Numerical Optimization of Active Heat Sinks Considering Restrictions of Selective Laser Melting

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Introduction: Additive manufacturing methods like Selective Laser Melting are used for manufacturing of complex topology optimized structures because of the great design freedom provided by a tool-free, layer-wise production. This design freedom also allows for compact designs of thermal components with good adaptation to geometrical boundary conditions, while manufacturing restrictions can be directly integrated into topology optimization simulations.

In this work a parametric optimization and a topology optimization approach for an active heat sink are compared, regarding the thermal performance, as shown in Figure 1.

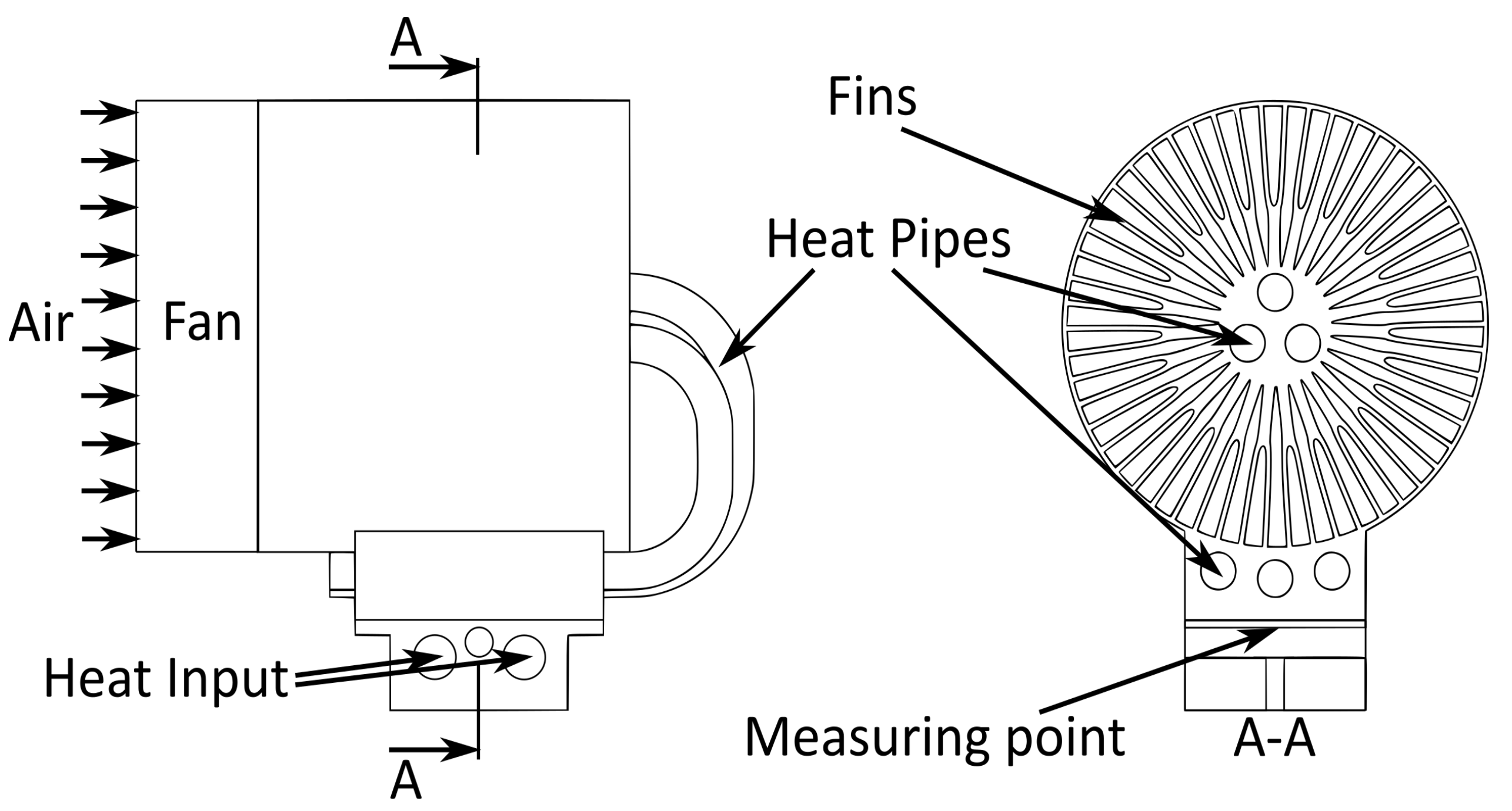

Figure 1. Definition of the problem.

Computational Methods: For the numerical analysis of the heat transfer, solutions are found for the governing conservation equation of energy. The general objective function in this optimization problem is equivalent to minimizing the total variation of the temperature in the design domain during a constant heat generation [1]. Since an active cooling with air is intended, a limit on the solid fraction is introduced to allow the fluid to pass by. The material distribution method (with the design variable ρ_{des}) is used for the topology optimization. The thermal conductivity is defined as a function of ρ_{des} by applying the SIMP rule [2]:

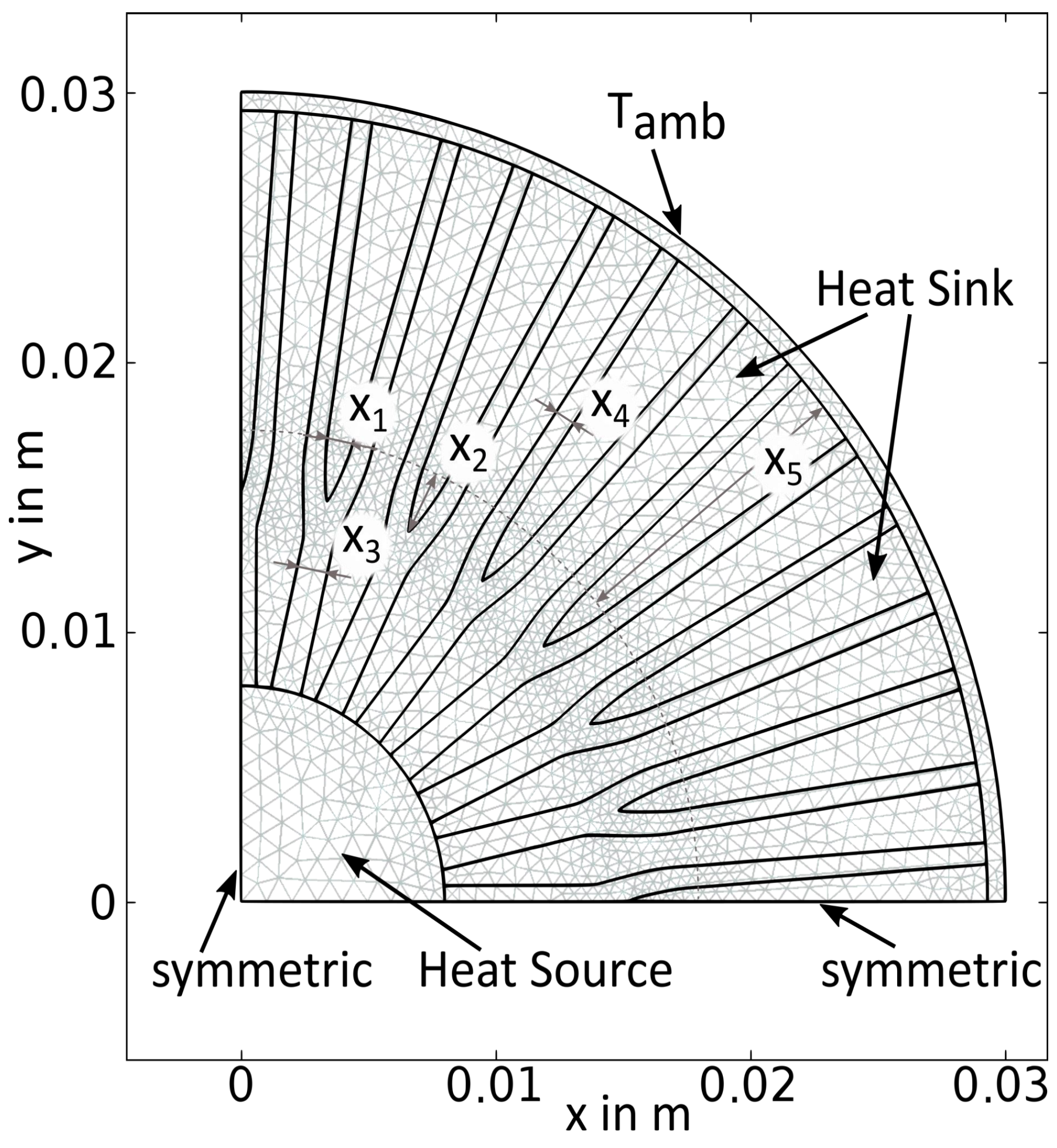

Figure 2. Used parameters (number of fins not included), mesh and boundary conditions for the parametric optimization.

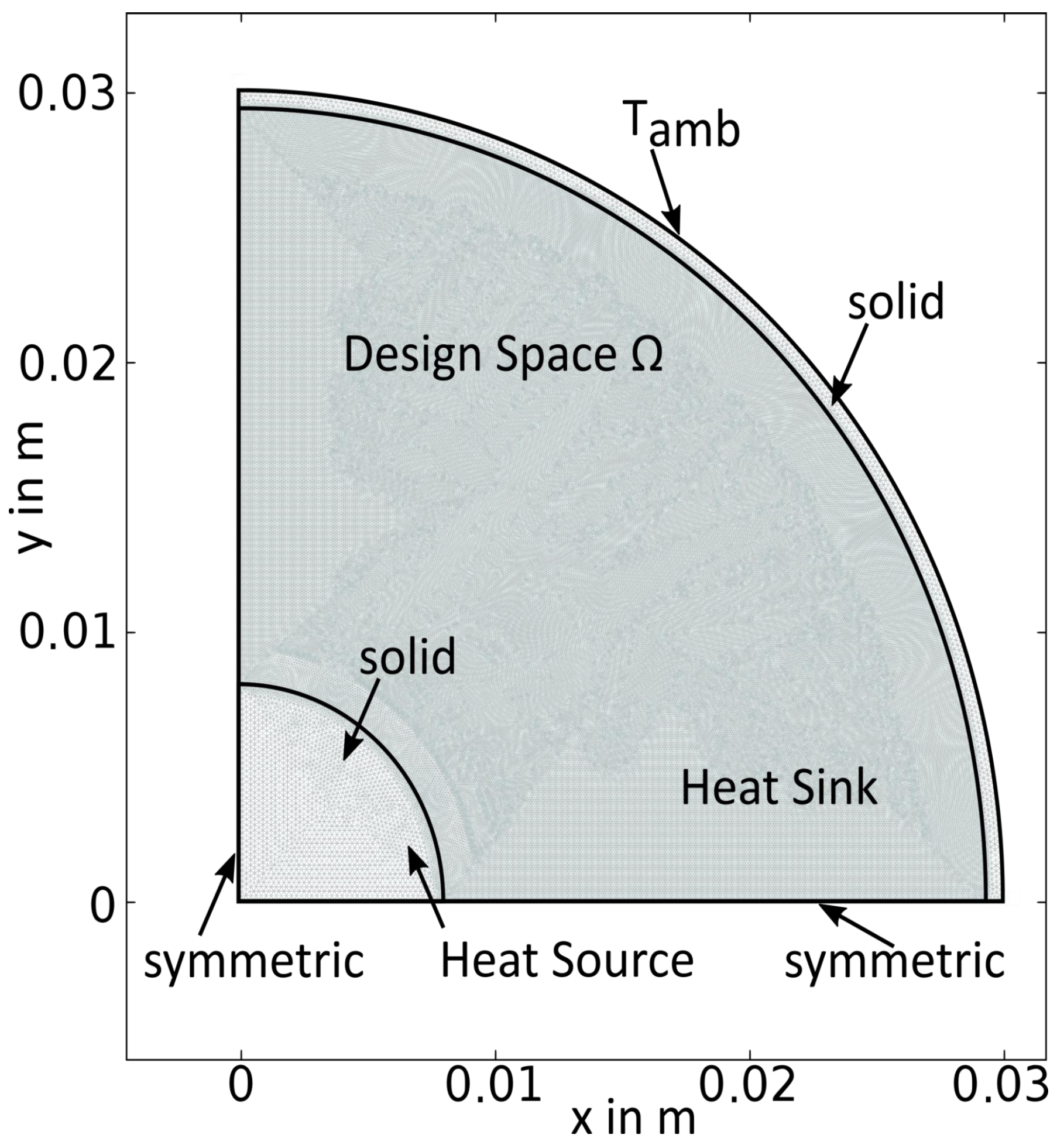

Figure 3. The boundary conditions and design space the topological optimization.

$$k = k_{min} + (k_{max} - k_{min}) \cdot \rho_{des}^{p}$$

Furthermore, the total variation of the design variable is used to define a penalty term as a wall thickness restriction. The final objective function has the form:

$$f = \int_{\Omega} \left[q \cdot k(\nabla T)^2 + (1-q)\frac{\mathrm{h}_0 \mathrm{h}_{\max}}{\mathrm{A}} |\nabla \rho_{des}(x)|^2 \right] \mathrm{d}\,\Omega,$$

$$0 \le \int_{\Omega} \rho_{des} \mathrm{d}\Omega \le \gamma$$

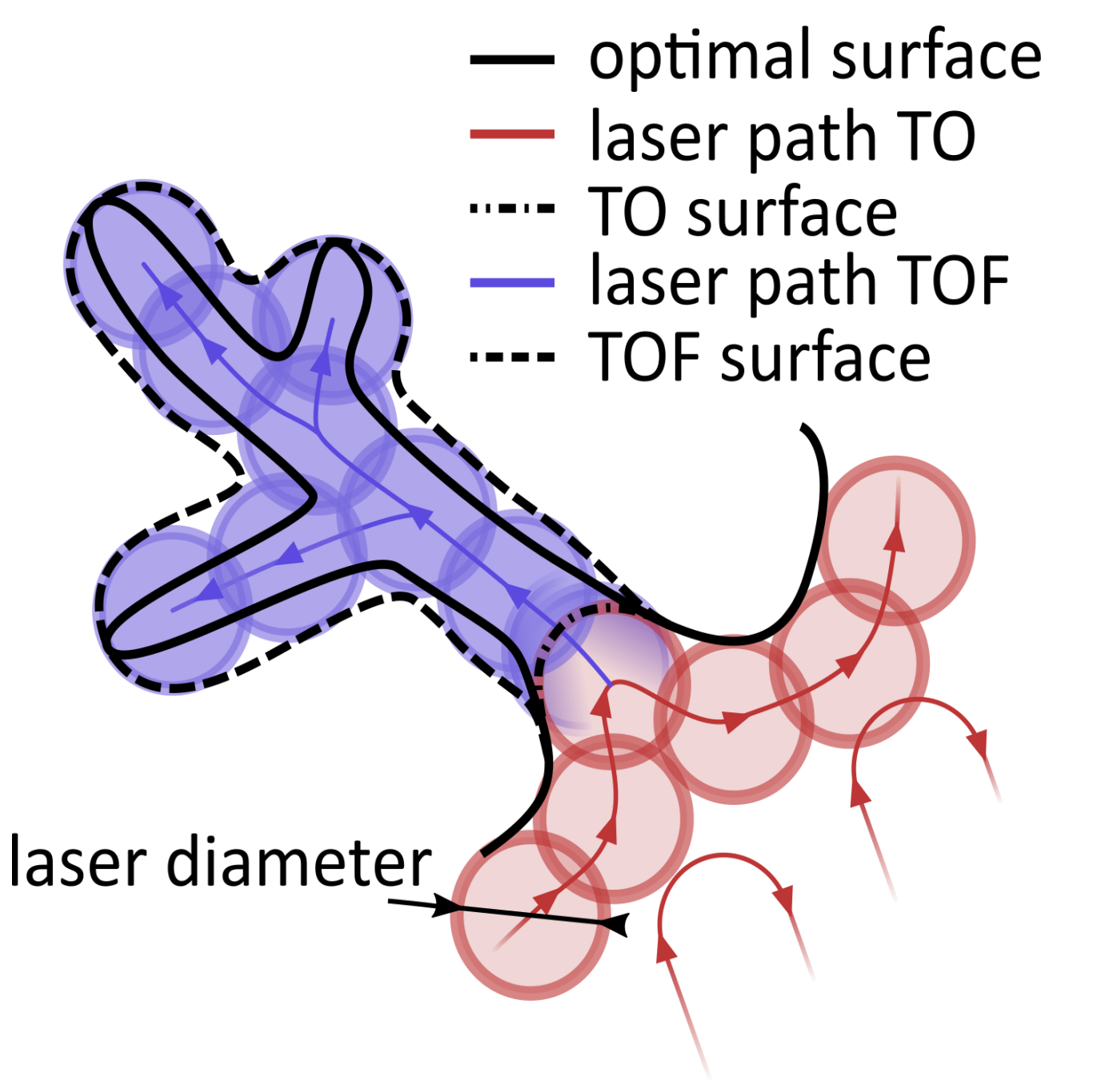

Figure 4. Laser paths and laser diameter in comparison to the mathematical optimal surface.

	CON	PA	TO	TOF
m in kg	0.550	0.170	0.134	0.140
R_{th} in K W^{-1}	0.360	0.462	0.376	0.373
R^*_{th} in K kg W^{-1}	0.198	0.079	0.050	0.053

Table 1. Mass (m), thermal resistance (Rth), and weight related thermal resistance (R*th) of the investigated Prototypes.

Results & Conclusions: The best weight related thermal resistance is achieved by the topological optimum without forced edging (TO), which is around five times better than the conventional component (CON) and thus ideally suited for lightweight construction applications. The topological optimum with forced edging (TOF) has a lower thermal resistance, but since it is a little bit heavier, the weighted thermal resistance is higher compared to TO.

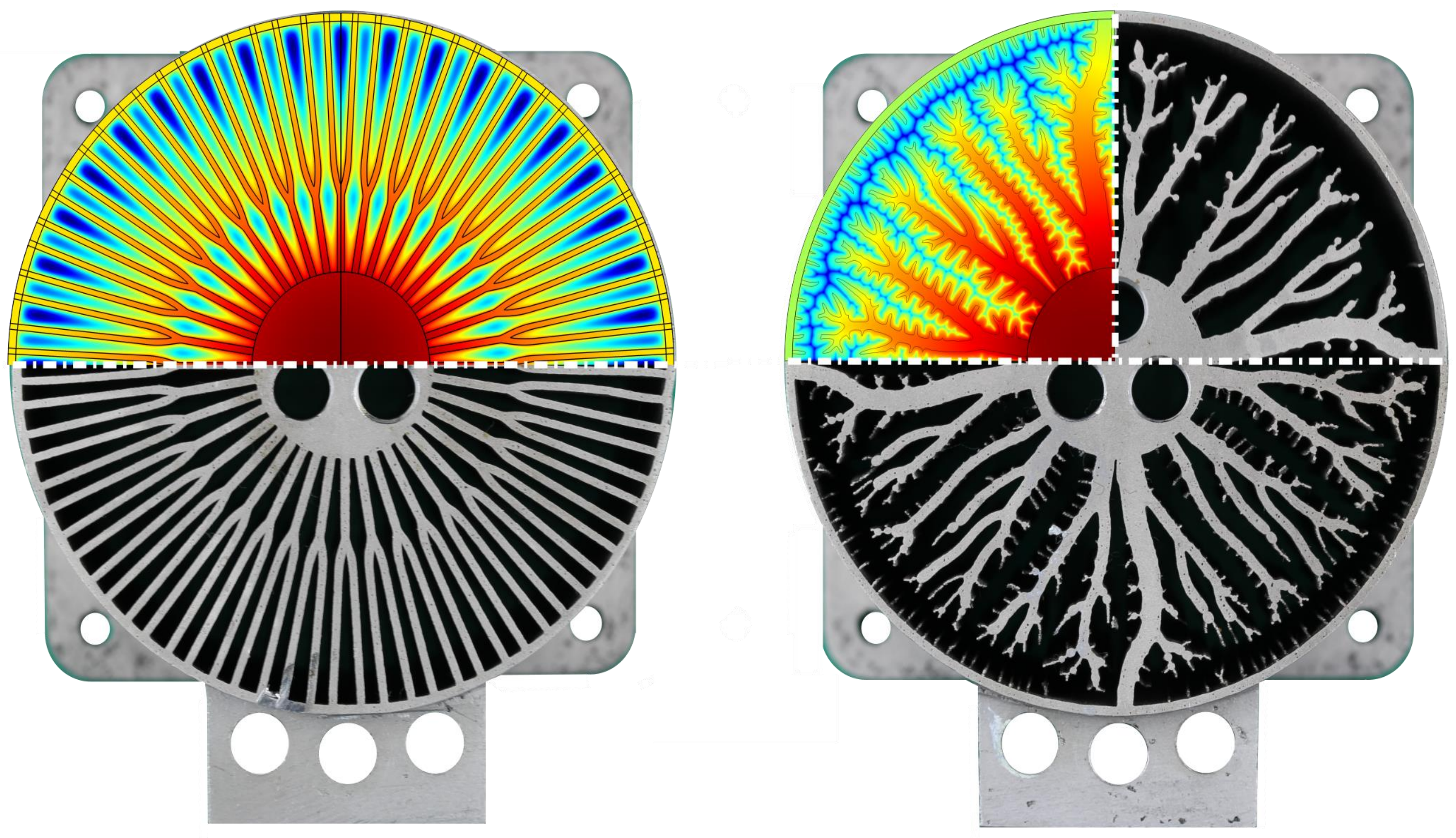

Figure 5. Simulation results and prototypes. Left: parametric optimum: top – simulation, bottom: printed and post-processed part. Right: topological optimum: upper left – simulation, upper right – printed and post-processed TO, bottom – printed and post-processed TOF

References:

1. E. M. Dede. Multiphysics topology optimization of heat transfer and fluid flow systems. COMSOL Users Conference, (2009)
2. M. P. Bendsøe, O. Sigmund. Topology Optimization: Theory, Methods and Applications. (2003)

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