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Data-driven Design Approach to Hierarchical Hybrid Structures with Multiple Lattice Configurations

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References

Zhen Liu, Liang Xia*, Qi Xia, Tielin Shi

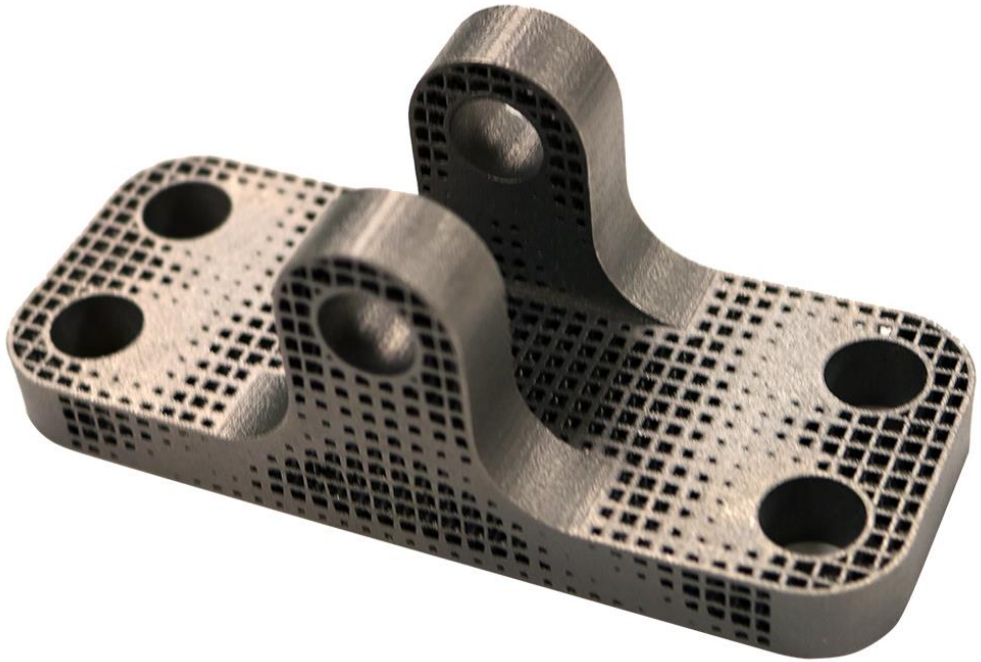
Data-driven design approach to hierarchical hybrid structures with multiple lattice configurations

Structural and Multidisciplinary Optimization, 2020, 61:2227-2235

Zijun Wu, Liang Xia*, Shuting Wang, Tielin Shi

Topology optimization of hierarchical lattice structures with substructuring

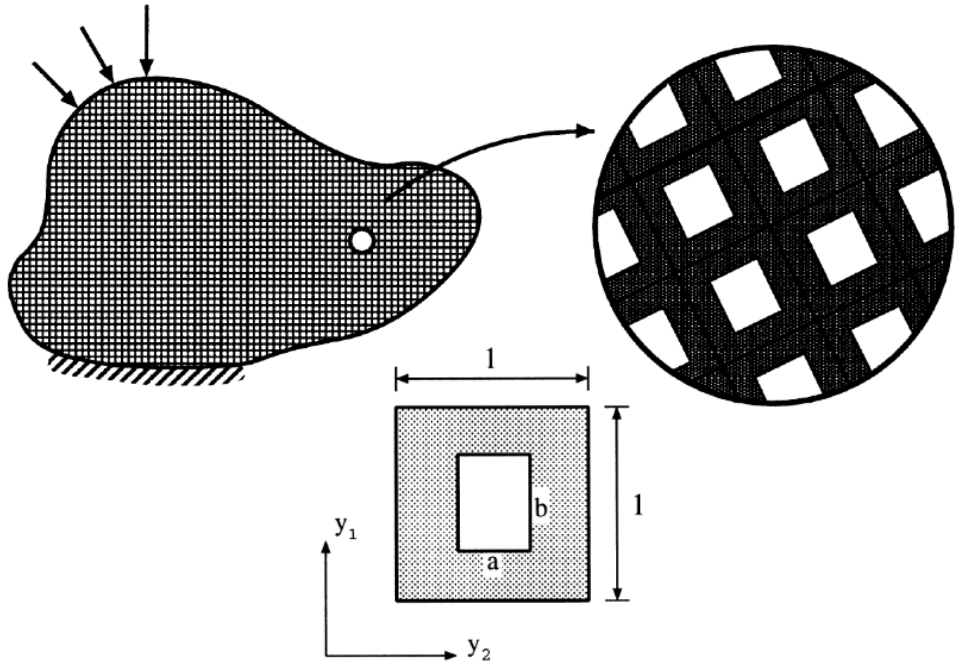
Computer Methods in Applied Mechanics and Engineering, 2019, 345:602-617



Bracket with Graded Lattices built by Additive Manufacturing

Cheng et al. 2017, 2018

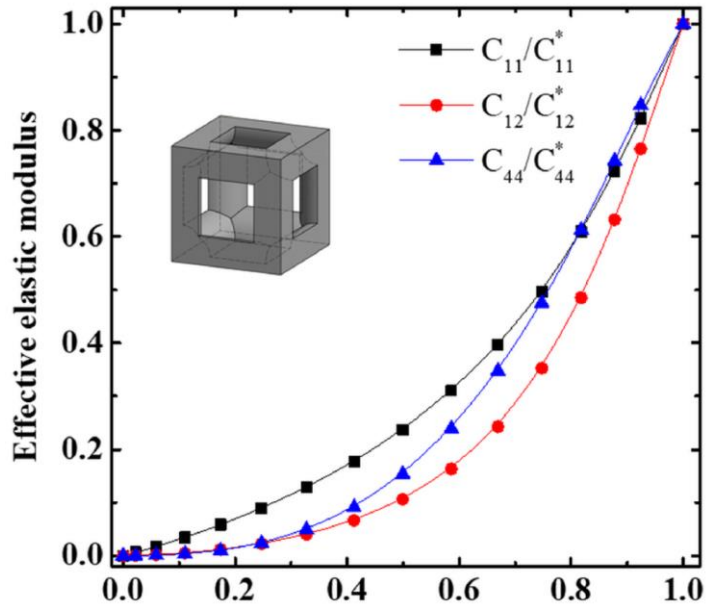
https://www.ansys.com/blog/inspections-additive-manufactured-parts-ct-scanning-simulation



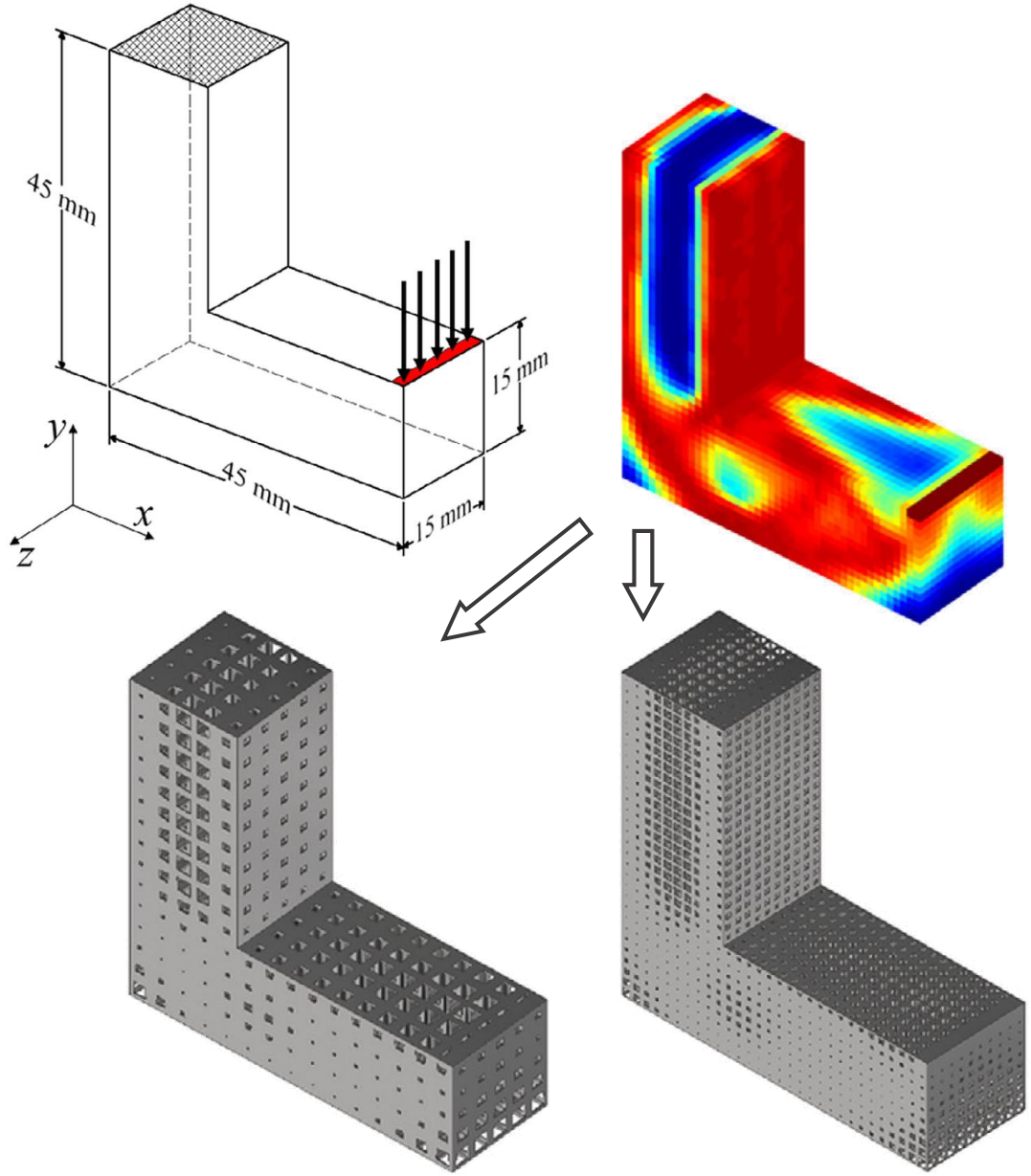
Homogenization Method Topology Optimization

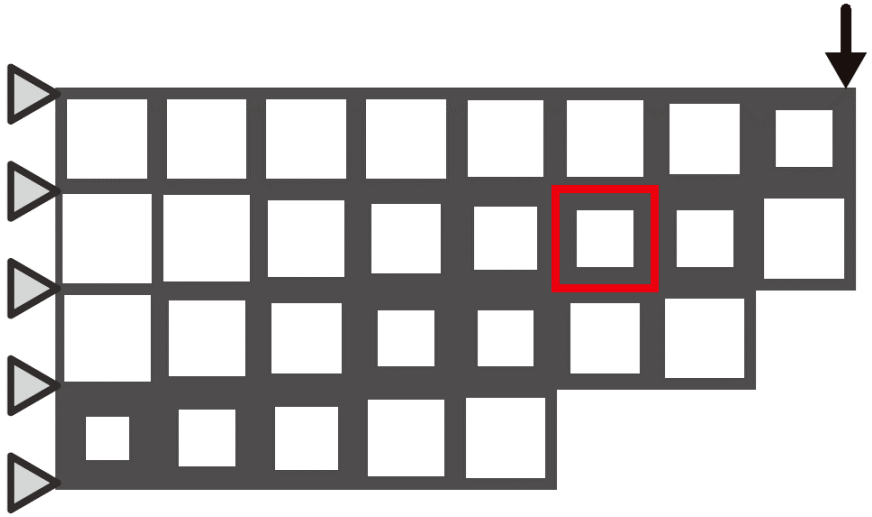
Bendsøe & Kikuchi, 1988

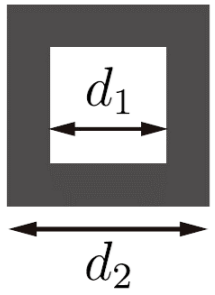
Separation of Scales



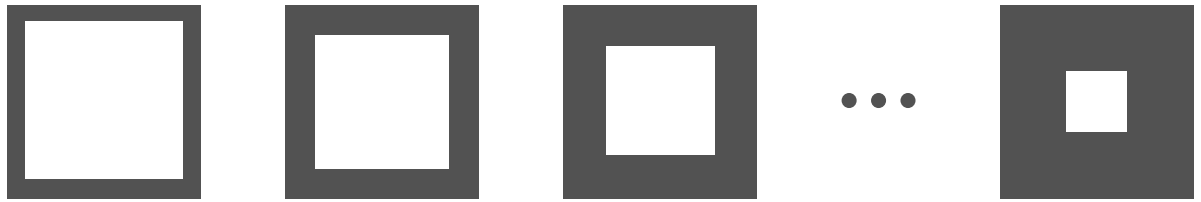
$$\begin{bmatrix} \overline{\sigma}_{11} \\ \overline{\sigma}_{22} \\ \overline{\sigma}_{33} \\ \overline{\sigma}_{12} \\ \overline{\sigma}_{23} \\ \overline{\sigma}_{31} \end{bmatrix} = \begin{bmatrix} \overline{C}_{11} & \overline{C}_{12} & \overline{C}_{12} & 0 & 0 & 0 \\ \overline{C}_{12} & \overline{C}_{11} & \overline{C}_{12} & 0 & 0 & 0 \\ \overline{C}_{12} & \overline{C}_{12} & \overline{C}_{11} & 0 & 0 & 0 \\ 0 & 0 & 0 & \overline{C}_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & \overline{C}_{44} & 0 \\ 0 & 0 & 0 & 0 & 0 & \overline{C}_{44} \end{bmatrix} \begin{bmatrix} \overline{\varepsilon}_{11} \\ \overline{\varepsilon}_{22} \\ \overline{\varepsilon}_{33} \\ 2\overline{\varepsilon}_{12} \\ 2\overline{\varepsilon}_{23} \\ 2\overline{\varepsilon}_{31} \end{bmatrix}$$





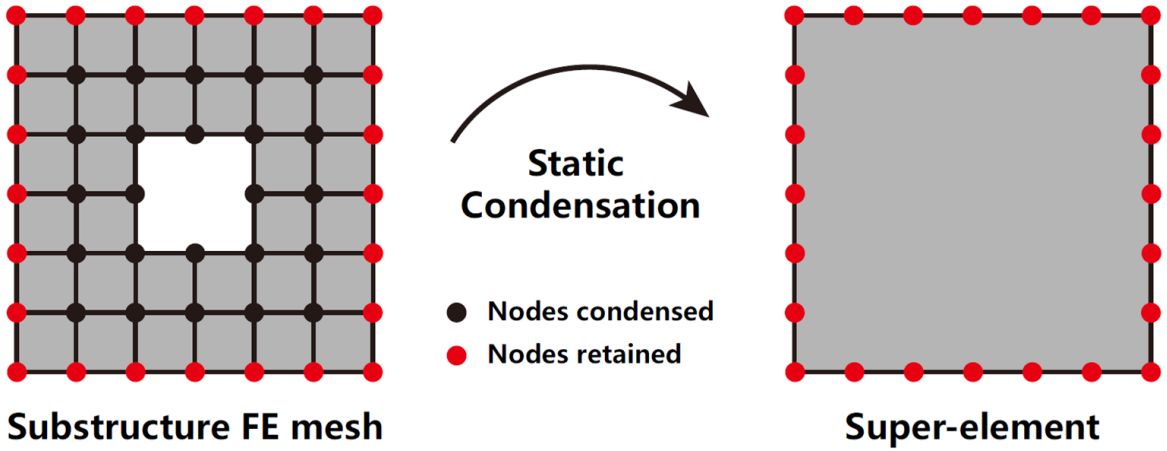


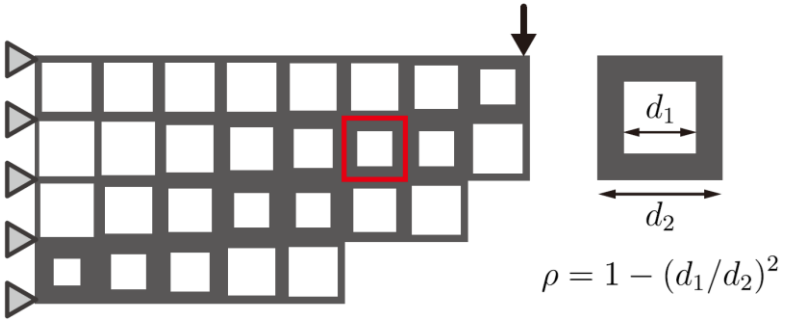
$$\rho = 1 - (d_1/d_2)^2$$



$$\mathbf{K}(\rho)$$

Stiffness Matrix





$$\begin{bmatrix} \mathbf{K}_{bb} & \mathbf{K}_{bi} \\ \mathbf{K}_{ib} & \mathbf{K}_{ii} \end{bmatrix} \begin{bmatrix} \mathbf{U}_b \\ \mathbf{U}_i \end{bmatrix} = \begin{bmatrix} \mathbf{F}_b \\ \mathbf{F}_i \end{bmatrix}$$

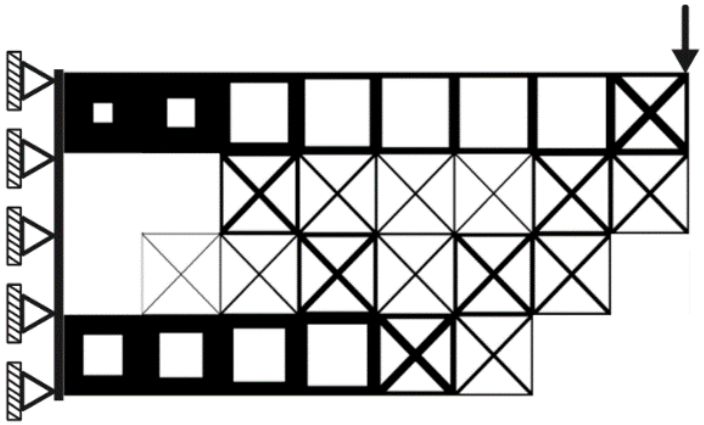
$$\mathbf{K}^{rd} = \mathbf{K}_{bb} - \mathbf{K}_{bi}\mathbf{K}_{ii}^{-1}\mathbf{K}_{ib}$$

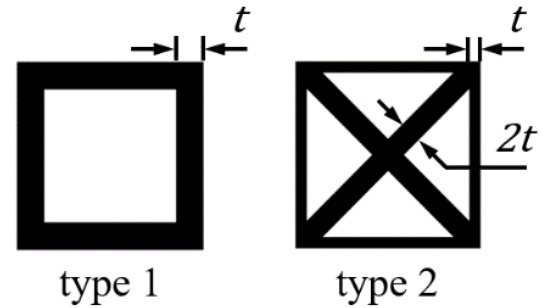
$\mathbf{K}^{rd}(\rho)$

Super-element stiffness matrices

Proper Orthogonal Decomposition (POD)
Interpolation of POD Projection Coefficients

$$\mathbf{K}^{rd}(\rho) \approx \tilde{\alpha}_1(\rho)[\phi_1] + \tilde{\alpha}_2(\rho)[\phi_2] + \cdots + \tilde{\alpha}_m(\rho)[\phi_m]$$





density : $y_{\min} \le y(t) \le y_{\max}$

Multiple Lattice Configurations

$$x_{ij} = 0 \text{ or } 1\,, \quad \sum_{j=1}^{M} x_{ij} = 0 \text{ or } 1$$

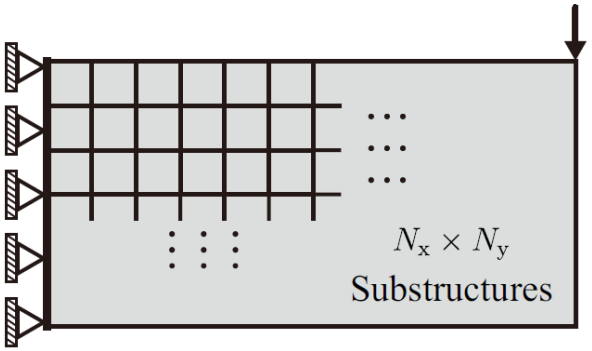
$$y_{\min} \le y_{ij} \le y_{\max}$$

$$0 \le s_{ij} \le 1$$

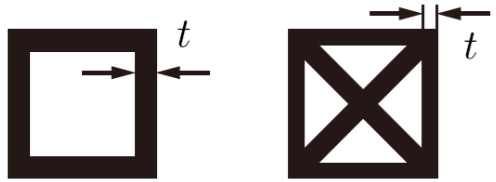
$$x_{ij} = \frac{\tanh(\beta\eta)+\tanh\left(\beta(s_{ij}-\eta)\right)}{\tanh(\beta\eta)+\tanh\left(\beta(1-\eta)\right)}$$

$$\mathbf{K}_i^{\mathrm{rd}}(x_{ij}, y_{ij}) = \sum_{j=1}^{M} \left\{ x_{ij}^{p} \prod_{k=1(\neq j)}^{M} \left(1 - x_{ik}^{p}\right) \right\} \mathbf{K}_{ij}^{\mathrm{rd}}(y_{ij})$$

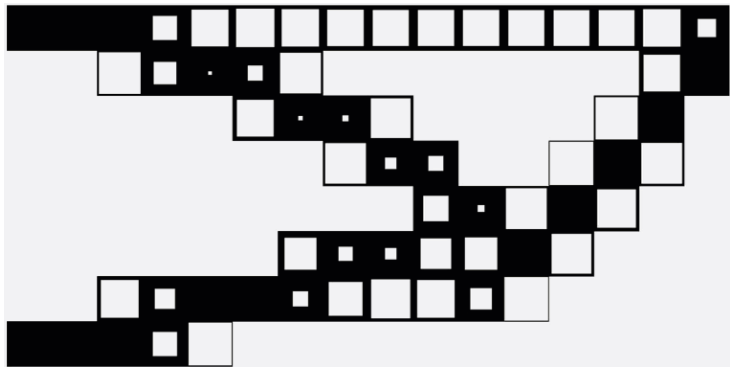
volume fraction 30%

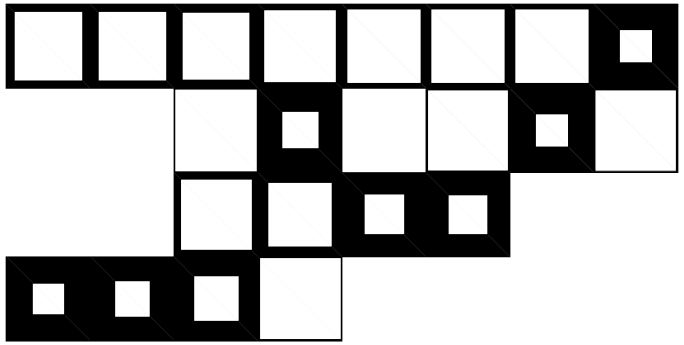


120×120
square elements

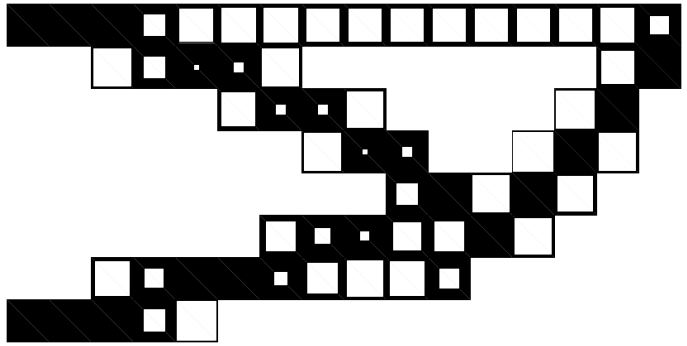


$0 < \rho(t) \leq 1$

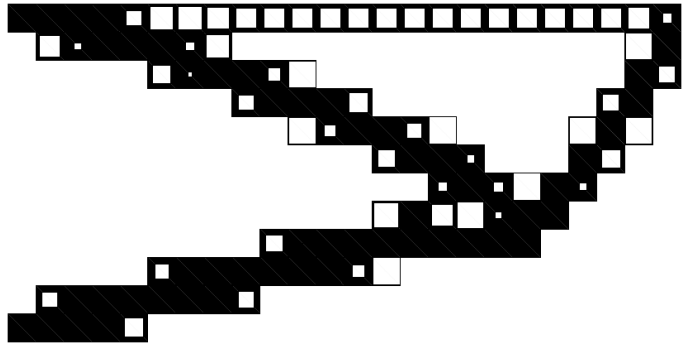




$8 \times 4 \quad c = 366.54$

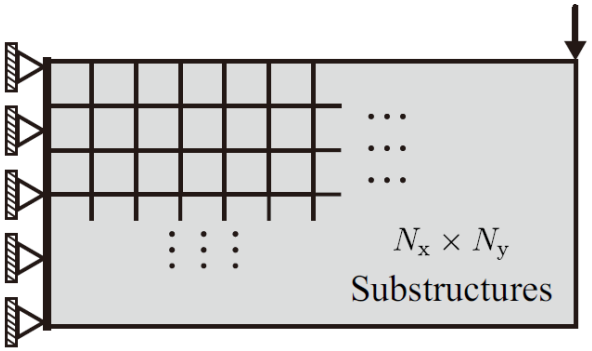


$16 \times 8 \quad c = 218.47$

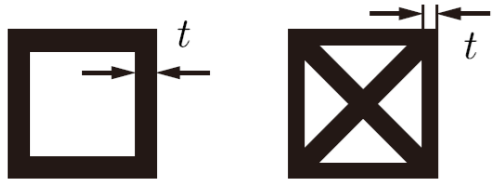


$24 \times 12 \quad c = 181.82$

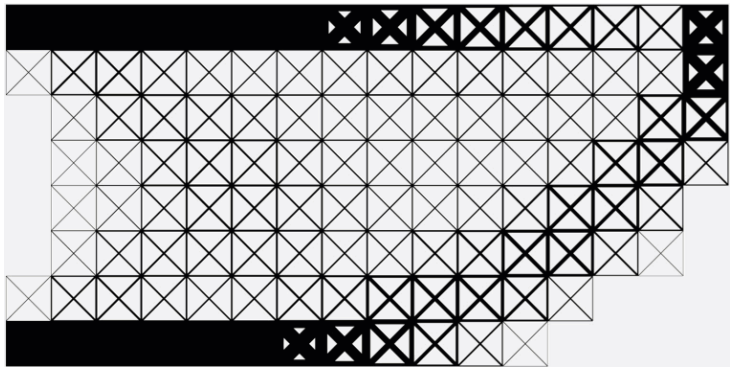
volume fraction 30%

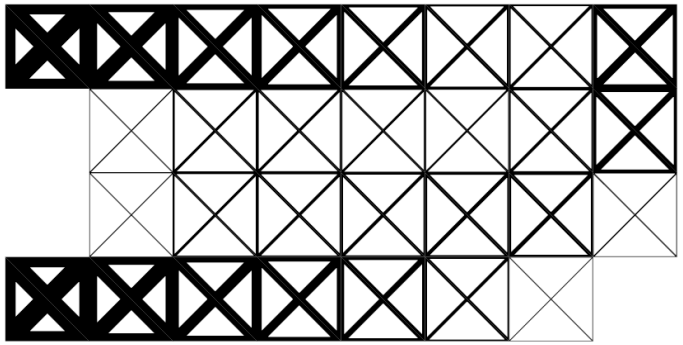


120×120
square elements

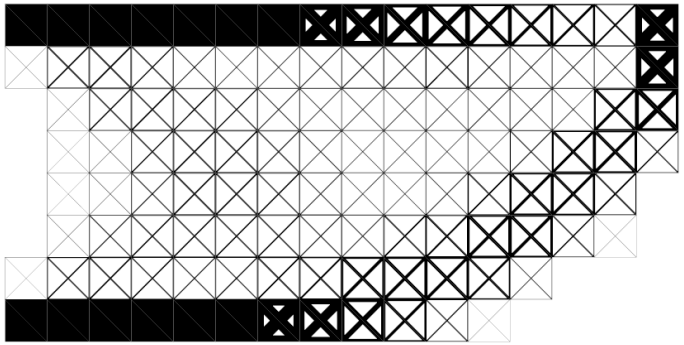


$0 < \rho(t) \leq 1$

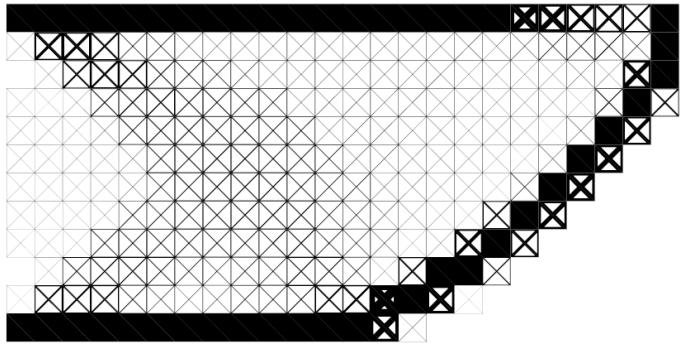




$8 \times 4 \quad c = 237.62$

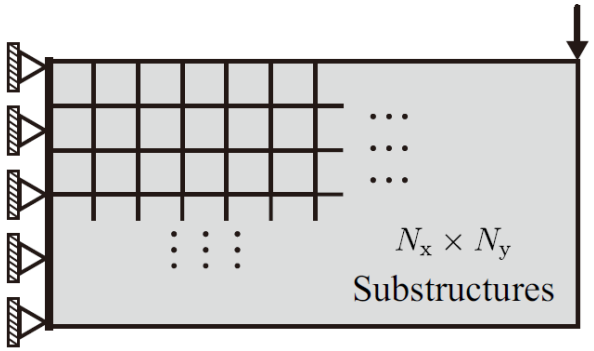


$16 \times 8 \quad c = 186.39$

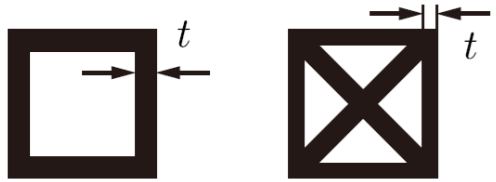


$24 \times 12 \quad c = 166.52$

volume fraction 30%



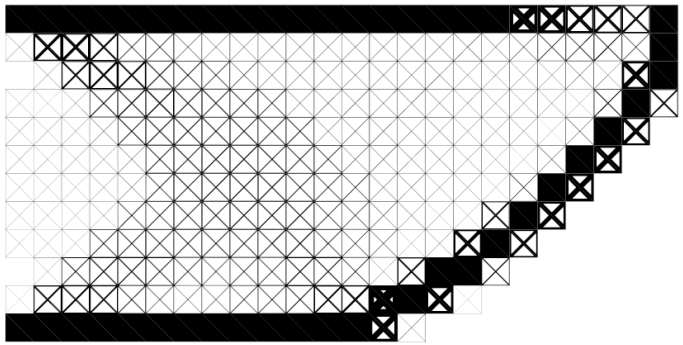
120×120
square elements



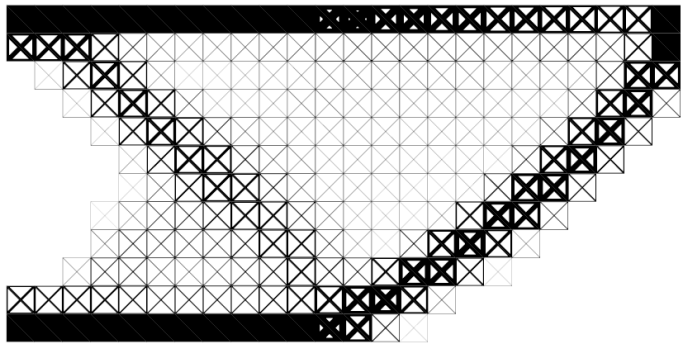
Case A Case B

$0 < \rho(t) \leq 1$

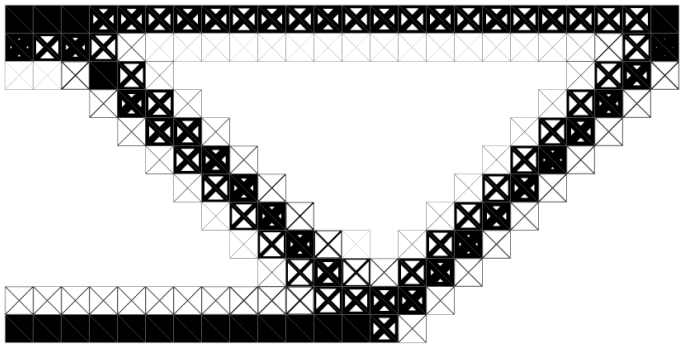
$$\rho^{(p-1)}\,\mathbf{K}^{\mathrm{rd}}(\rho)$$



$p = 1.0 \quad c = 166.52$

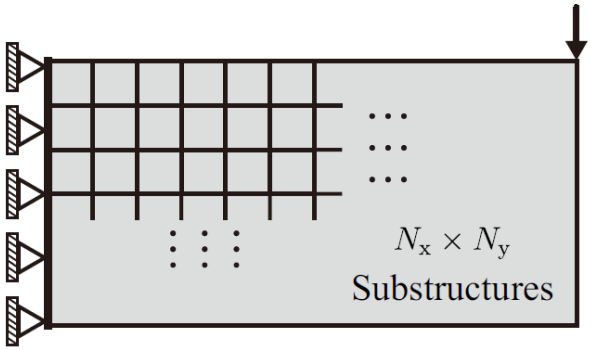


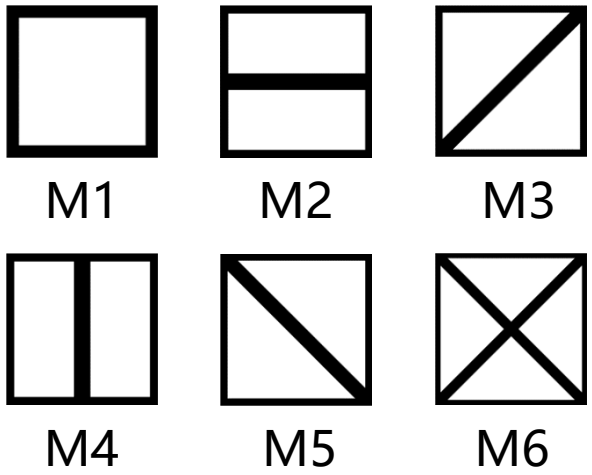
$p = 1.5 \quad c = 171.50$



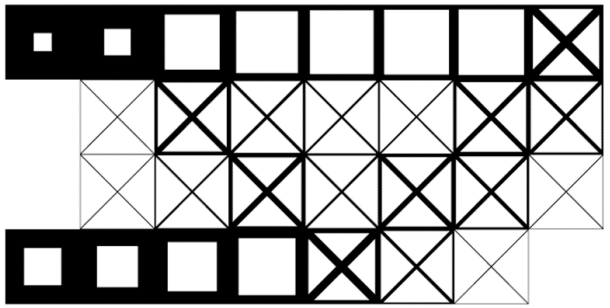
$p = 2.0 \quad c = 175.22$

volume fraction 30%

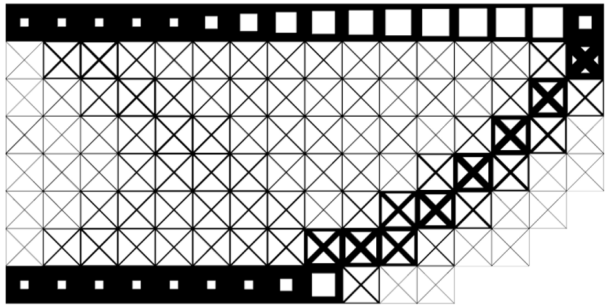




M1&M6 2 types

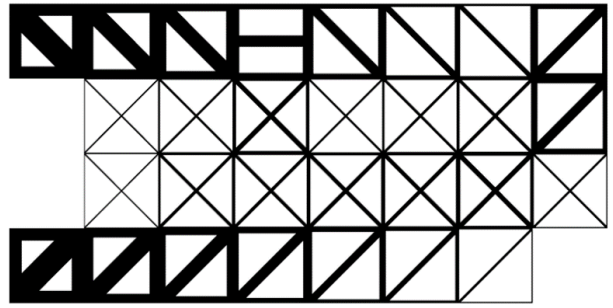


$c = 224.23$

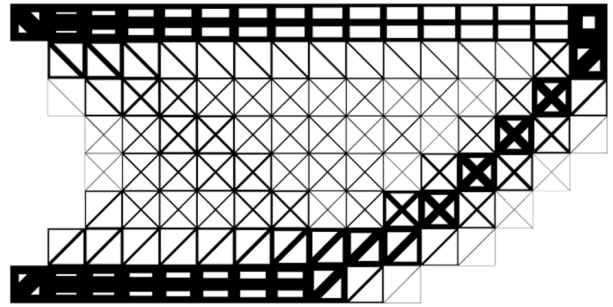


$c = 183.27$

M1–M6 6 types



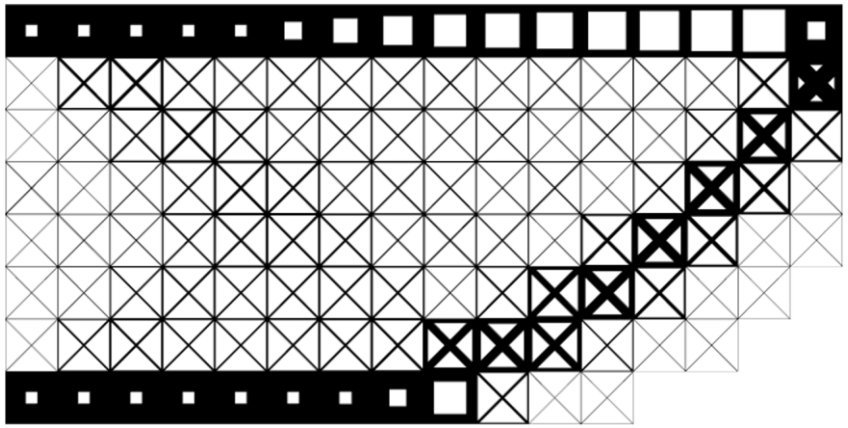
$c = 215.92$



$c = 172.97$

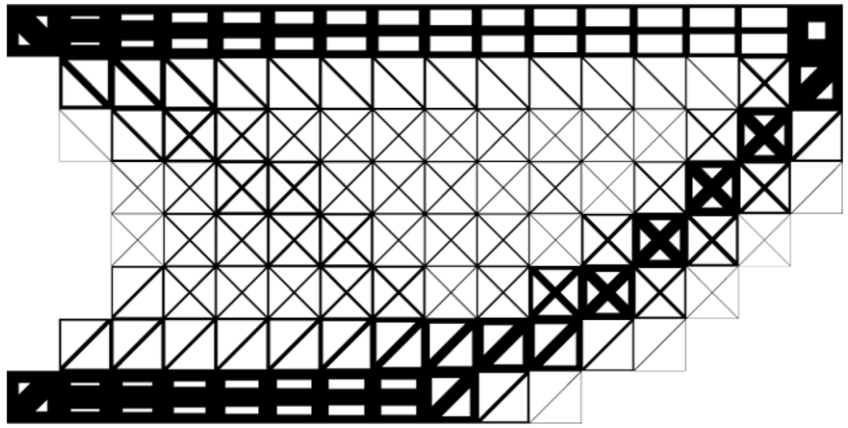
M1&M6 2 types

$c = 183.27$



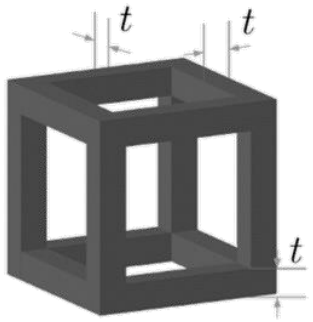
M1–M6 6 types

$c = 172.97$

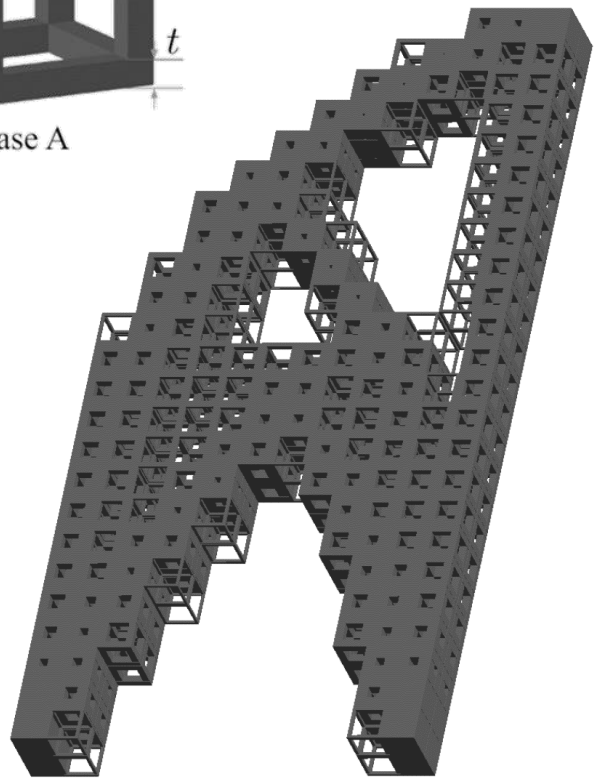


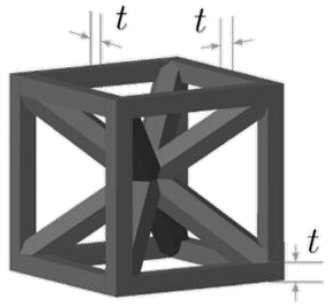
	M1	M2	M3	M4	M5	M6
M1&M6	20.7%	\	\	\	\	79.3%
M1–M6	0.9%	19.4%	18.5%	0.0%	14.8%	46.4%

some 3D designs

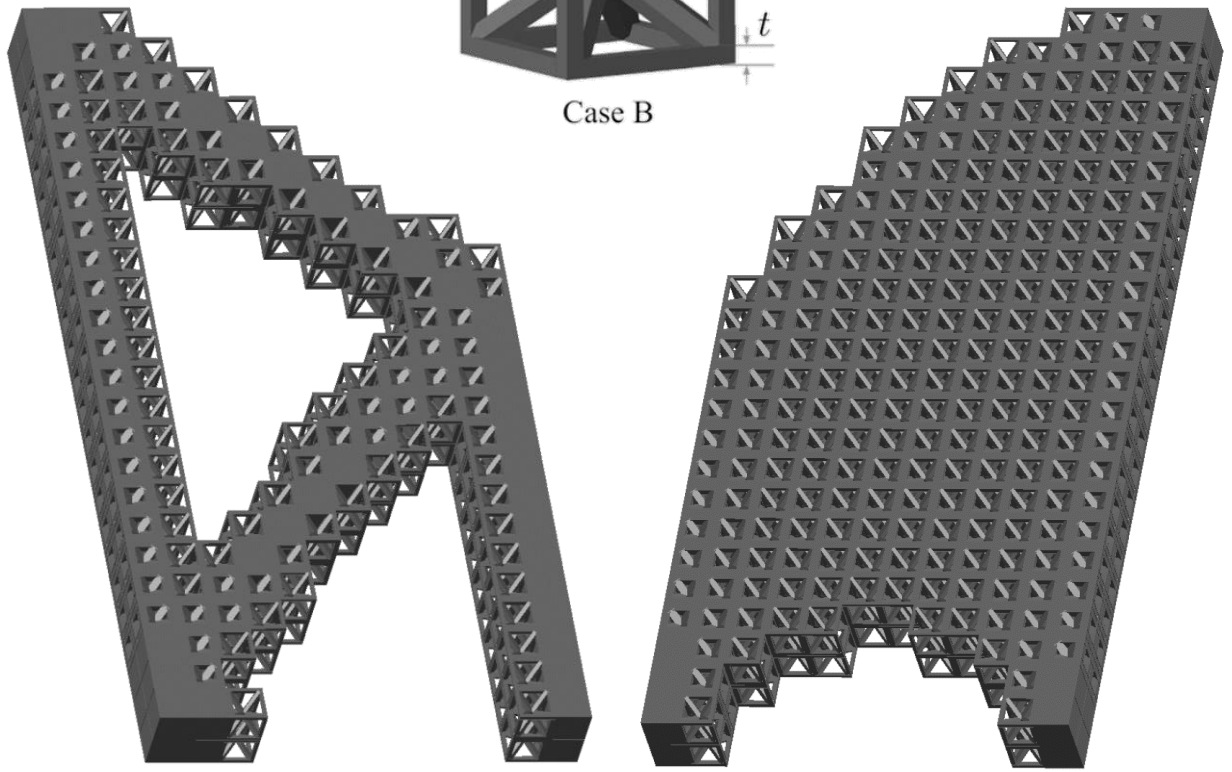


Case A



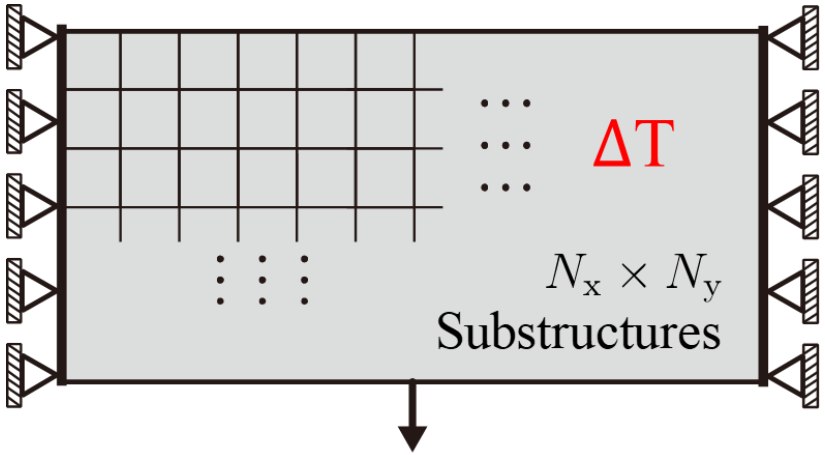


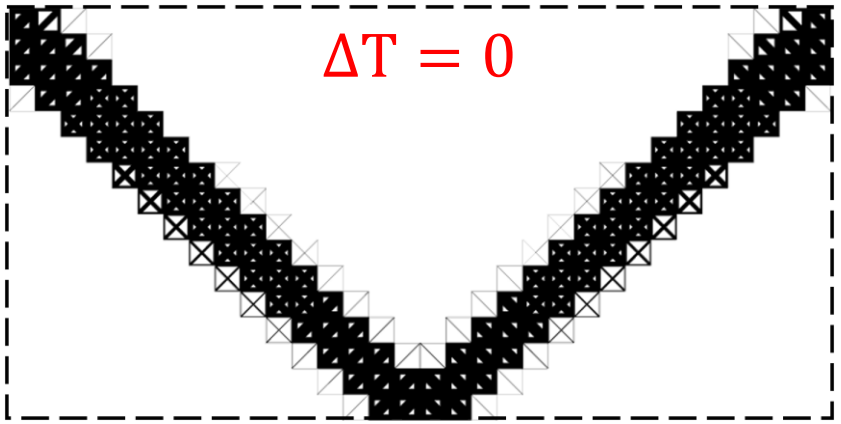
Case B

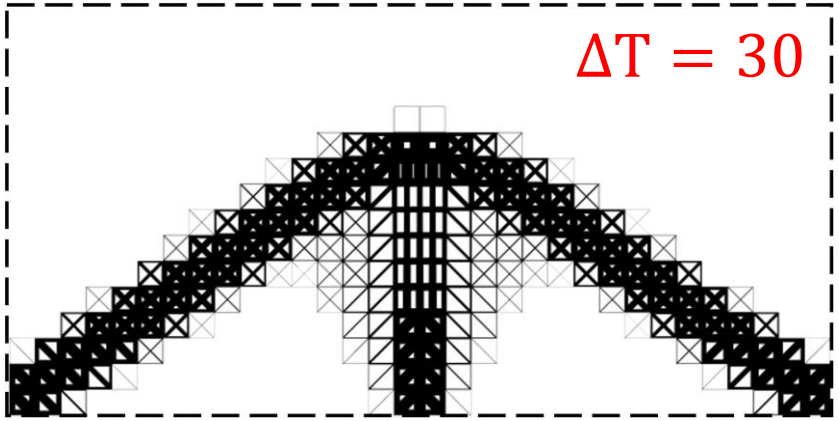


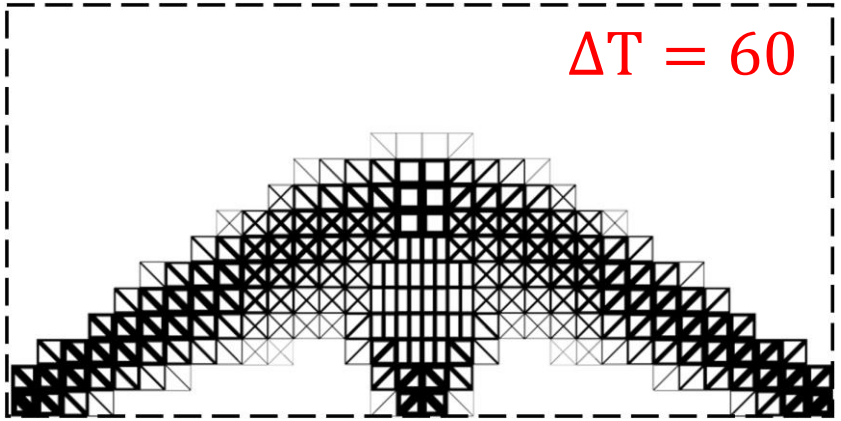
thermal-elastic designs

volume fraction 20% / 6 lattice types / $0.05 \leq y \leq 0.95$



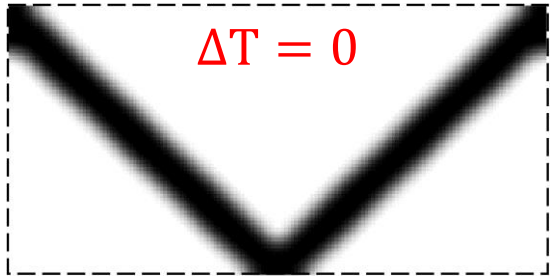


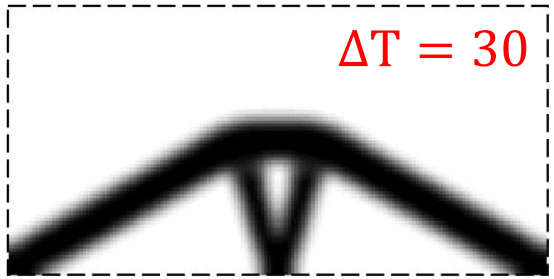


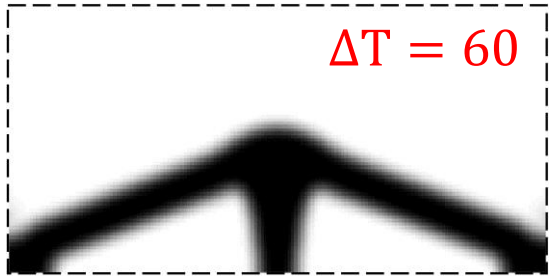


thermal-elastic designs

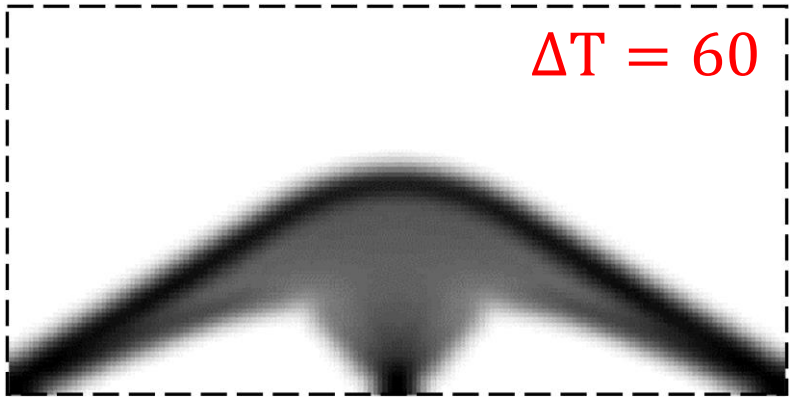
volume fraction 20% $0.05 \leq y \leq 0.95$



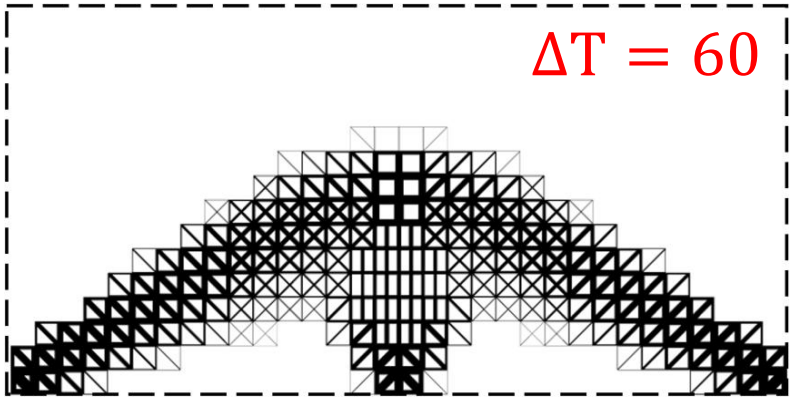




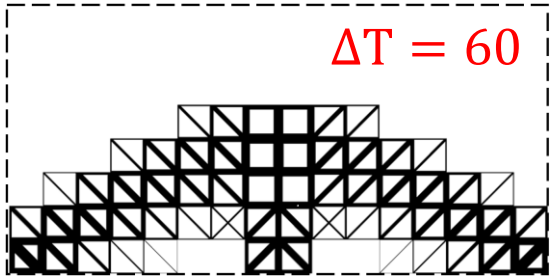
c = 10813



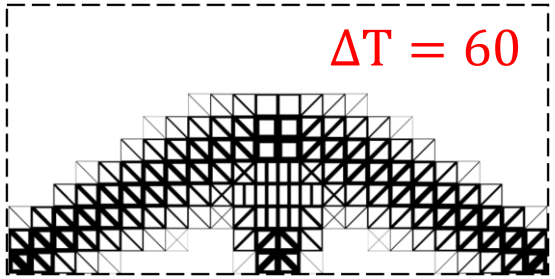
c = 5897



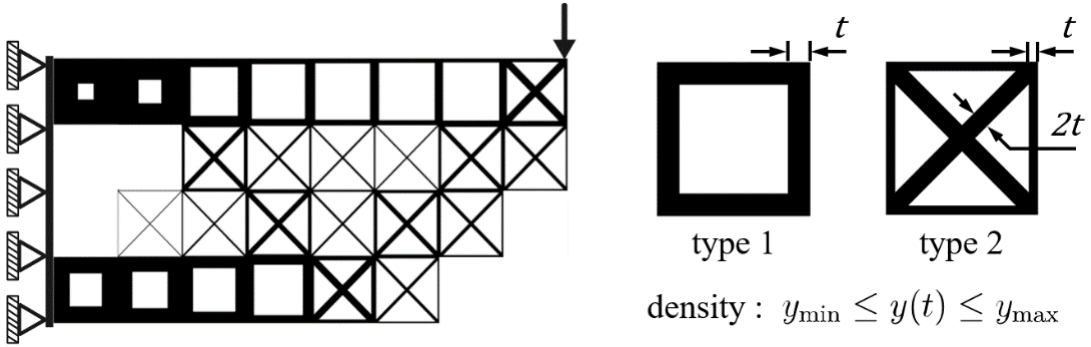
c = 6021



c = 5956



c = 5850



Physically interpretable
for intermediate densities
& fully coupled

An alternative approach to lattice topology optimization

interpolation on substructure stiffness matrix

A lot can be done within this framework

stress constraints, fracture, thermal, dynamic, 3D printing, ...

Thank you for your attention !