

NUMERICAL TOOLS FOR TOPOLOGY OPTIMIZATION OF COMPUTATIONAL METAMATERIAL DESIGNS

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Motivation

- Millions of dollars are wasted every year in fuel consumption in the aerospace and automotive industry, this being directly related to the total weight of the vehicles. Consequently, the **reduction of their weight** becomes **crucial** in order to reduce both the **cost of materials** and the **cost of their operation**, while maintaining certain properties.



- Optimal topologies** can be computed via **Topology optimization techniques**, which determine, from a mathematical standpoint, the **optimal position and shape of the corresponding voids** in a predefined design domain, without requiring the interaction of an engineer.

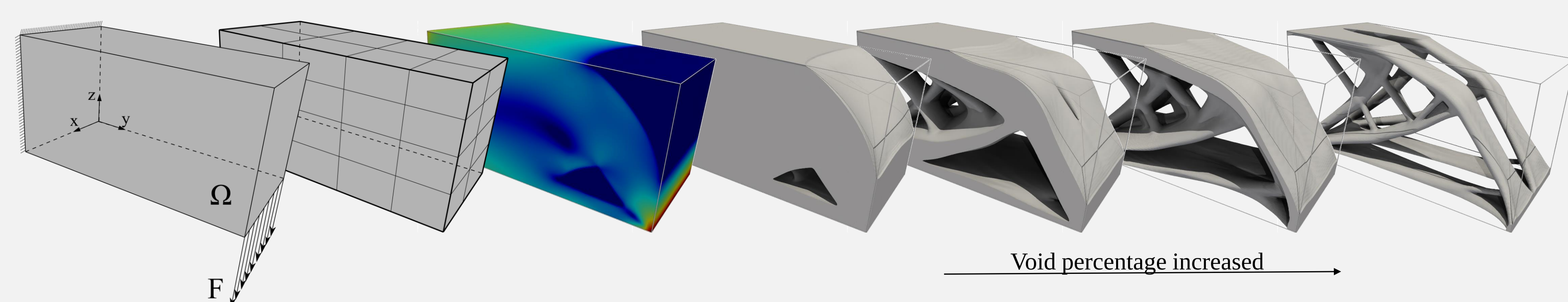
- Topology Optimization** has become an active research field to seek **new, non-intuitive optimal designs** in a wide range of design problems governed by different physical problems: solid mechanics, thermal problems and acoustics, among others, requiring high computational resources.

- The aim of this work is the formulation and development of a **new topology optimization approach** which reduces the required computational cost, allowing to optimize complex industrial structures with manufacturability constraints in a reasonable amount of time.

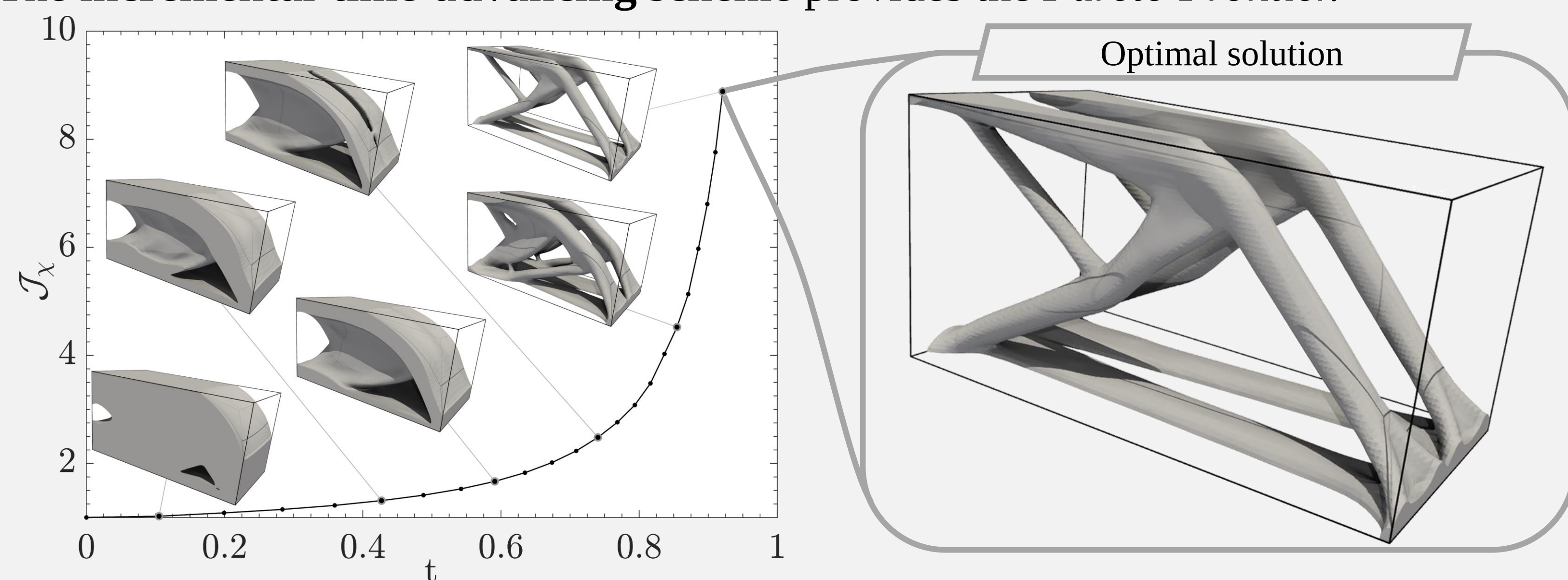
COMPLEXITY
COMPLIANCE
THERMAL
STATE
VOLUME
INTEGRAL
STRUCTURAL
ANALYTICS
LAYOUT
CONSTRAINT
OPTIMIZATION
COMPLEX
FUNCTION
DESIGN
COMPUTATIONAL
RESEARCH
COMPLIANT
MECHANISMS
MANUFACTURABILITY
PARETO
FRONTIER

Structural problem

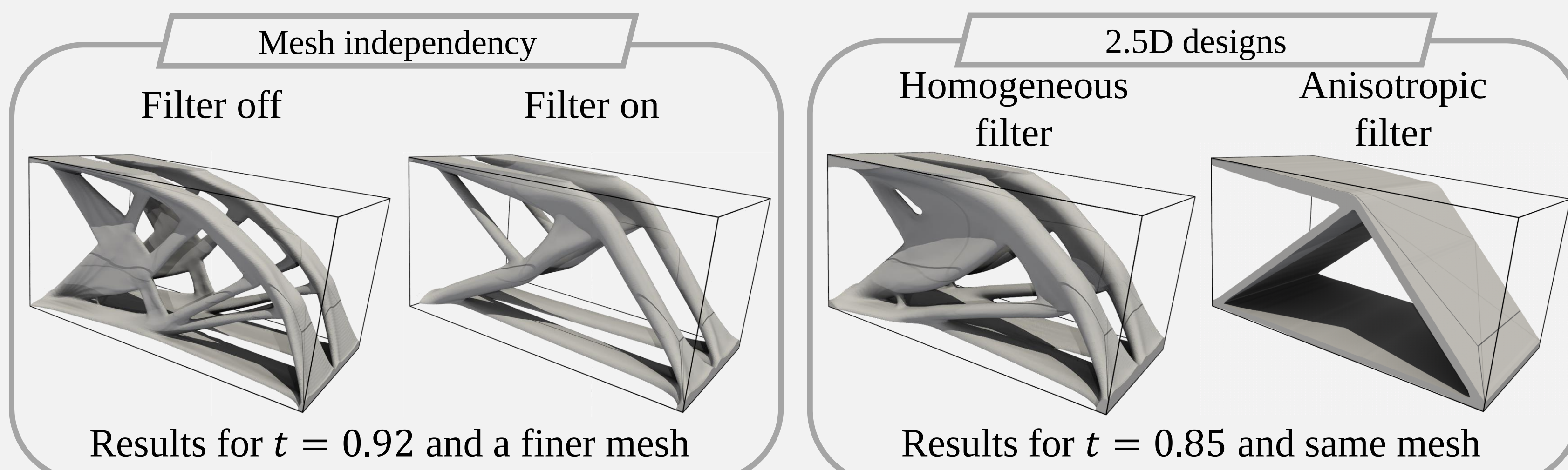
Topology optimization allows to find the optimal layout of a given structure that minimizes the **mean compliance** for a given **volume percentage**.



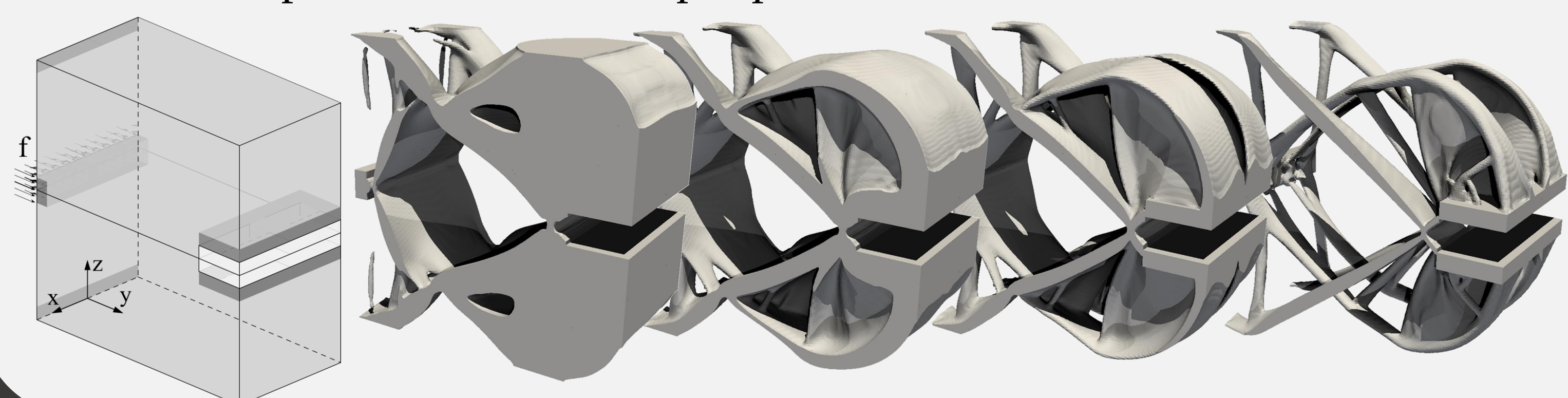
The **incremental-time-advancing scheme** provides the **Pareto Frontier**.



Filter technique: Laplacian regularization

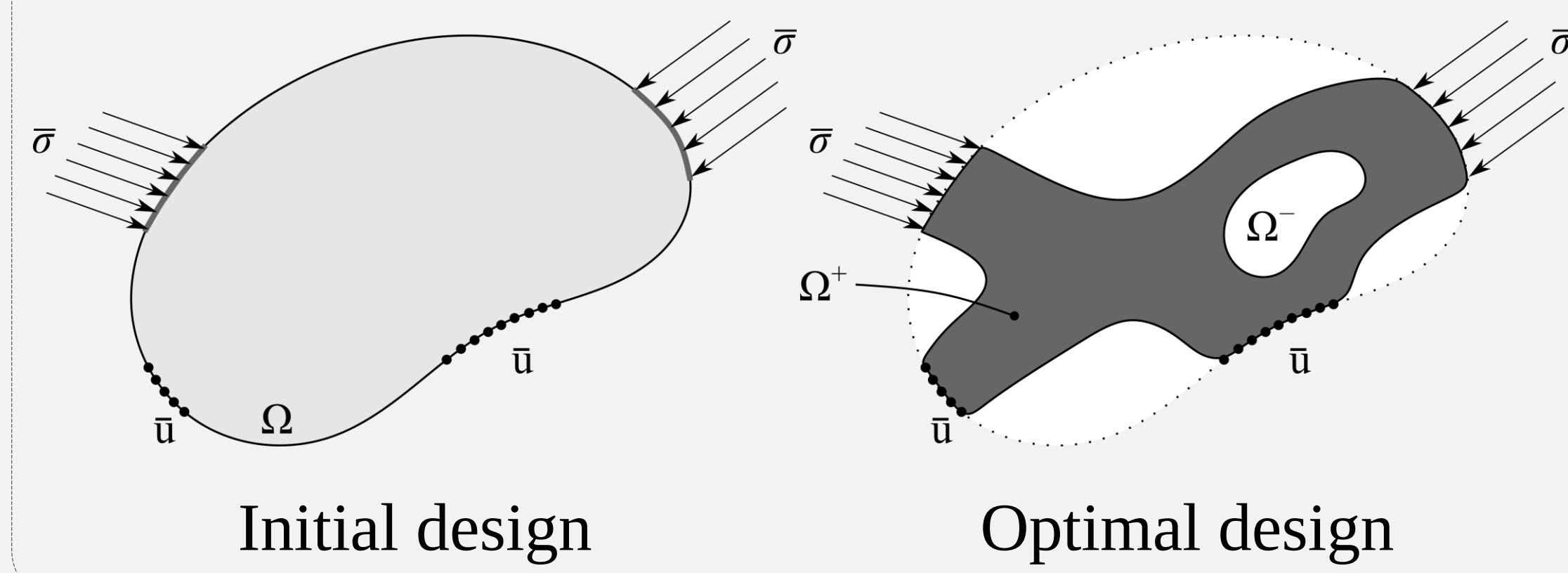


Optimization of Compliant mechanisms: design of flexible structures to achieve a desired displacement at the **output port**.



Formulation

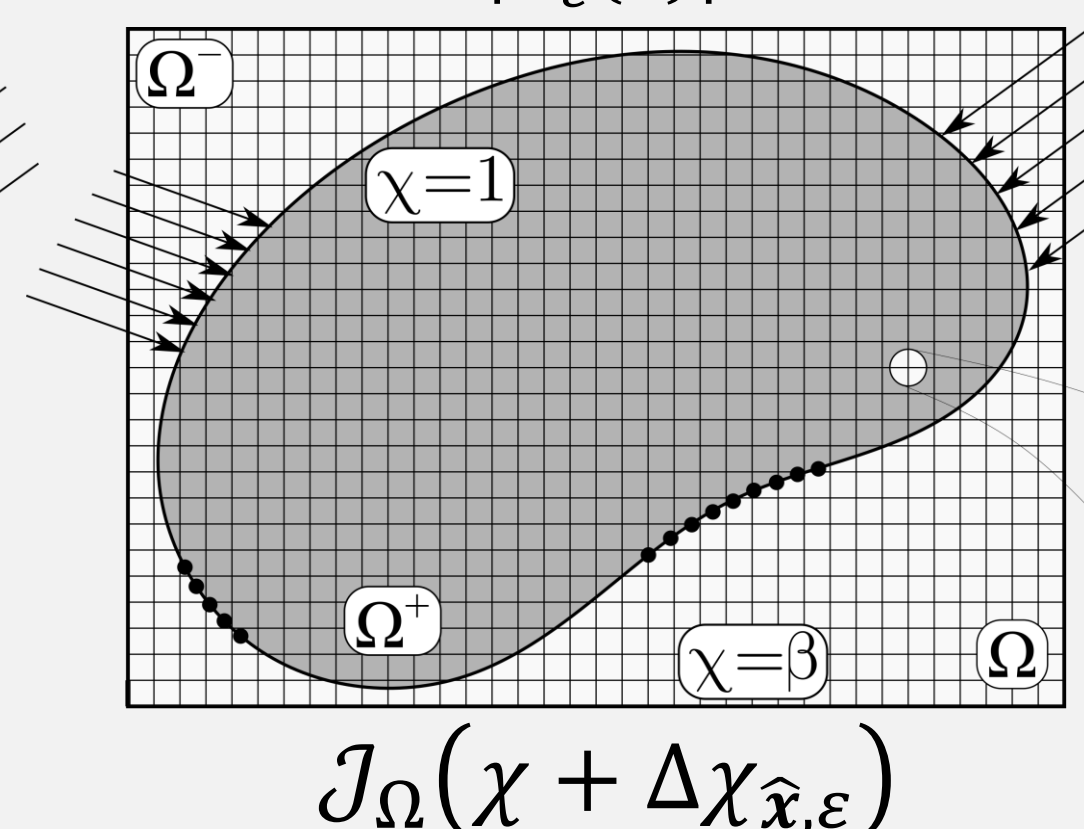
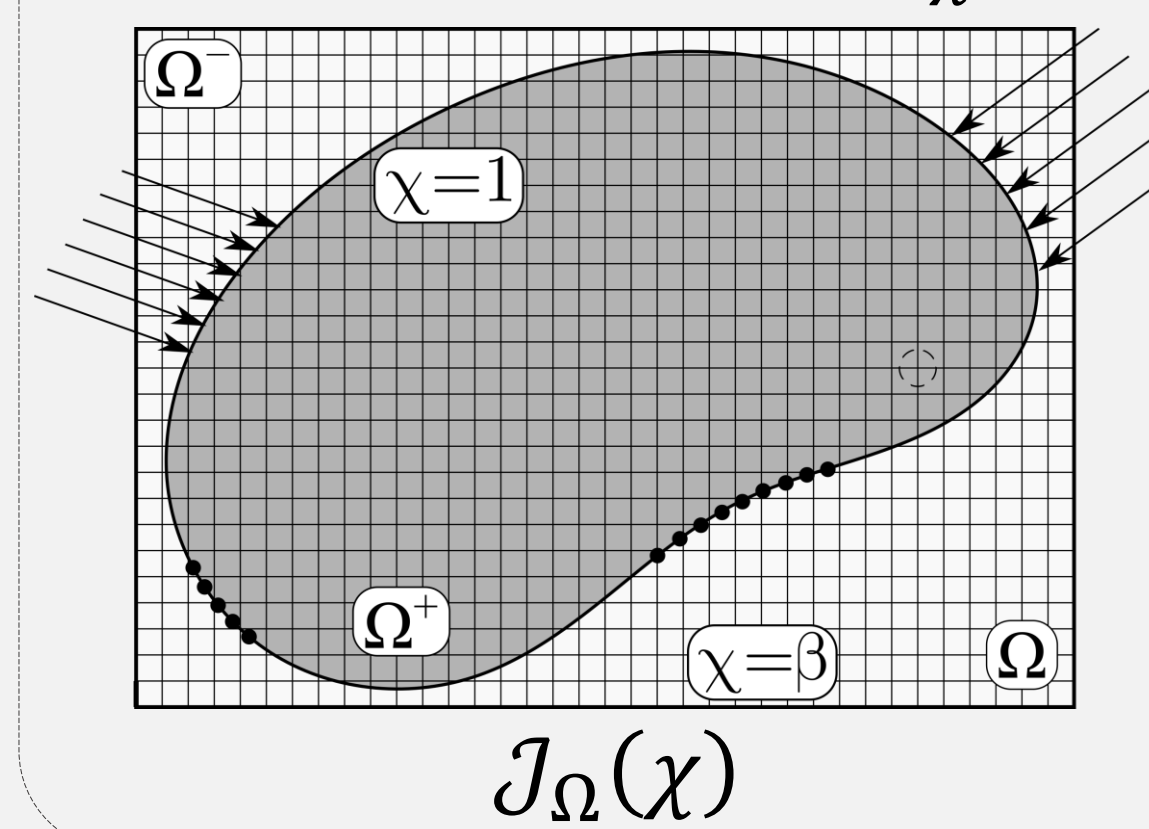
The **topology optimization problem** is formulated as a **minimization of a cost functional** subjected to a **volume constraint** and governed by a state equation.



Design domain Ω^+ is embedded in a fixed mesh and can be defined via the **characteristic function**, used as the **design variable**.

A new **Relaxed Topological Derivative (RTD)** evaluated as

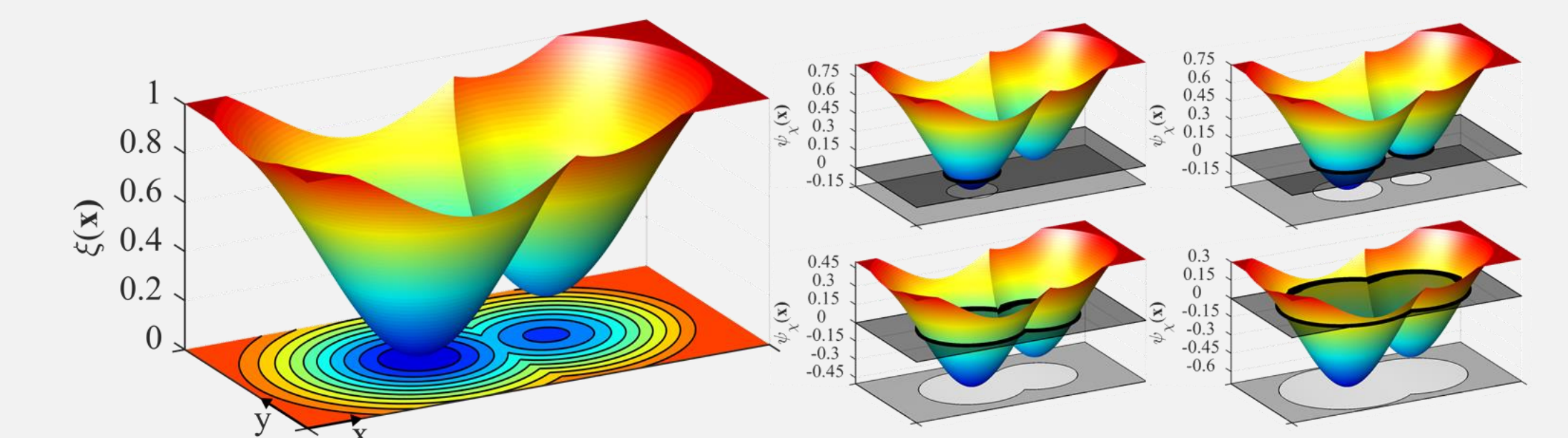
$$\frac{\delta J_{\Omega}(\chi)}{\delta \chi}(\bar{x}) = \lim_{\varepsilon \rightarrow 0} \frac{J_{\Omega}(\chi + \Delta \chi_{\bar{x}, \varepsilon}) - J_{\Omega}(\chi)}{|\Omega_{\varepsilon}(\bar{x})|} = \frac{\partial j(\chi, \bar{x})}{\partial \chi} \Delta \chi(\bar{x})$$



measures the change in **cost function** $J(\chi)$ when a small area changes from one material (stiff) to another (void), being consistent with the **ersatz material approach**.

The **incremental-time-advancing scheme** provides the **Pareto Frontier of optimal solutions** with respect to the volume constraint, allowing the user to select the desired optimal design.

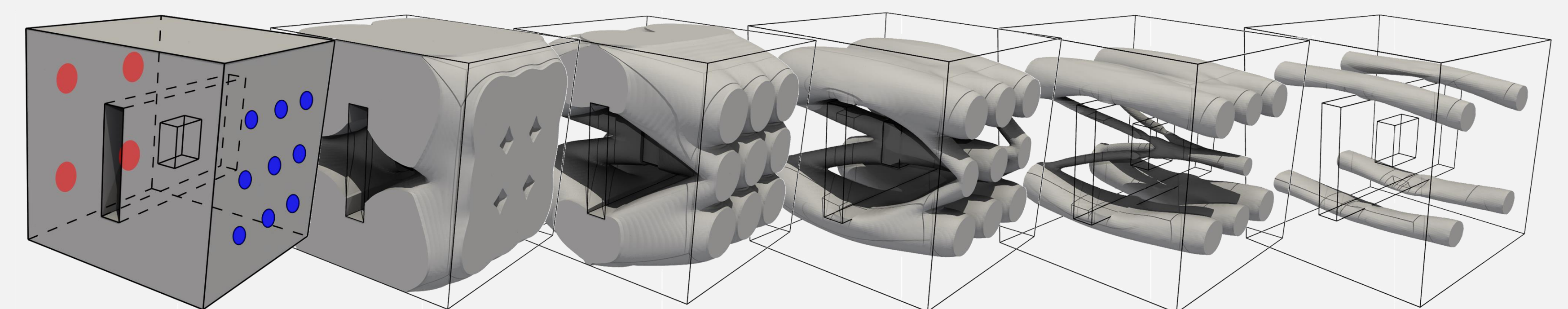
Cutting & Bisection Algorithm



The **optimal topology** is obtained as the solution to a **closed-form optimality criteria**, fulfilling the target volume constraint via a **bisection algorithm**.

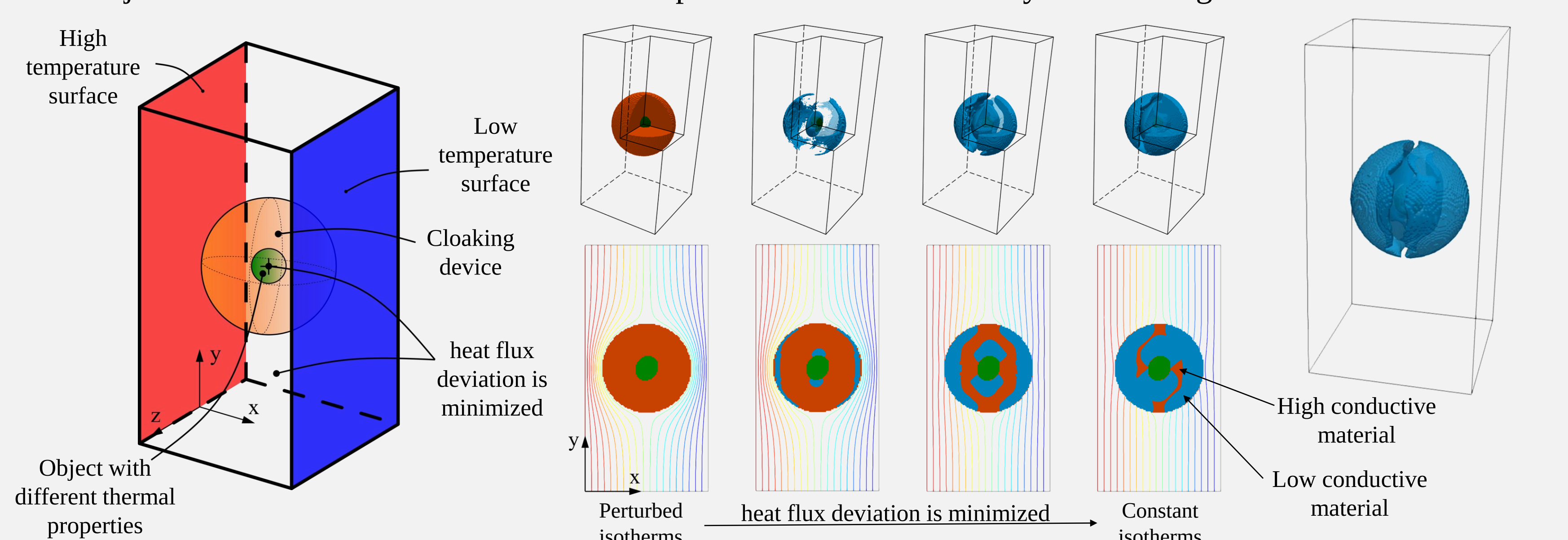
Thermal problem

Heat conduction is maximized in the structure for a given **volume percentage**.



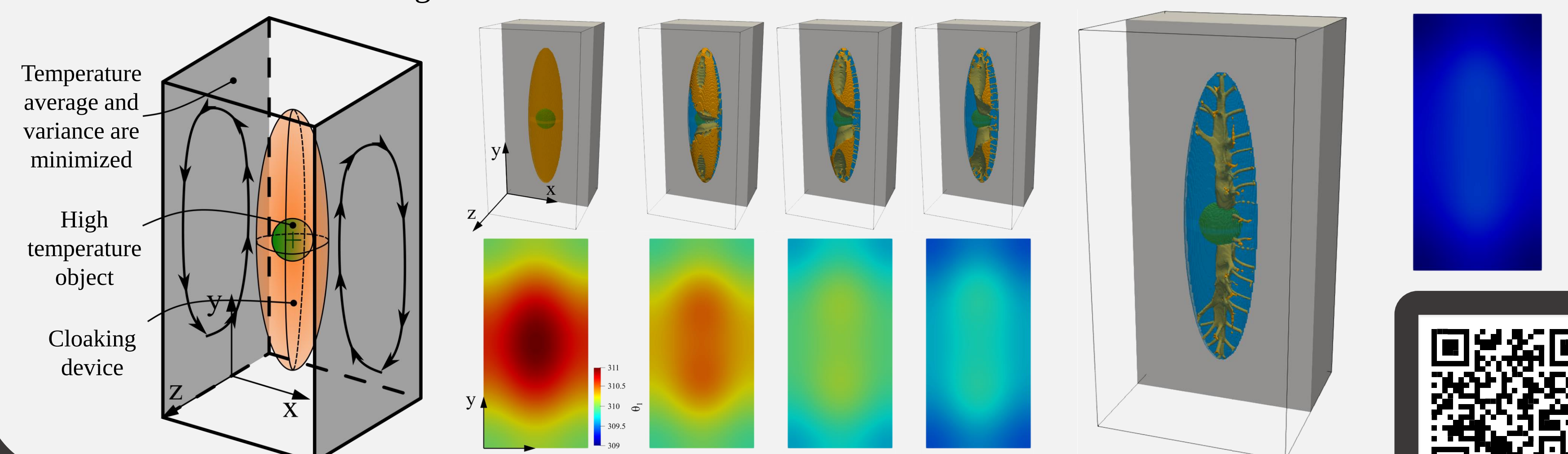
Thermal cloaking: Heat flux manipulation

The object is cloaked from the exterior via manipulation of the heat flux by the cloaking device.



Thermal cloaking: Average and variance temperature minimization

The thermal heat of a device is distributed by the cloaking device and dissipated through convection on the lateral surfaces to avoid being detected on the left surface.



Conclusions

- The present method is up to **10 times faster** than the equivalent **Level-set method**, when using an **incremental-time-advancing scheme**.
- Smooth black-and-white designs** with **minimum filament size control** are obtained, improving **manufacturability** compared to other approaches.



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