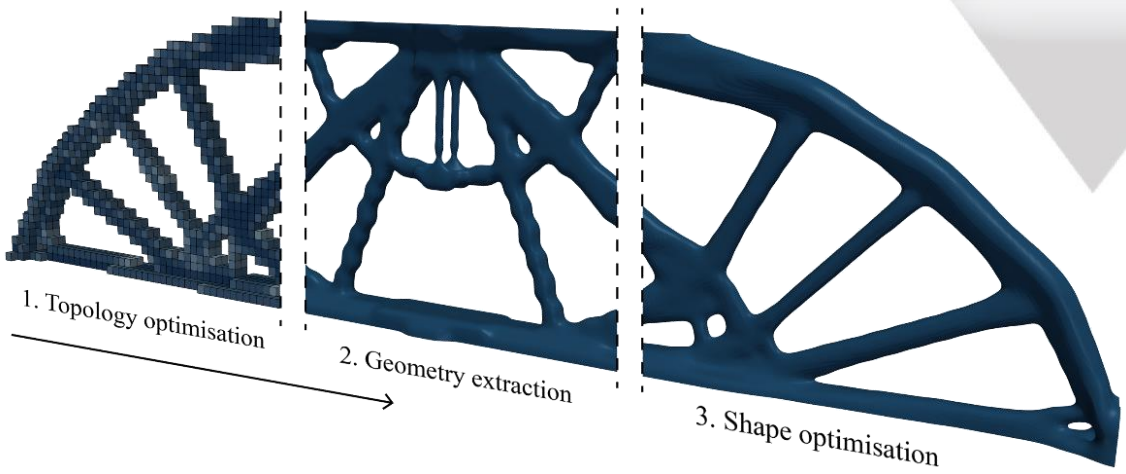


Performance – accuracy





Conclusions



- Automatically smooth and optimised designs
- Almost no intermediate densities
- Computation times are high (or low?)
- No remeshing, still sufficient analysis accuracy
- Easily extendable to other types of optimisation problems

Thank you very much!

engineering innovation

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