About the implementation of bi-directional topology optimization in ACELAN-COMPOS package

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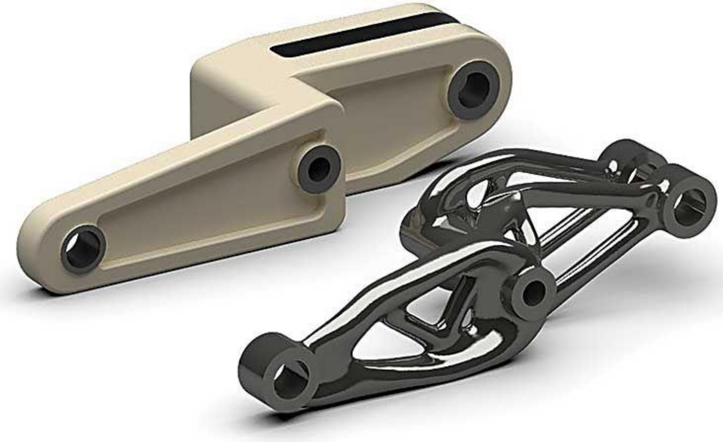
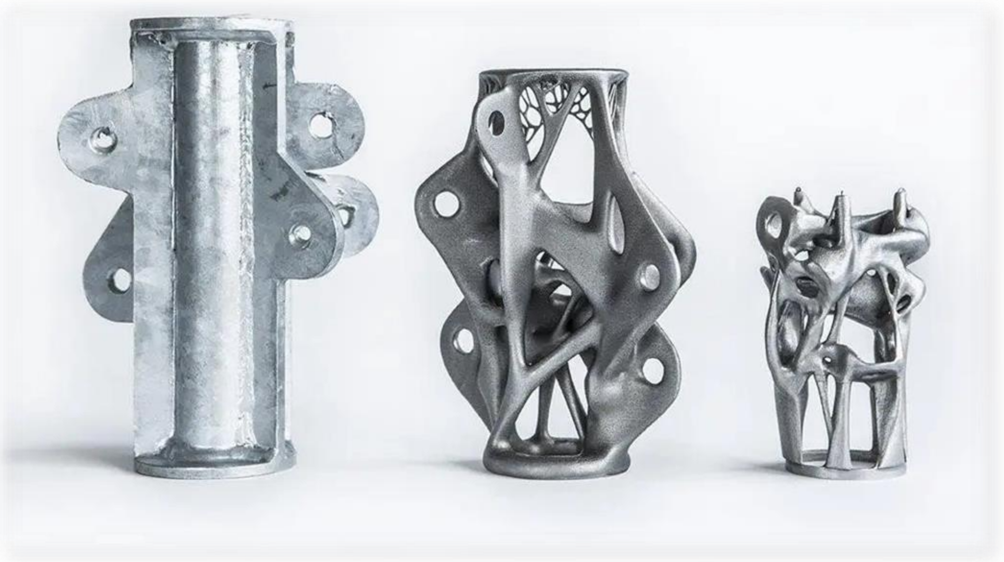
Topology optimization problems





Mathematical model

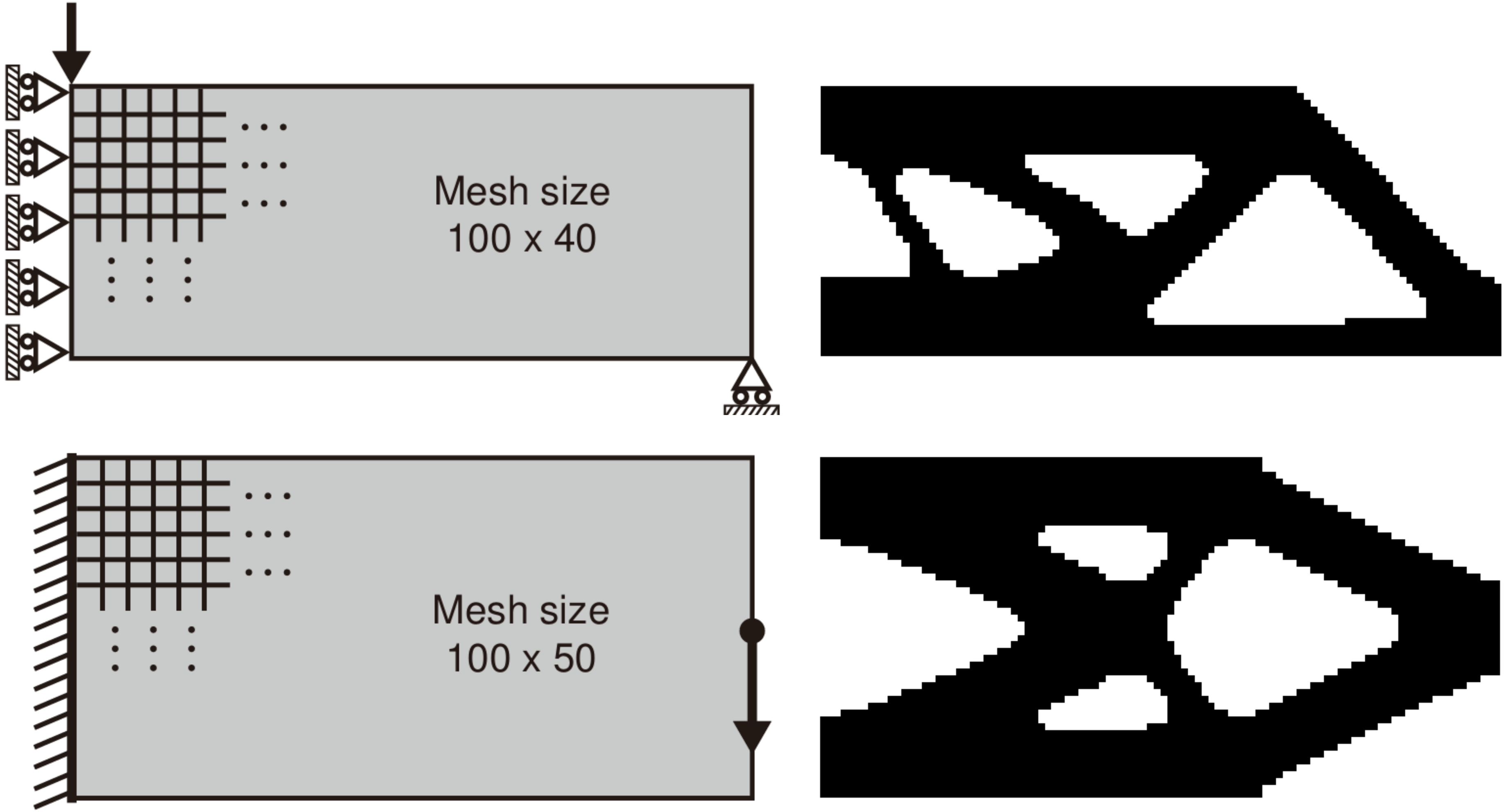
$$\rho_j \omega^2 \ddot{\mathbf{u}} - \nabla \cdot \boldsymbol{\sigma} = \mathbf{f}_j;$$

$$\boldsymbol{\sigma} = \mathbf{c}_j^E \cdot\cdot \boldsymbol{\varepsilon};$$

$$\boldsymbol{\varepsilon} = (\nabla \mathbf{u} + \nabla \mathbf{u}^T)/2,$$

$\boldsymbol{\sigma}$ – stress tensor,
ρ_j – density,
$\boldsymbol{\varepsilon}$ – strain tensor,
$\boldsymbol{u}$ – displacement vector,
$\boldsymbol{f_j}$ – vector of mass forces,
$\boldsymbol{c_j^E}$ – elastic constant tensor of the body with number j,
ω – circular frequency.

Topology optimization problem



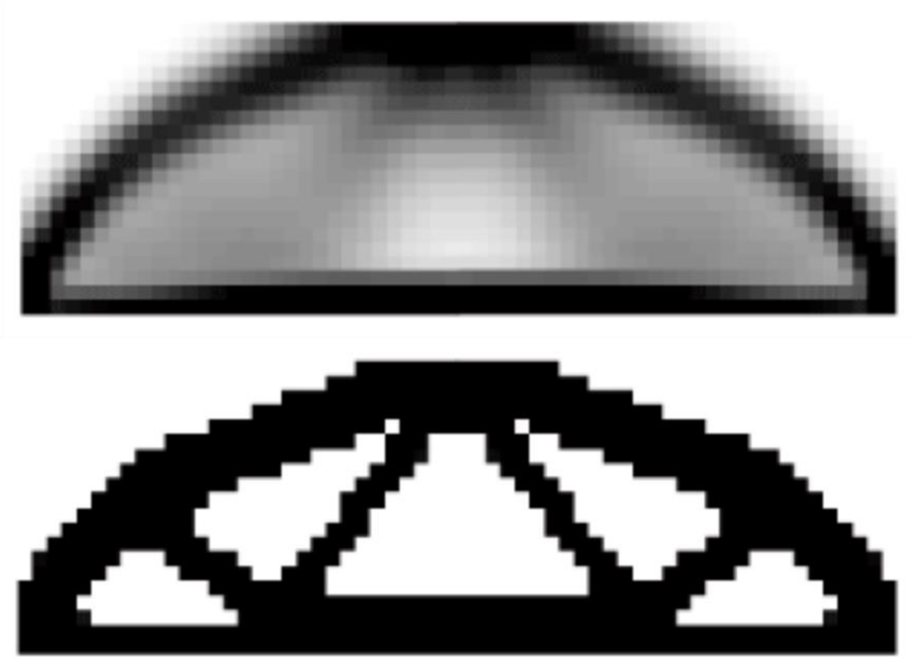
L. Xia, Q. Xia, X. Huang, Y. M. Xie, Bi-directional Evolutionary Structural Optimization on Advanced Structures and Materials: A Comprehensive Review

Solid Isotropic Material with Penalization method

$$E_{ijkl}(x) = \rho(x)^p E_{ijkl}^0, \quad p > 1$$

$$\int_\Omega \rho(x) d\Omega \le V; \quad 0 \le \rho(x) \le 1, \quad x \in \Omega$$

$$E_{ijkl}(\rho = 0) = 0, \quad E_{ijkl}(\rho = 1) = E_{ijkl}^0$$



$\rho(x)$ – estimated density,

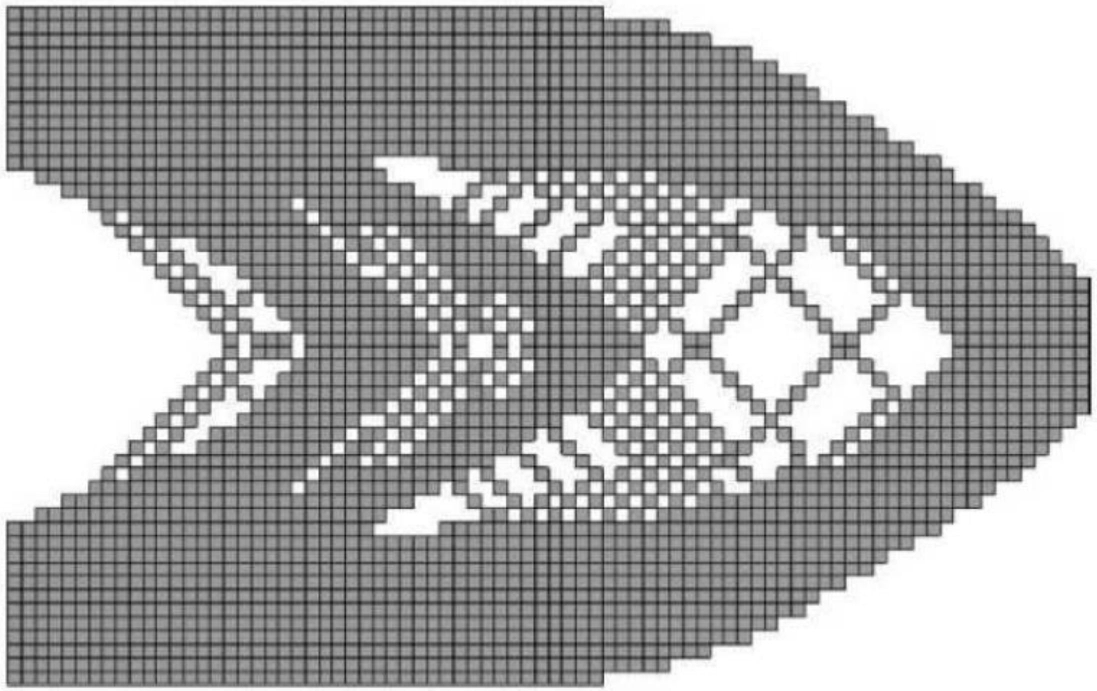
E_{ijkl}^0 – material properties of isotropic material,

p – penalization parameter,

V – volume of source material.

Evolutionary Optimization methods

Xie, Steven, 1990: the ESO method uses the stress level as an indicator for the gradual removal of inefficient material for a structure expecting that the resulting structure could evolve towards an optimal shape and topology



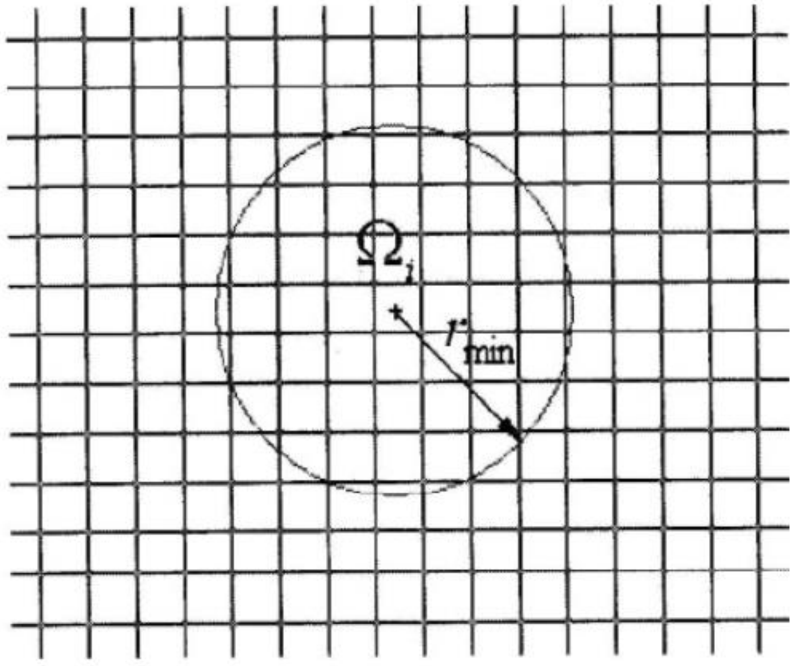
Basic version cons:

- Material removed on early stages could be useful later
- Checkerboards

Bidirectional Evolutionary Optimization

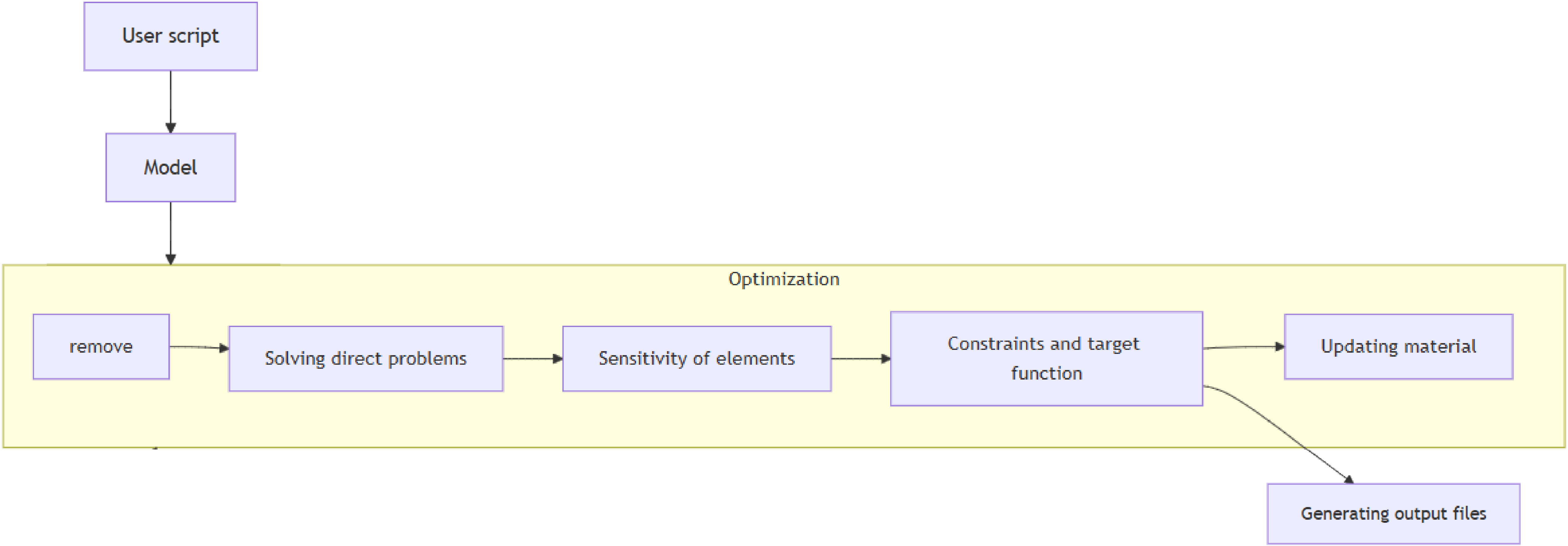
$$\begin{cases} \sigma_e^{\mathrm{vm}} < c_{\mathrm{rr}} \cdot \sigma_{\max}^{\mathrm{vm}} \rightarrow \text{element removal} \\ \tilde{\sigma}_e^{\mathrm{vm}} > c_{\mathrm{ir}} \cdot \sigma_{\max}^{\mathrm{vm}} \rightarrow \text{element addition} \end{cases}$$

Core idea: some material is removed, some is added (restored!) on each step of optimization



Each element measured as weighted sum with neighbors

Solution of the optimization problem in ACELAN-COMPOS package



A model for optimization

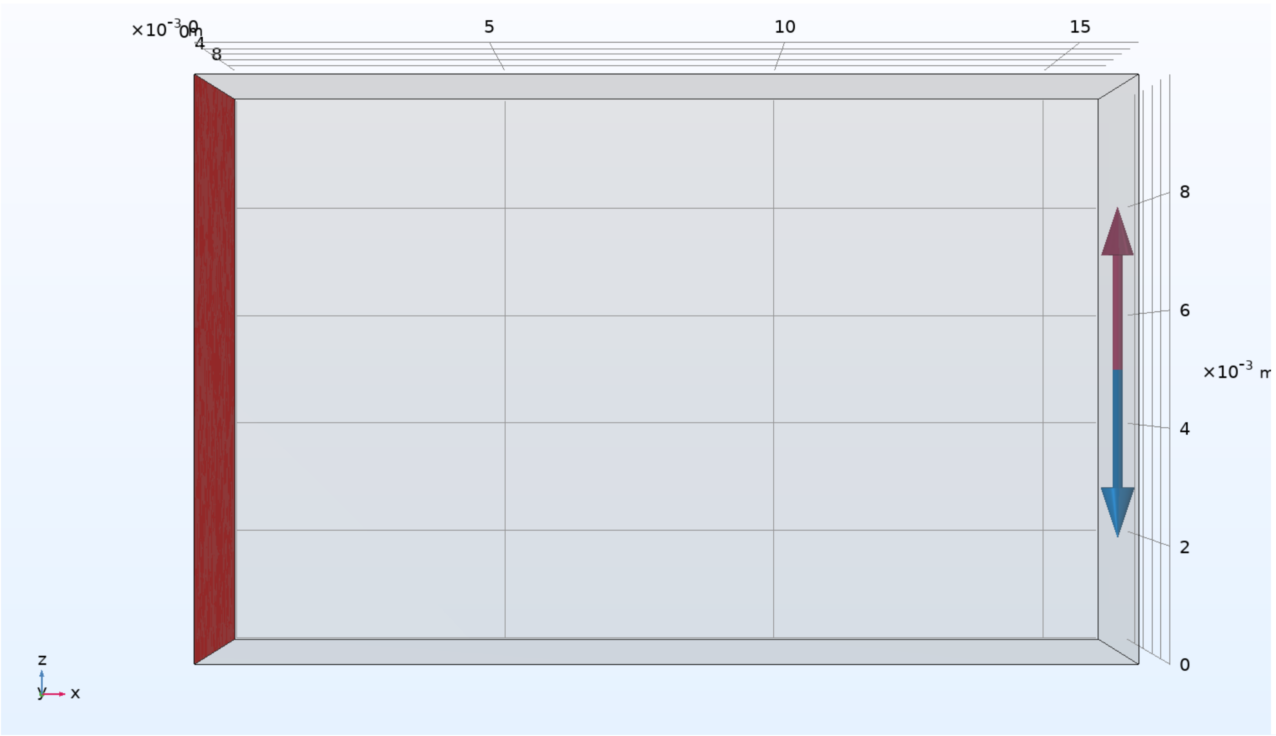


Fig. 1. The scheme of boundary conditions for the model

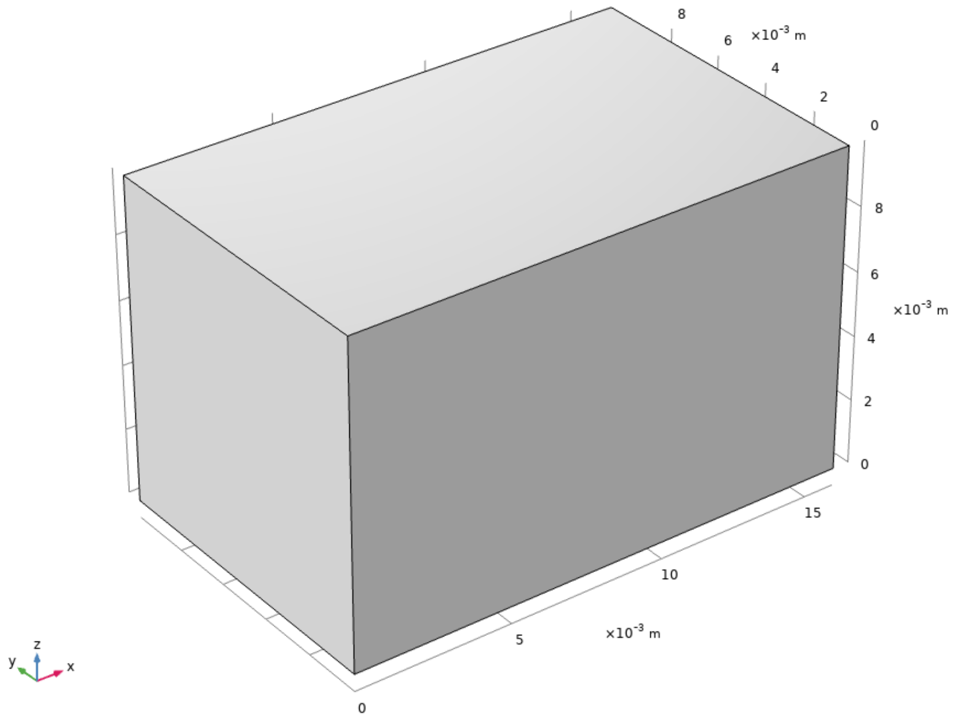
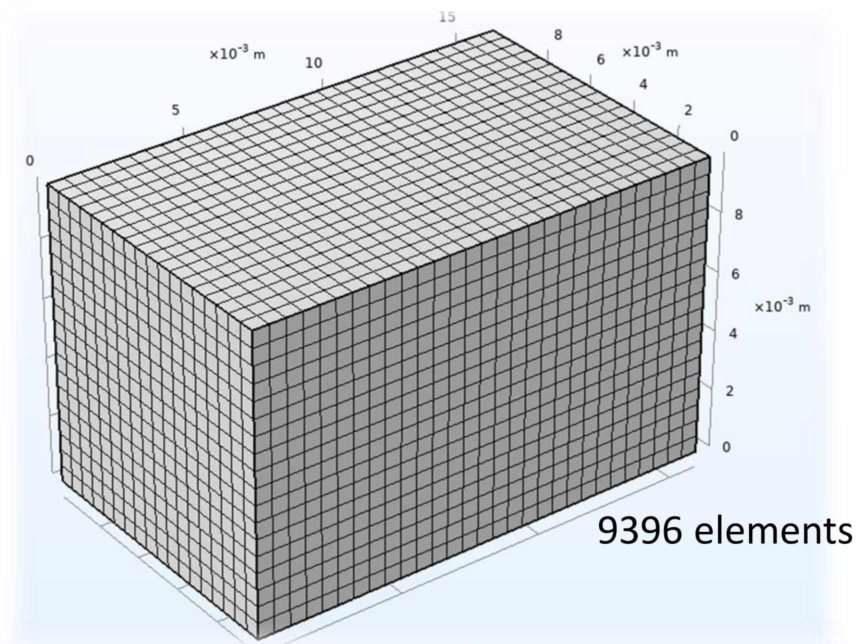
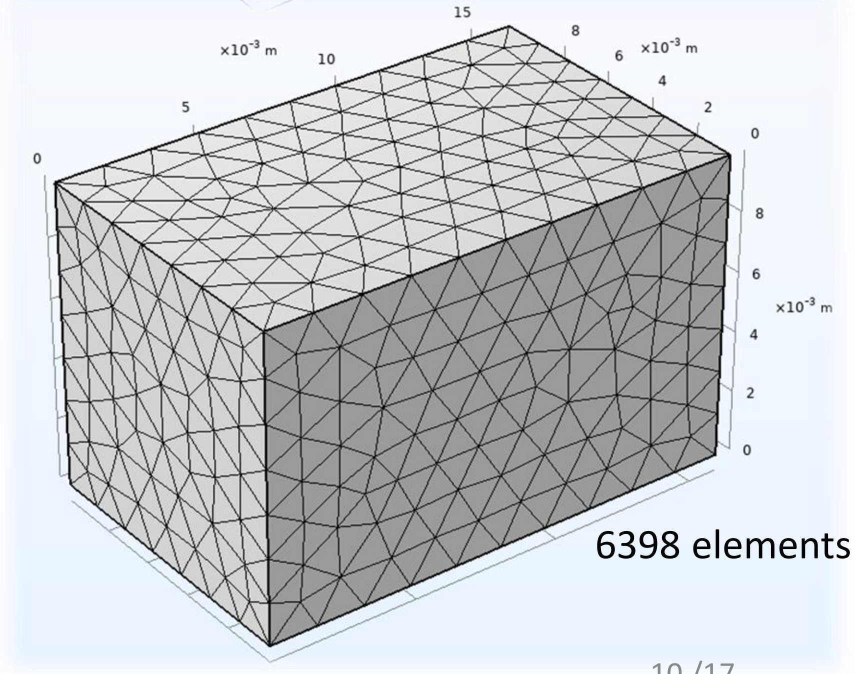


Fig. 2. Model before optimization

Material properties

	PZT-4	Pseudo Material
$\rho, kg/m^3$	7500	1
$c_{11}^{E,eff}, 10^{10}, N/m^2$	13.9	13.9e-2
$c_{12}^{E,eff}, 10^{10}, N/m^2$	7.78	7.78e-2
$c_{13}^{E,eff}, 10^{10}, N/m^2$	7.43	7.43e-2
$c_{33}^{E,eff}, 10^{10}, N/m^2$	11.5	11.5e-2
$c_{44}^{E,eff}, 10^{10}, N/m^2$	2.56	2.56e-2
$e_{33}^{eff}, C/m^2$	15.1	0
$e_{31}^{eff}, C/m^2$	-5.2	0
$e_{51}^{eff}, C/m^2$	12.7	0
$\kappa_{11}^{S,eff} / \varepsilon_0$	730	1
$\kappa_{33}^{S,eff} / \varepsilon_0$	635	1





Optimization result of the hexahedron model

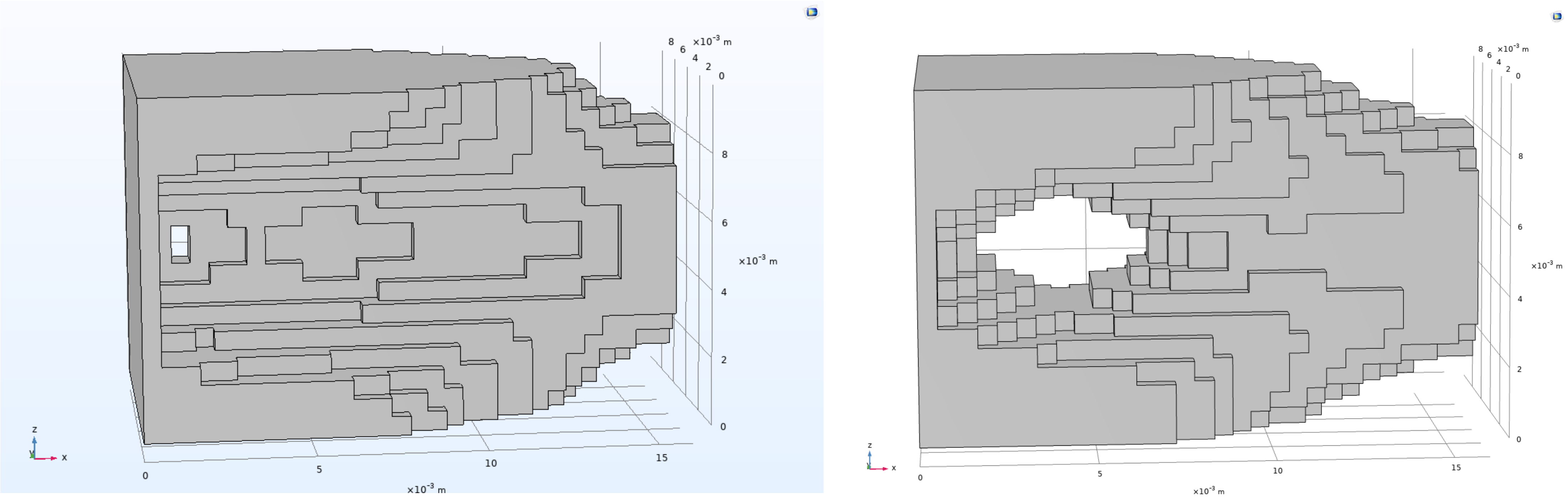


Fig. 3. Optimization results for 50 % material removed

First implementation BESO method

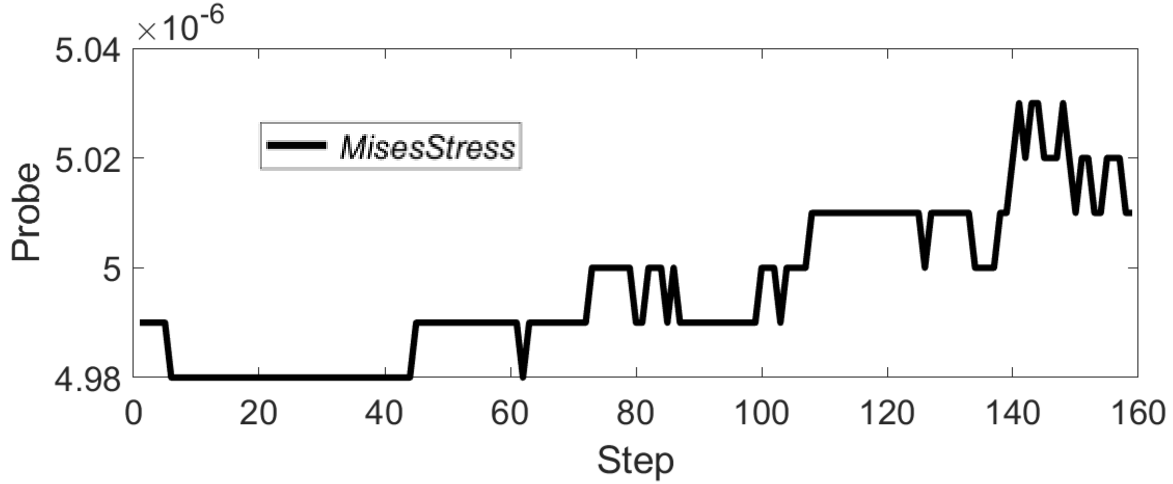


Fig. 4. Dependence of the Mises stress on the optimization step (Pa)

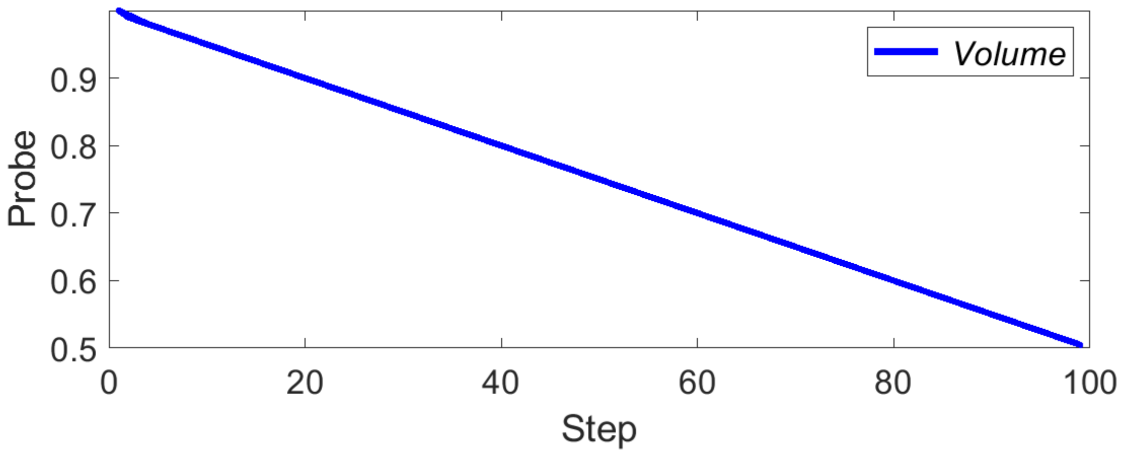


Fig. 5. Dependence of volume on the optimization step

First implementation BESO method

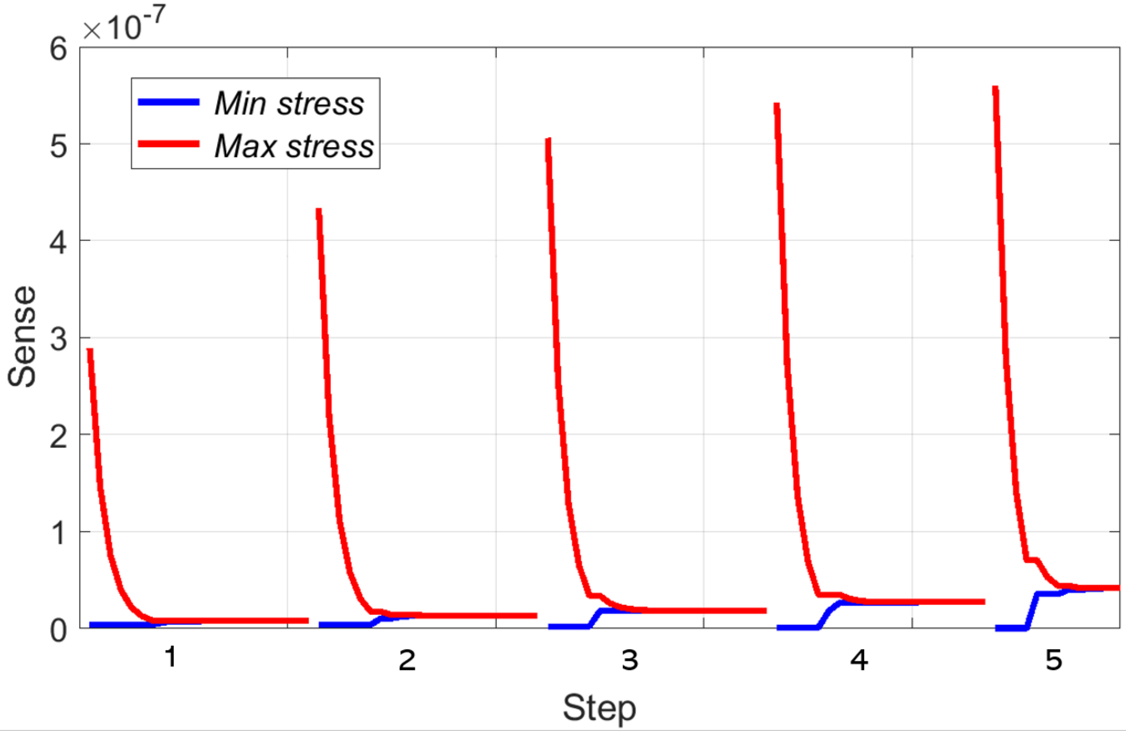


Fig. 6. Dependence of minimum and maximum stresses on the optimization step

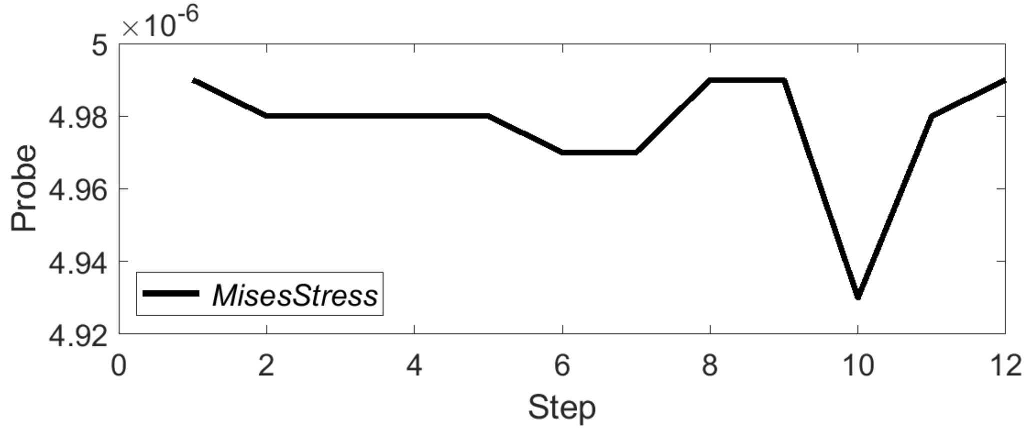


Fig. 7. Dependence of the Mises stress on the optimization step (Pa)

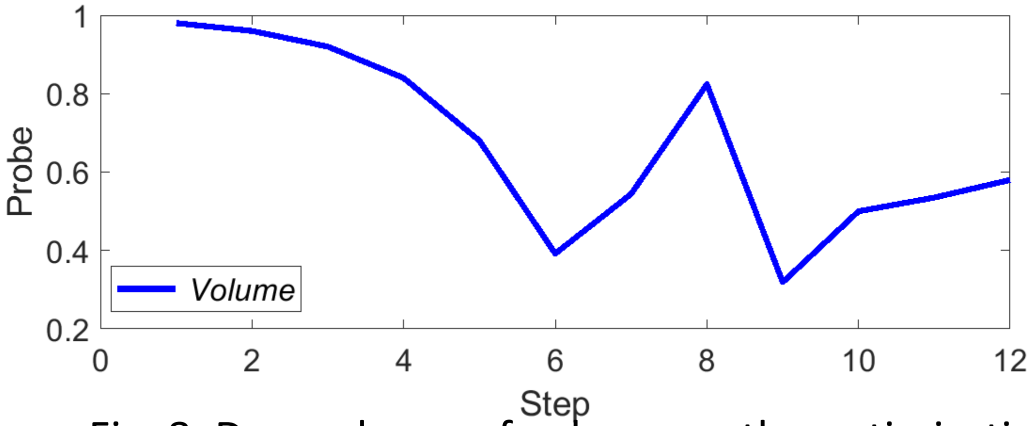


Fig. 8. Dependence of volume on the optimization step

Optimization result of the tetrahedron model

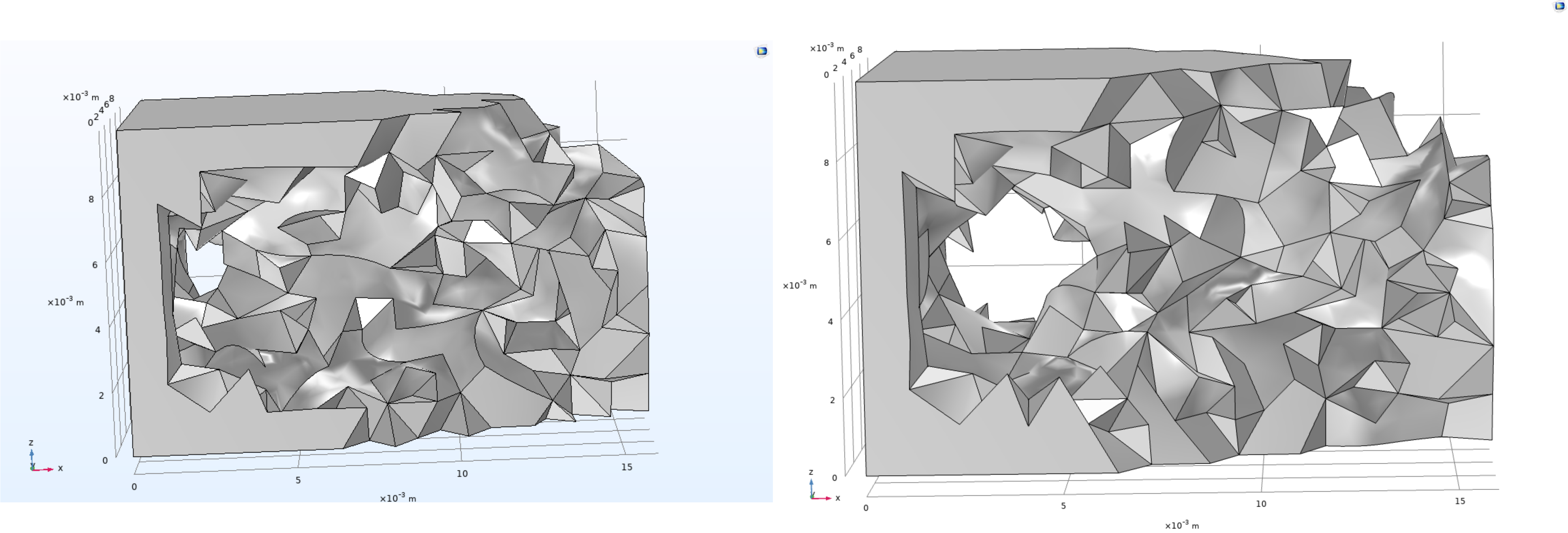


Fig. 9. Optimization results for 50 % material removed

Conclusion

- A module for topology optimization in ACELAN-COMPOS package based on evolutionary methods has been designed and implemented
- This module can be used to conduct a series of numerical experiments to create efficient designs of piezoelectric transducers
- Numerical experiments with model problems have been carried out

References

1. Bendsøe, M. P. Topology Optimization: Theory, Methods and Application / M. P. Bendsøe, O. Sigmund; – M. : Berlin: Springer, 2003. – 370 p.
2. Oganesyan, P. A. Topology designs optimization in ABAQUS package / P. A. Oganesyan, S. N. Shevtsov // Samara Scientific Centre of the Russian Academy of Sciences. – 2013. – T. 16. – № 6(2). – C. 543–549.
3. Huang, X. Evolutionary topology optimization of continuum structures: Methods and applications / X. Huang, Y.M. Xie; – M. : N.-Y.: Wiley, 2010. – 217 p.
4. Xia, L. Bi-directional Evolutionary Structural Optimization on Advanced Structures and Materials: A Comprehensive Review / L. Xia, Q. Xia, X. Huang, Y. M. Xie // Archives of Computational Methods in Engineering. – 2016. – № 25(2). – P. 437–478.
5. Ghabraie, K. An improved soft-kill BESO algorithm for optimal distribution of single or multiple material phases / K. Ghabraie // Structural and Multidisciplinary Optimization. – 2015. – № 52(4). – P. 773–790.

Thank you for your attention

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