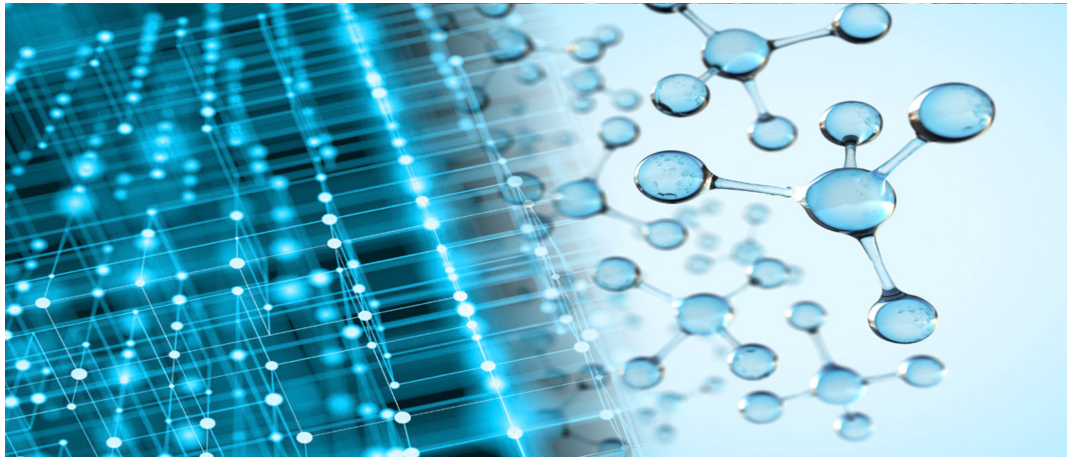
Optimal Design and Distribution of Unit Cells

Introduction into Optimization for Programmable Mechanics

Dr. Alexander Leichner
Dr. Heiko Andrä
M.Sc. Tobias Lichti

Fraunhofer Institute for
Industrial Mathematics (ITWM)
Kaiserslautern



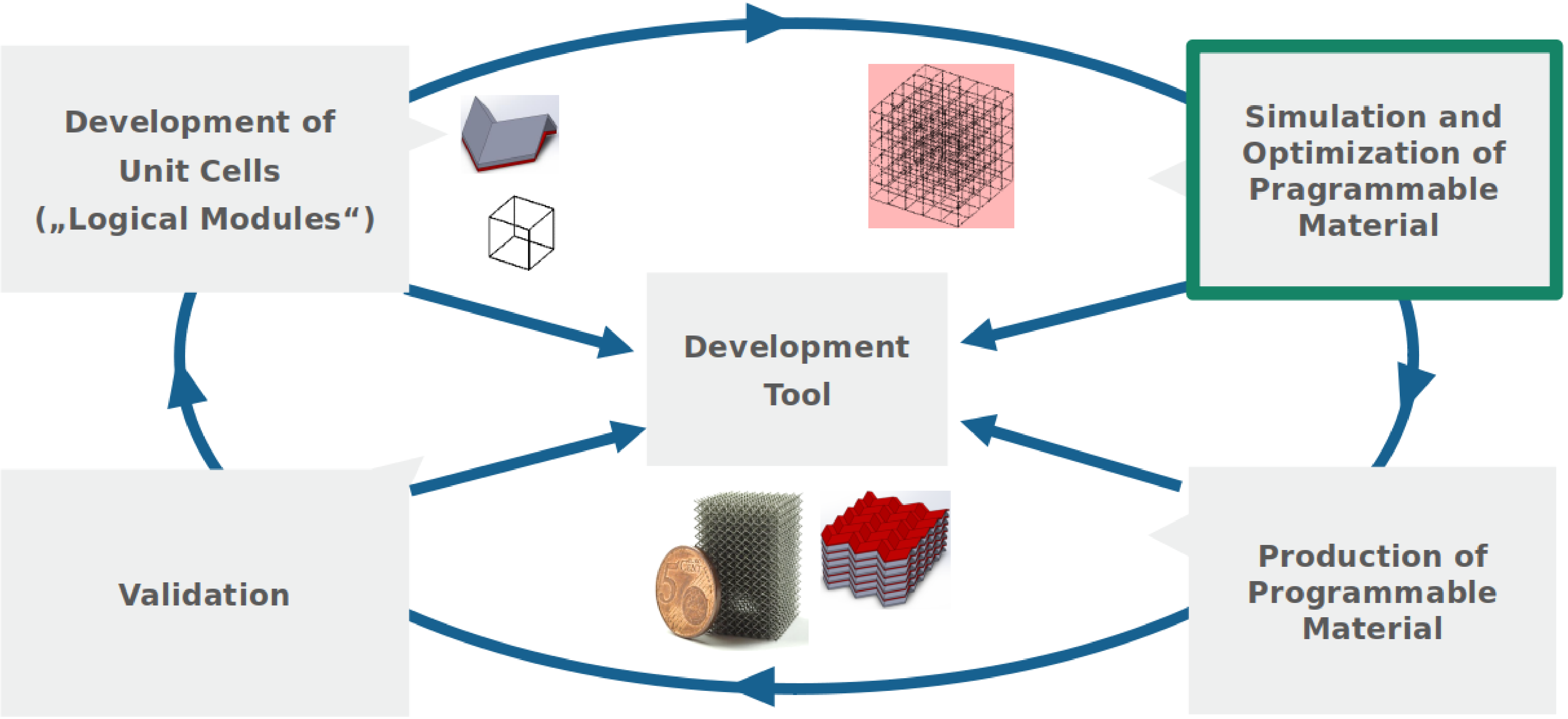
Fraunhofer
CPM

Overview

- Cluster Programmable Materials
  - Motivation
  - Focus on Programmable Mechanics
- Optimization Framework
  - Establishing data base for artificial material law
  - Handling with Unit Cells
- Foil Unit Cell
  - Simulation and Production
  - Programming a Deformation
  - Diverse Solutions
  - Optimization Performance
- Conclusion and Outlook
  - Summary
  - Future Work

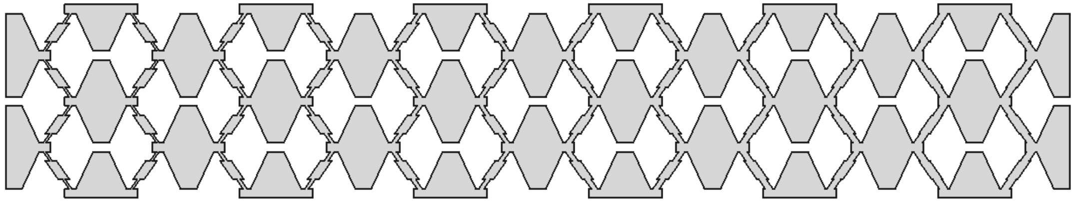
Cluster Programmable Materials - Motivation

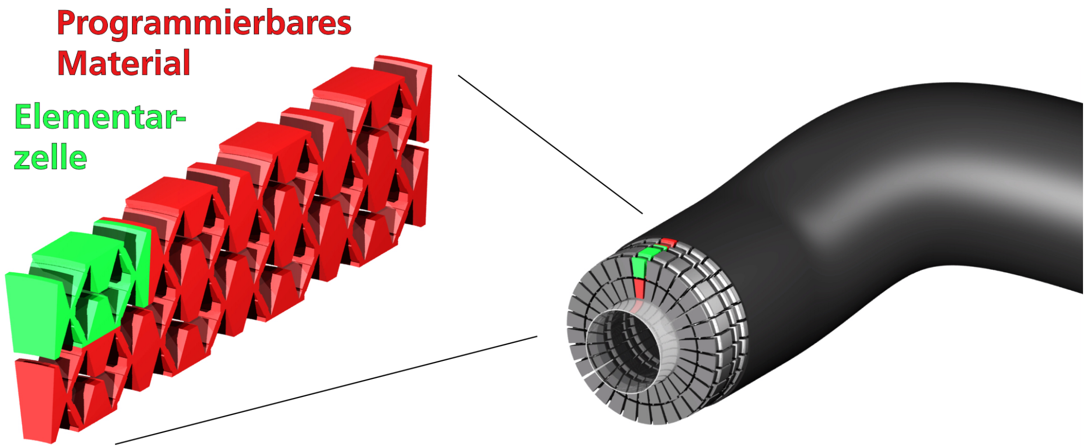
- Combining strength and competences of many Fraunhofer institutes
- Summarizing them into a Cluster for **parallel** research



Cluster Programmable Materials - Focus on Programmable Mechanics

- Realization of exotic or unnatural material behavior
- Implementation of custom made mechanics for special purposes



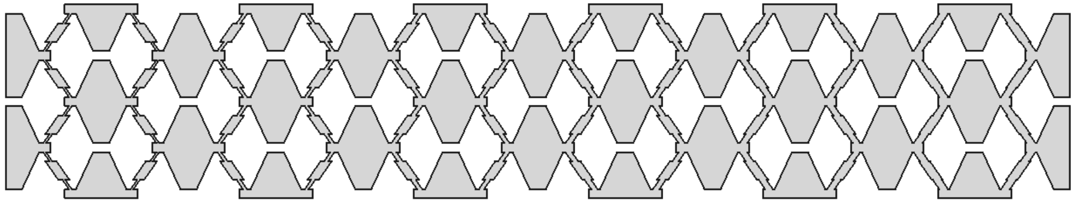


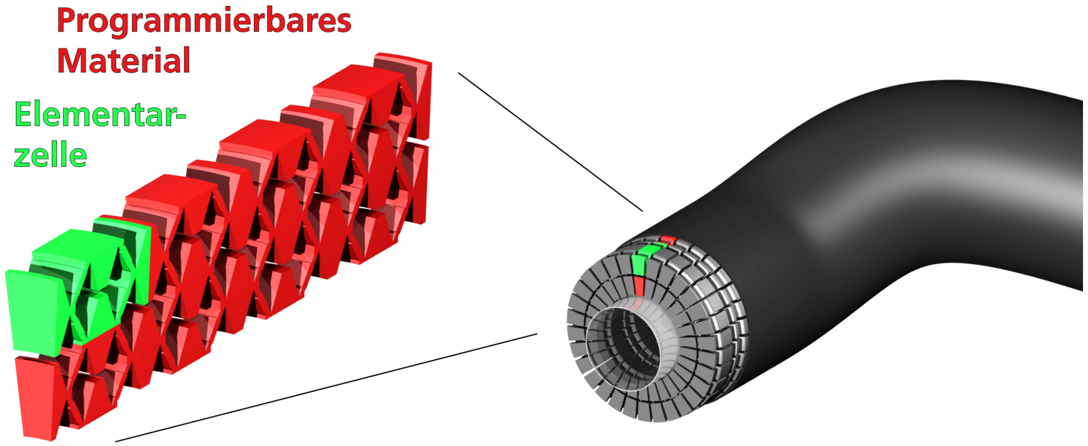
Definition of Programmable Materials (PM) as a subset of Meta-Materials

PM are responsive functional materials whose mechanical properties (or shape) can be switched (or functionally changed) by an external trigger (stimulus). In contrast to mechatronic systems, this responsiveness is achieved solely by the complex internal structure of the material.

Cluster Programmable Materials - Focus on Programmable Mechanics

- Realization of exotic or unnatural material behavior
- Implementation of custom made mechanics for special purposes





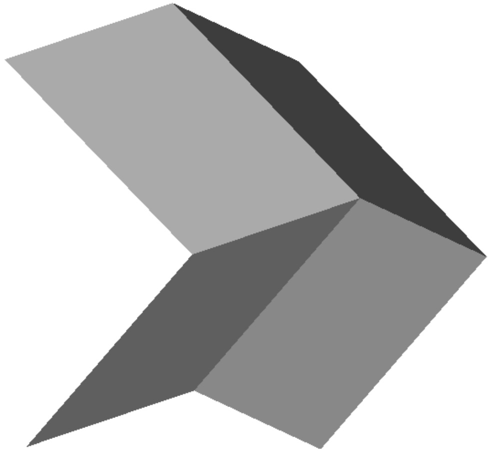
Programmable Materials consist of Unit Cells

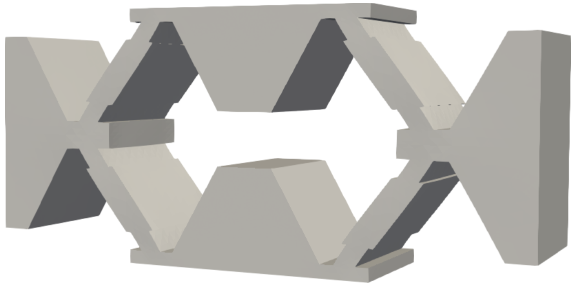
- In order to be regarded as homogeneous material:
  - Unit cells must be sufficiently **miniaturized** → Surrogate model as material law
  - **Many** unit cells must be arranged into arrays → Adjoint approach for distribution of unit cells

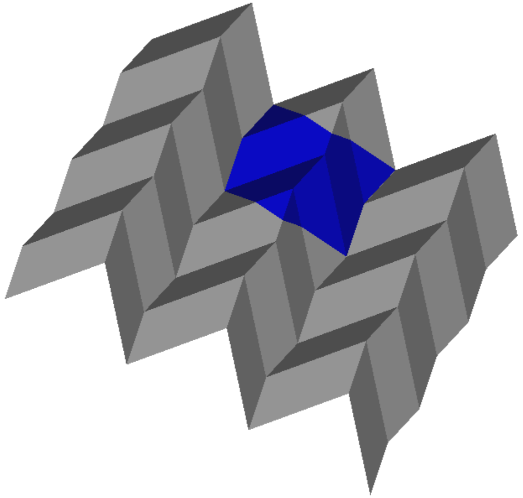
Fraunhofer CPM

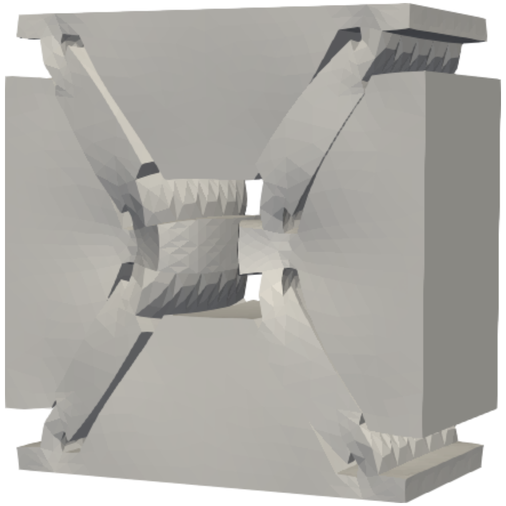
Cluster Programmable Materials - Focus on Programmable Mechanics

- Examples for unit cells



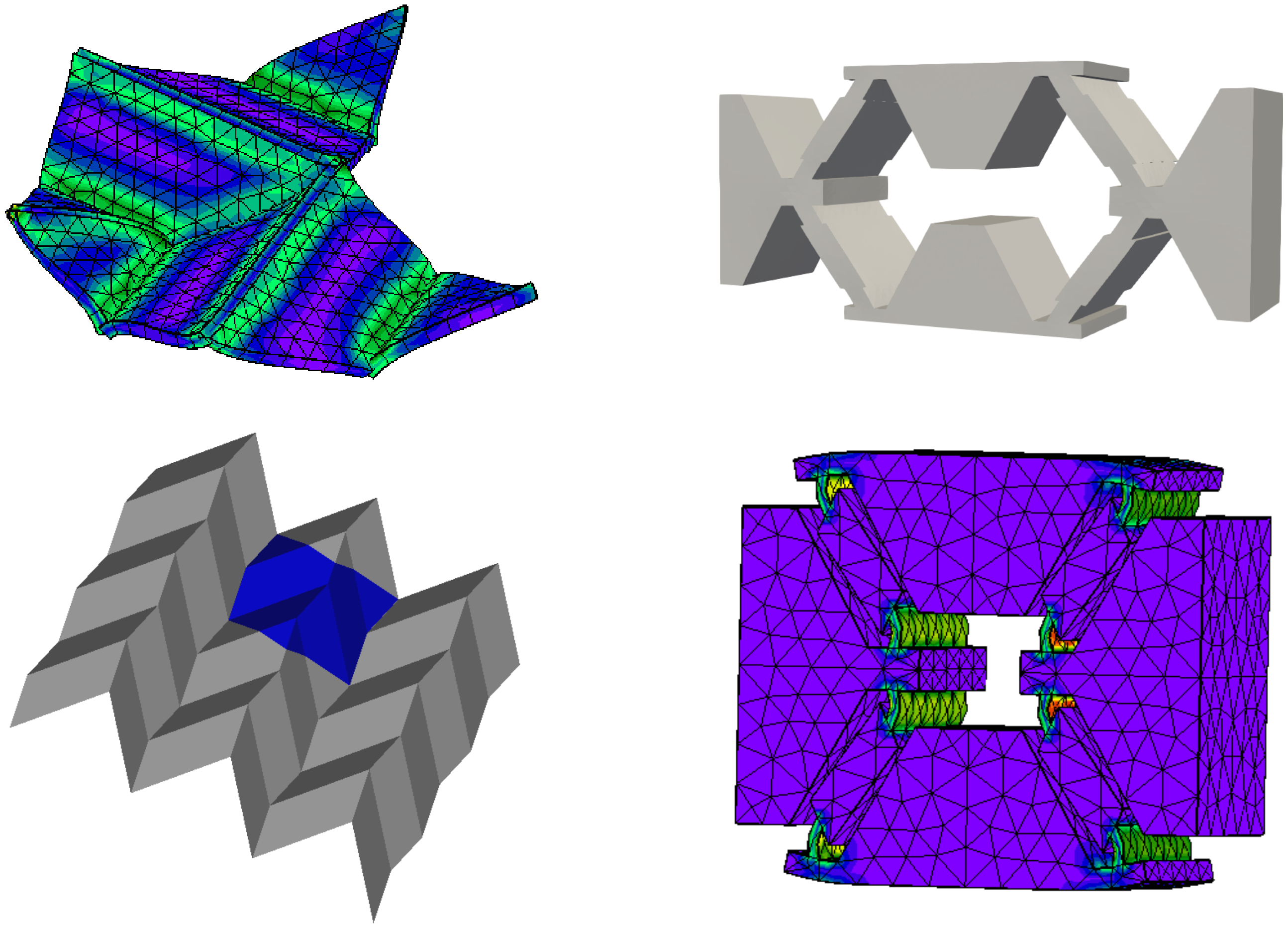






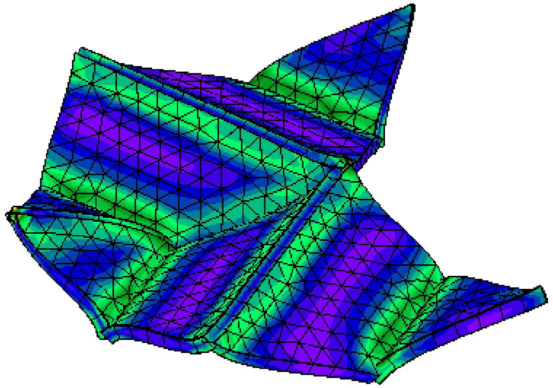
Cluster Programmable Materials - Focus on Programmable Mechanics

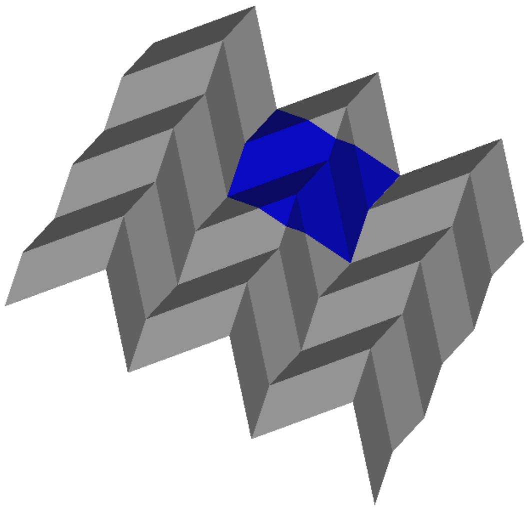
- Examples for unit cells

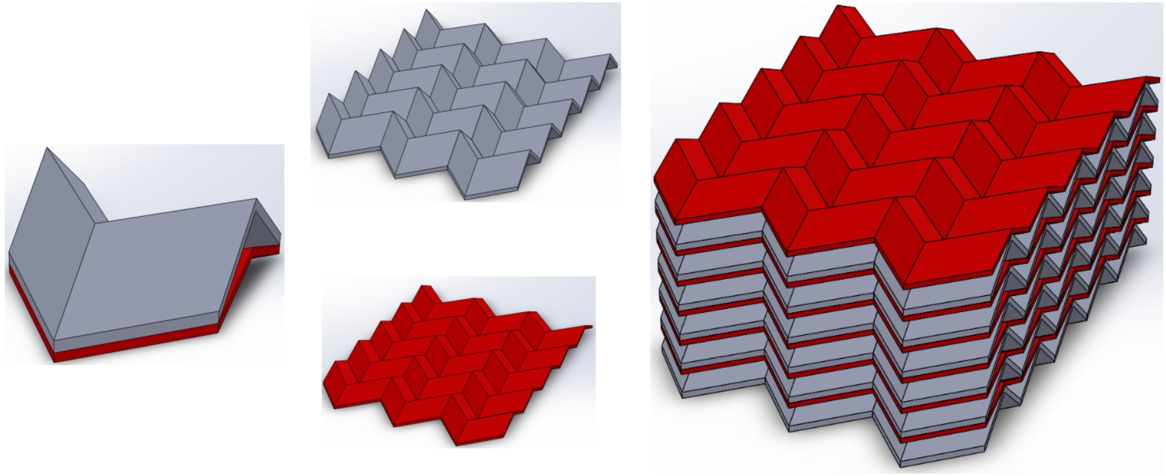


Fraunhofer CPM

Cluster Programmable Materials - Focus on Programmable Mechanics







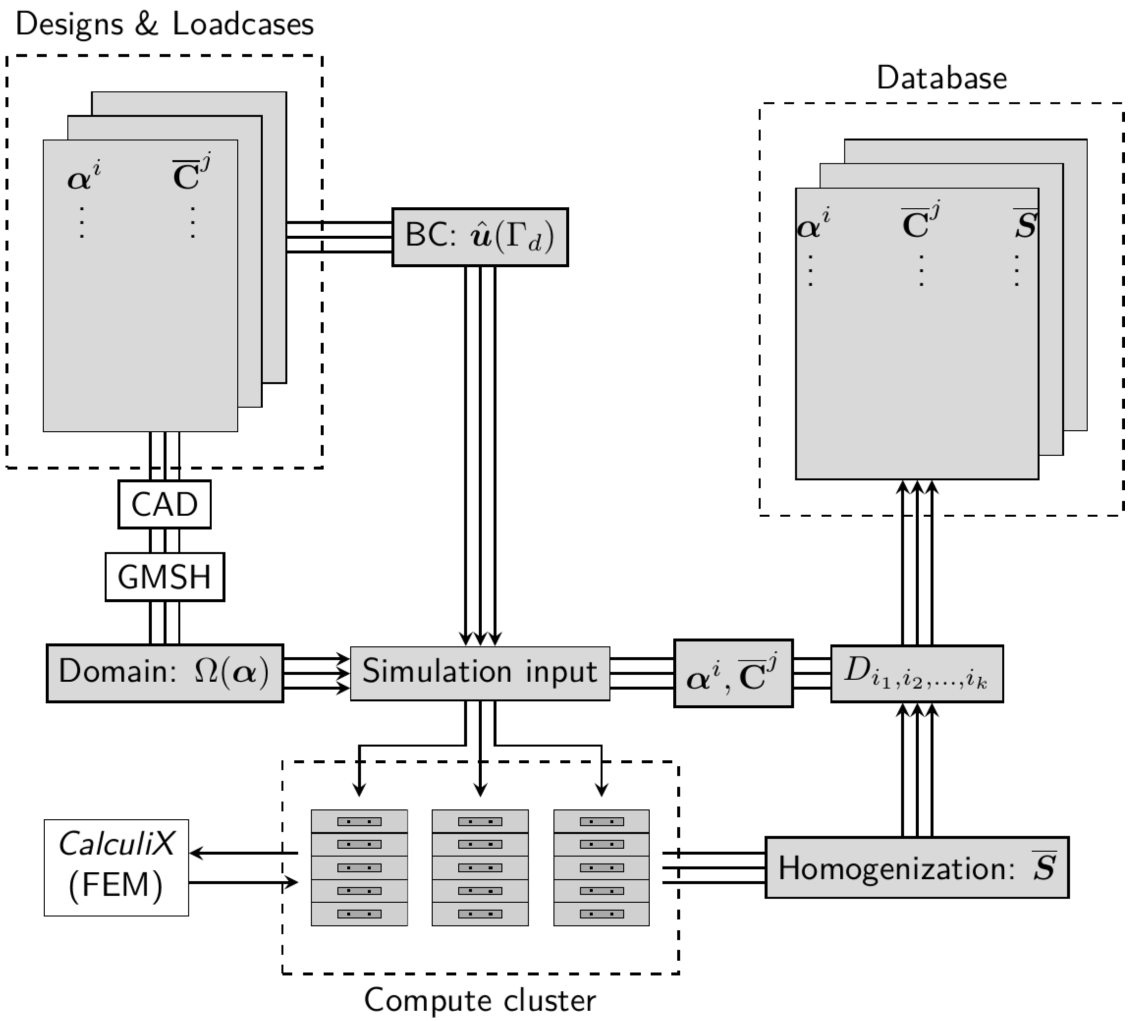
- Foil produced in deep drawing process
  $\rightarrow$ cheap and robust
- Extension into 3D by stacking
- Different offsets allow implementation

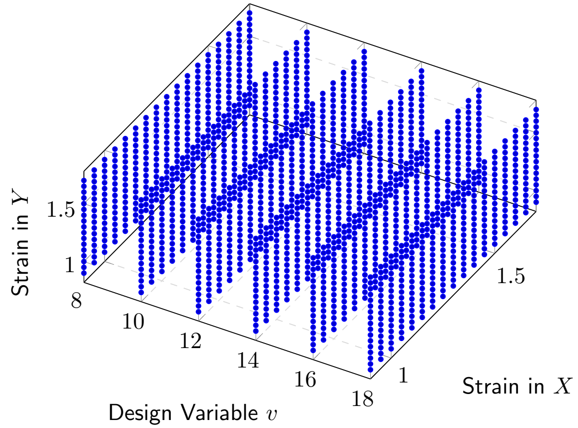
- Application of surrogate material model in unit cell array

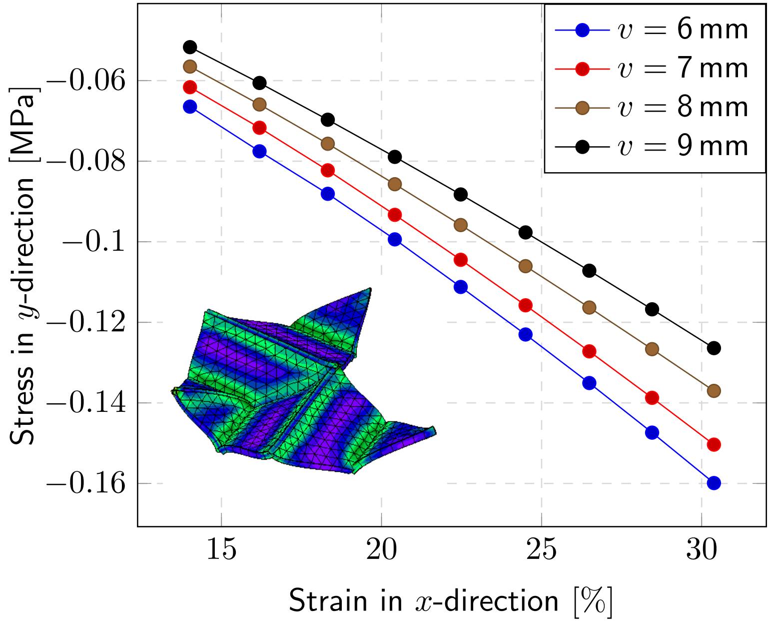
$\rightarrow$ Establishing artificial material laws based on homogenization results

Fraunhofer CPM

Optimization Framework - Establishing data base for artificial material law



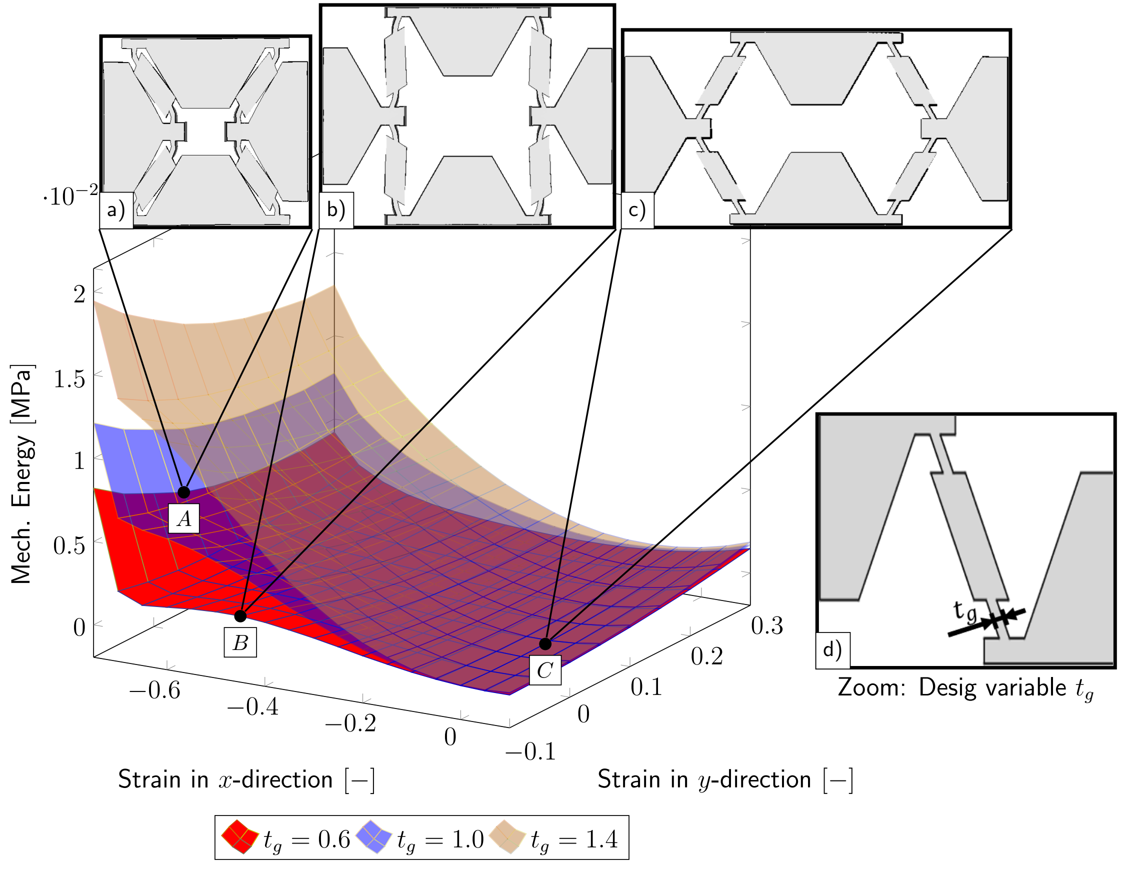


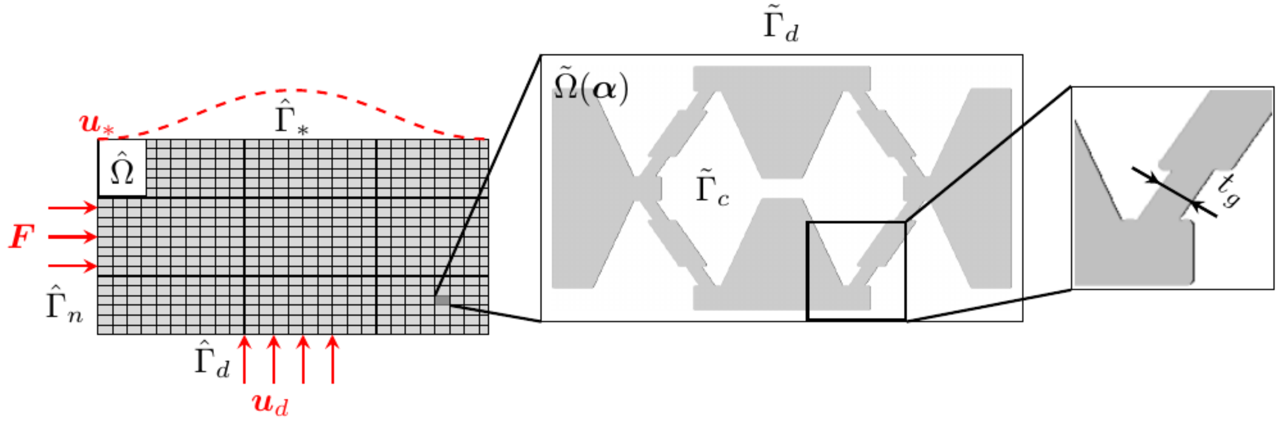


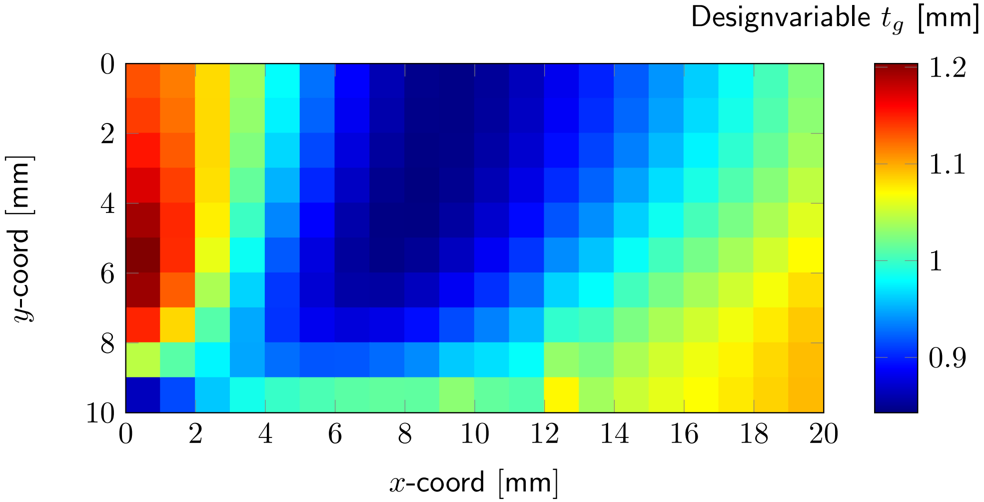
Fraunhofer CPM

Optimization Framework - Handling with Unit Cells

- Optimization with arbitrary periodic unit cells
- Homogenization with learning methods



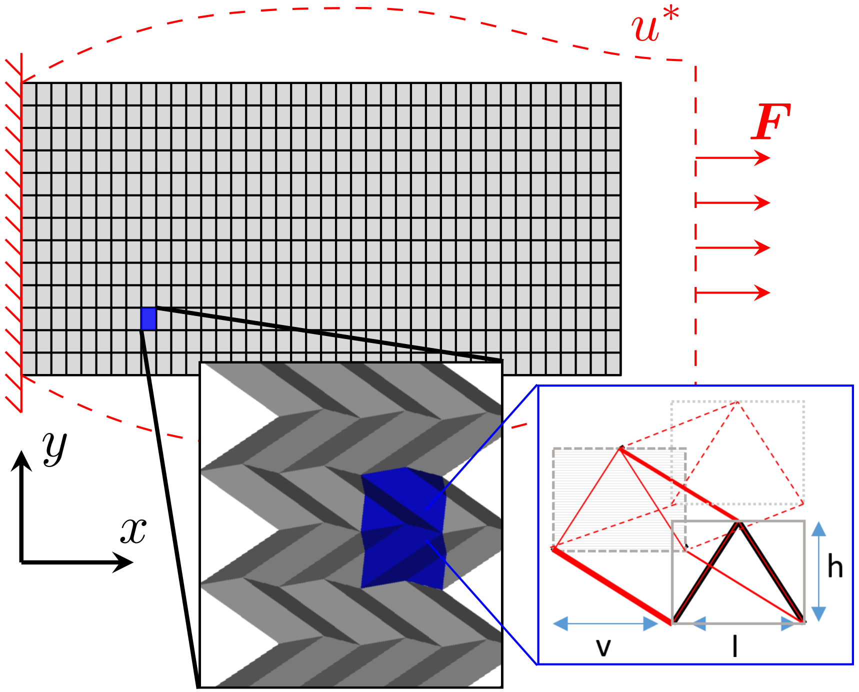




Fraunhofer
CPM

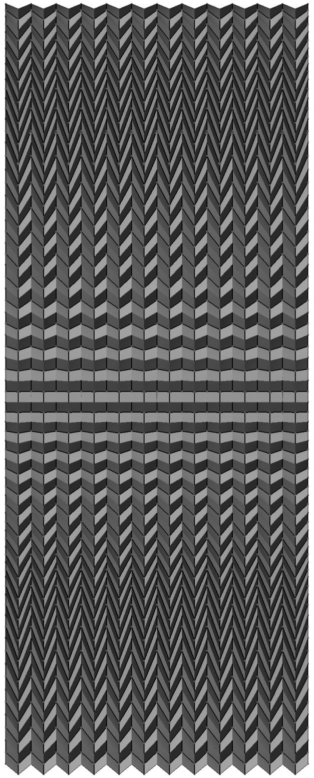
Foil Unit Cell - Simulation and Production

- Example for optimization
- Unit cells made of foil
- Production deep drawing
- Parameter: Offset *v*



Stencil

Deformed foil

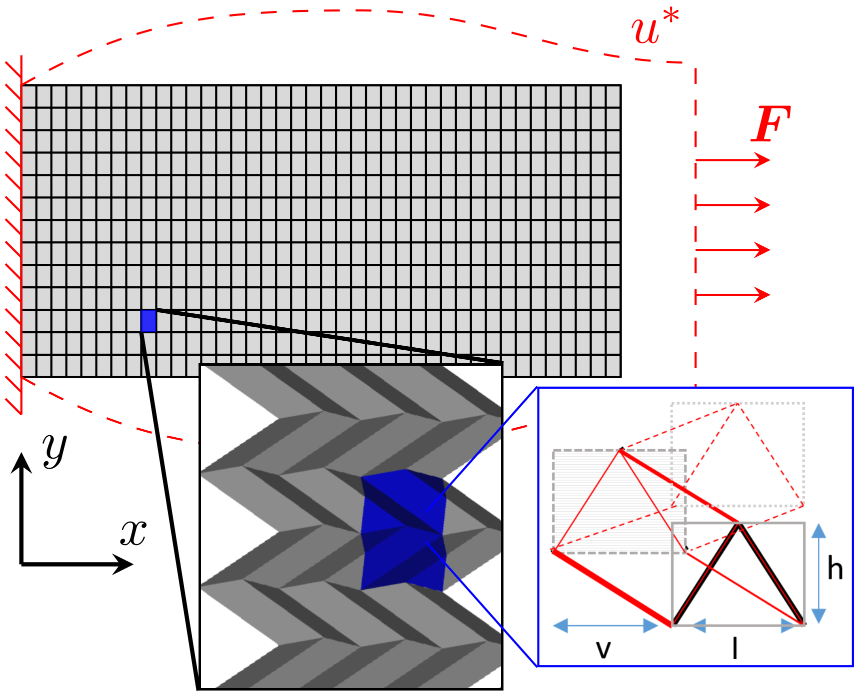


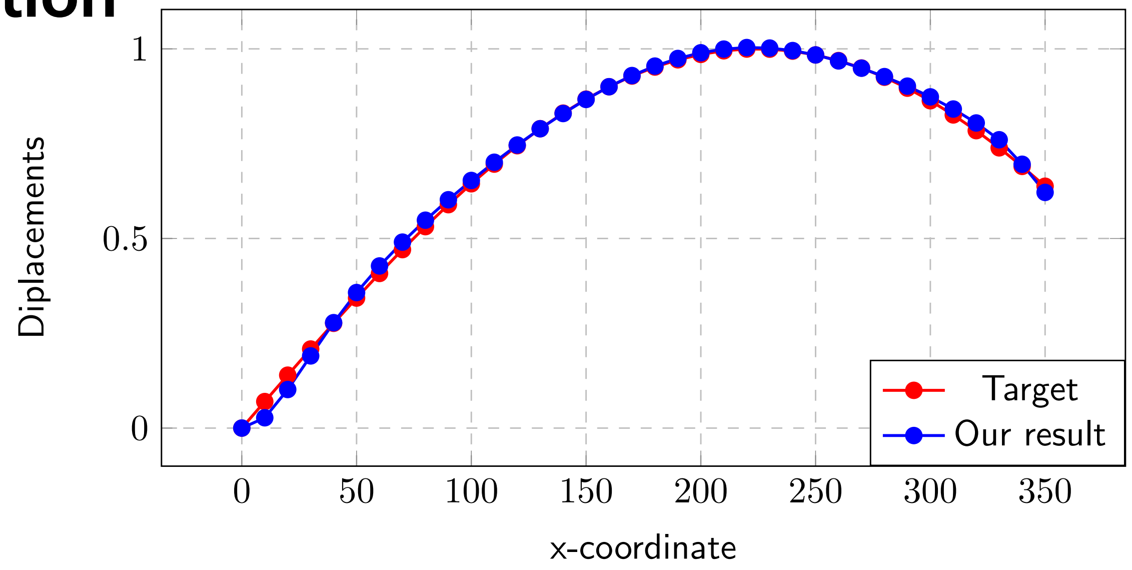
Computer model

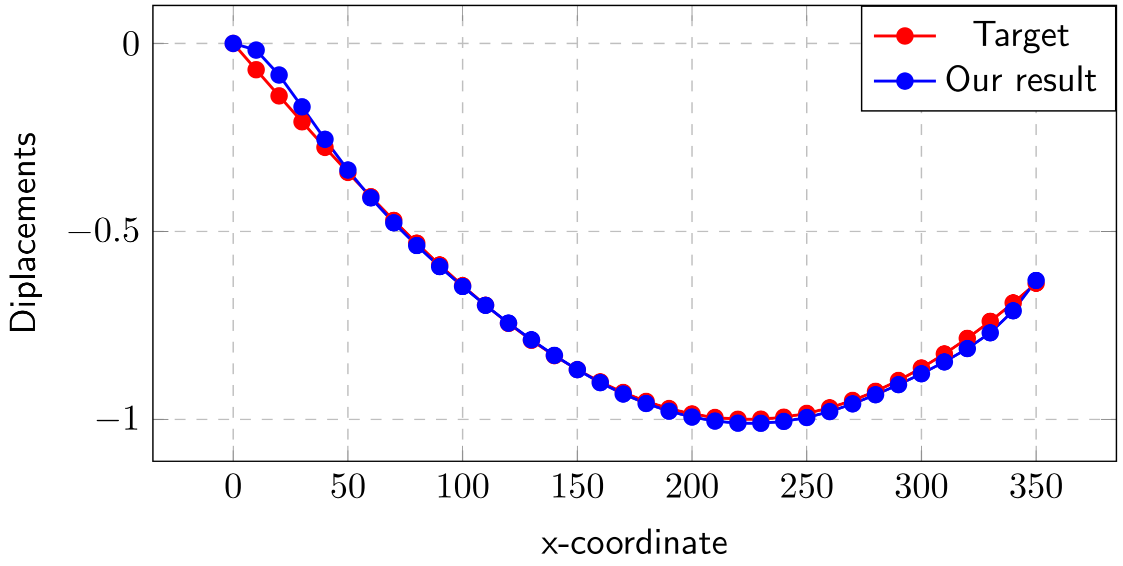
Fraunhofer CPM

Foil Unit Cell - Programming a Deformation

- Example for optimization
- Targets:
  - Symmetric deformation
  - Computation and target are matching



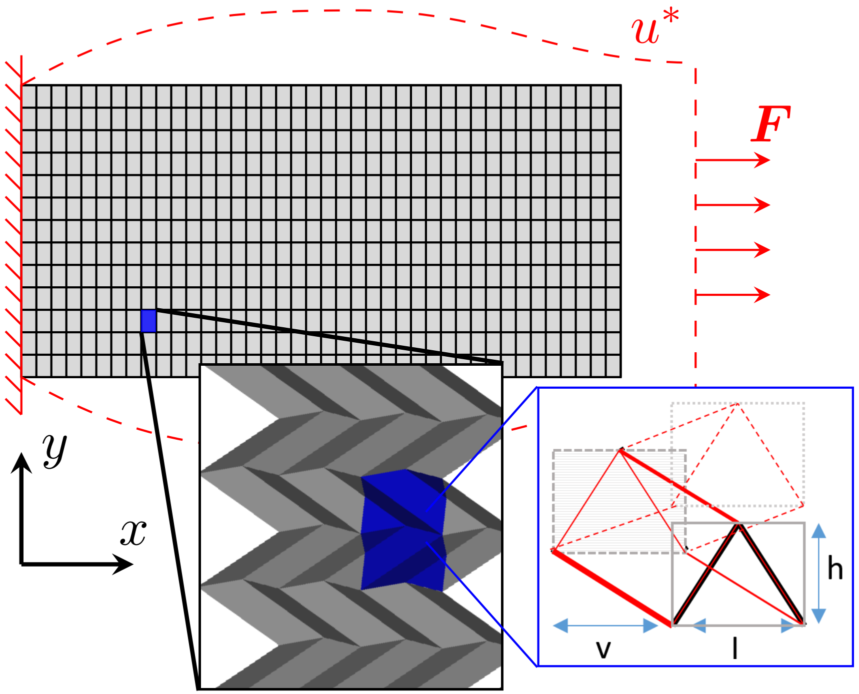


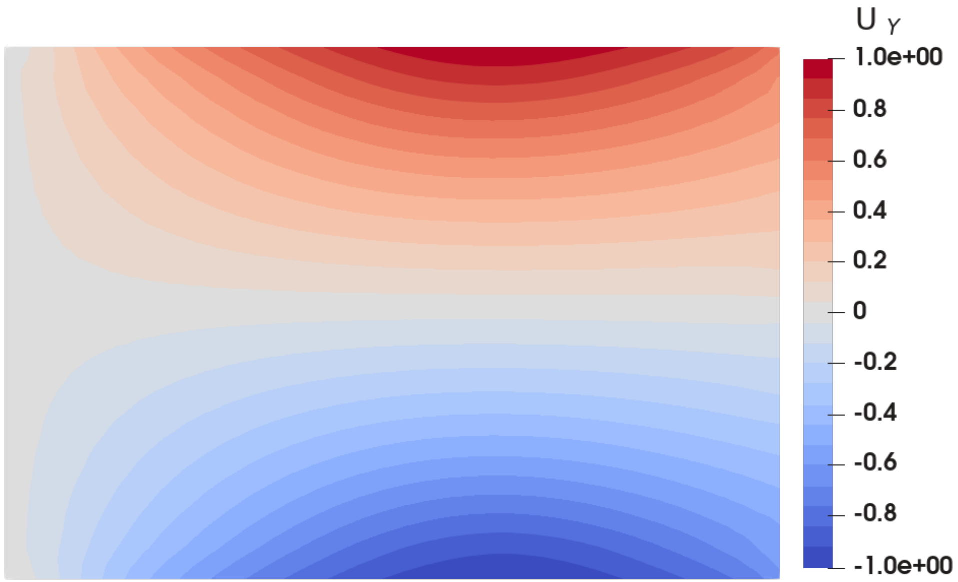


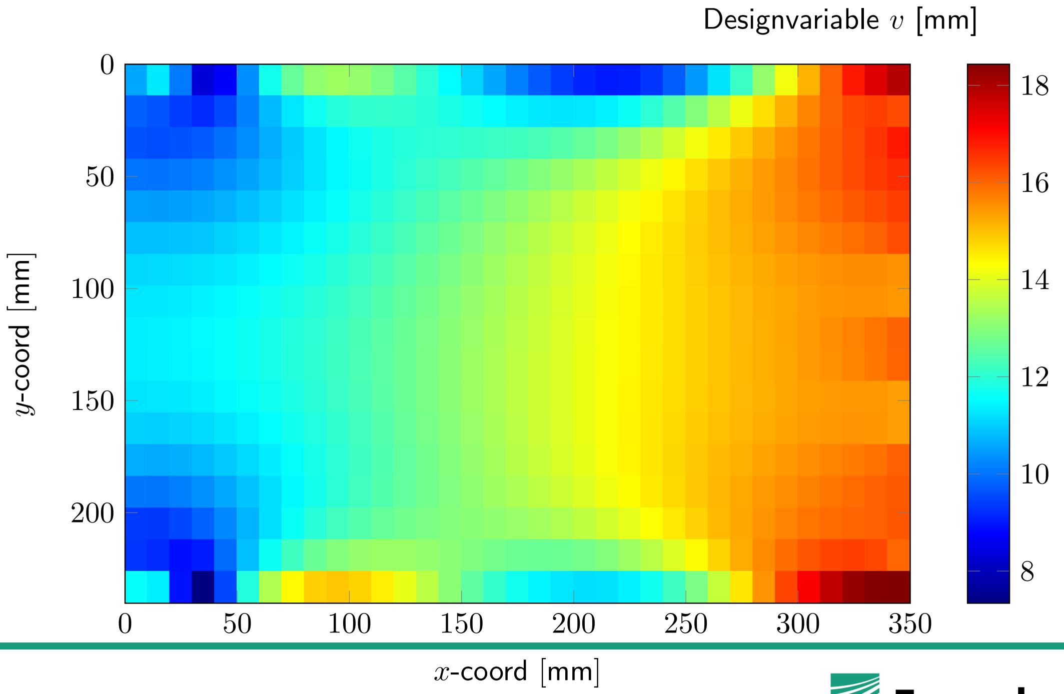
Fraunhofer CPM

Foil Unit Cell - Programming a Deformation

- Example for optimization
- Targets:
  - Symmetric deformation
  - Computation and target are matching



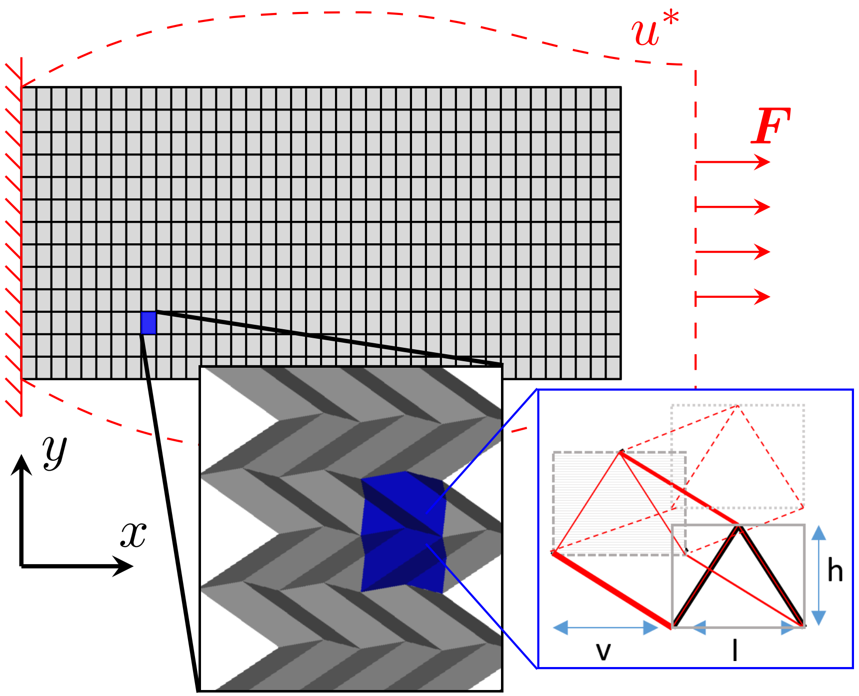


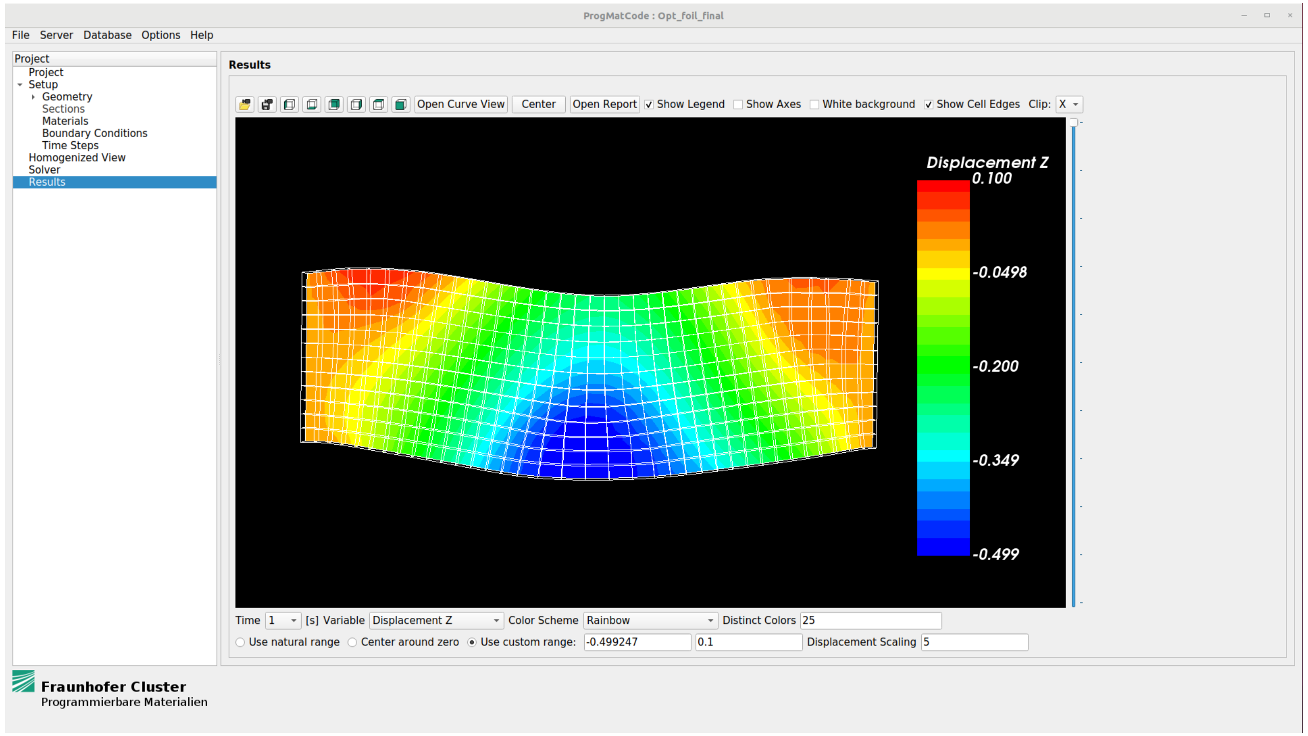


Fraunhofer CPM

Foil Unit Cell - Diverse Solutions

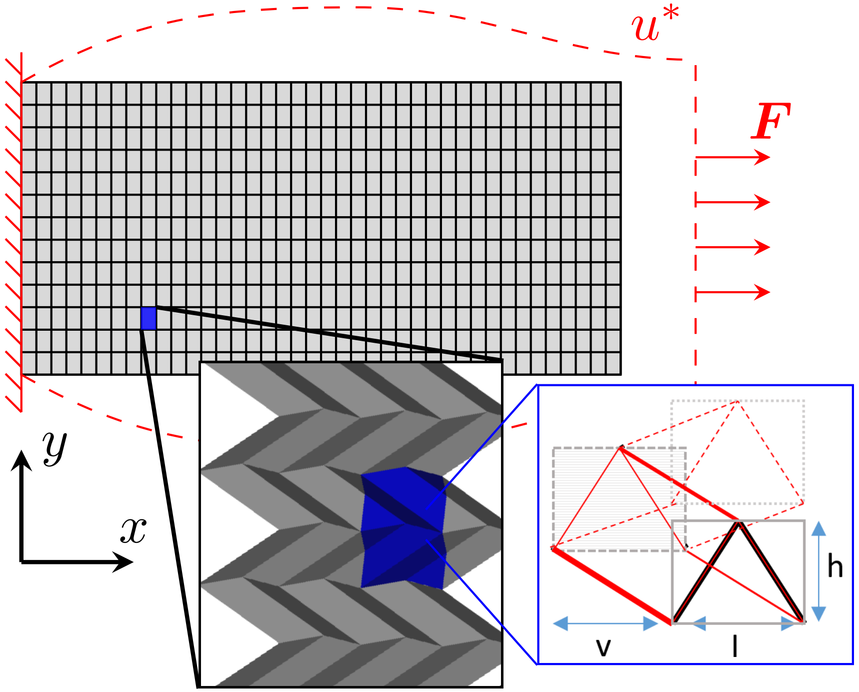
- Example for optimization
- Targets:
  - Asymmetric deformation
  - Different solutions possible

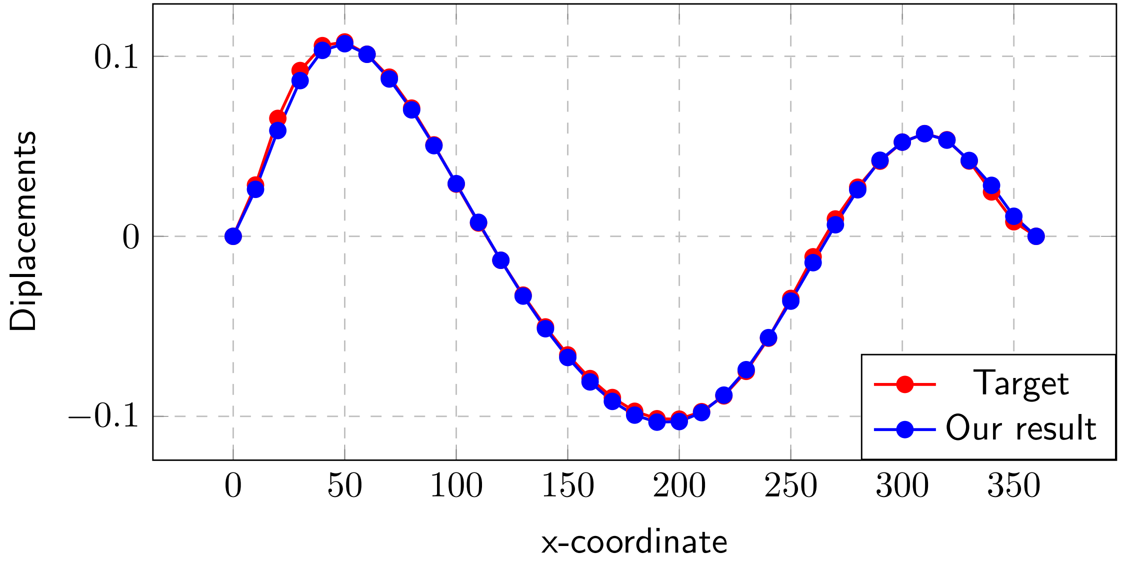


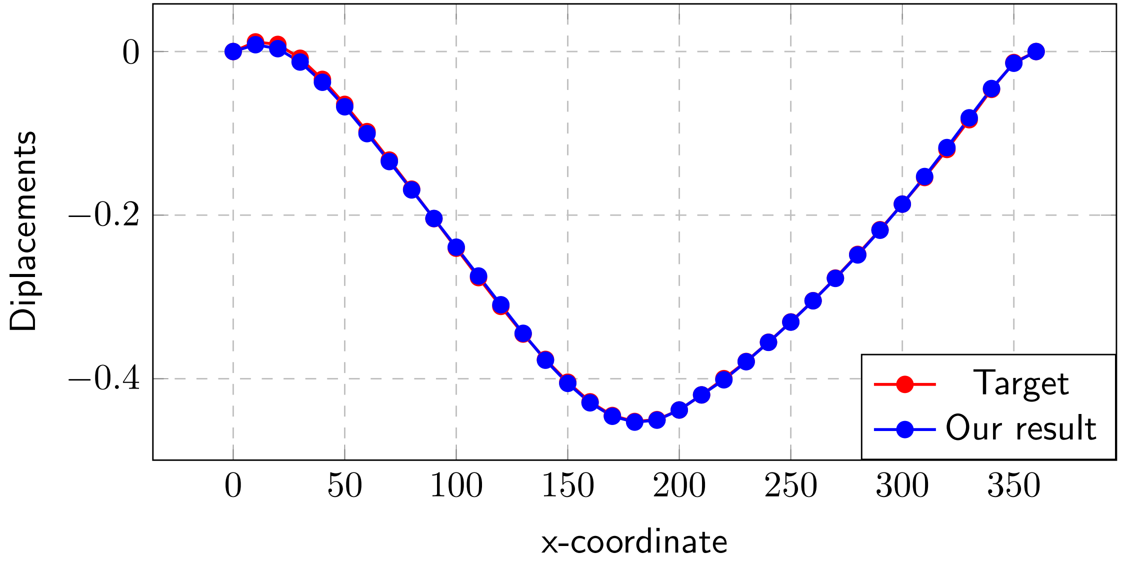


Foil Unit Cell - Diverse Solutions

- Example for optimization
- Targets:
  - Asymmetric deformation
  - Different solutions possible

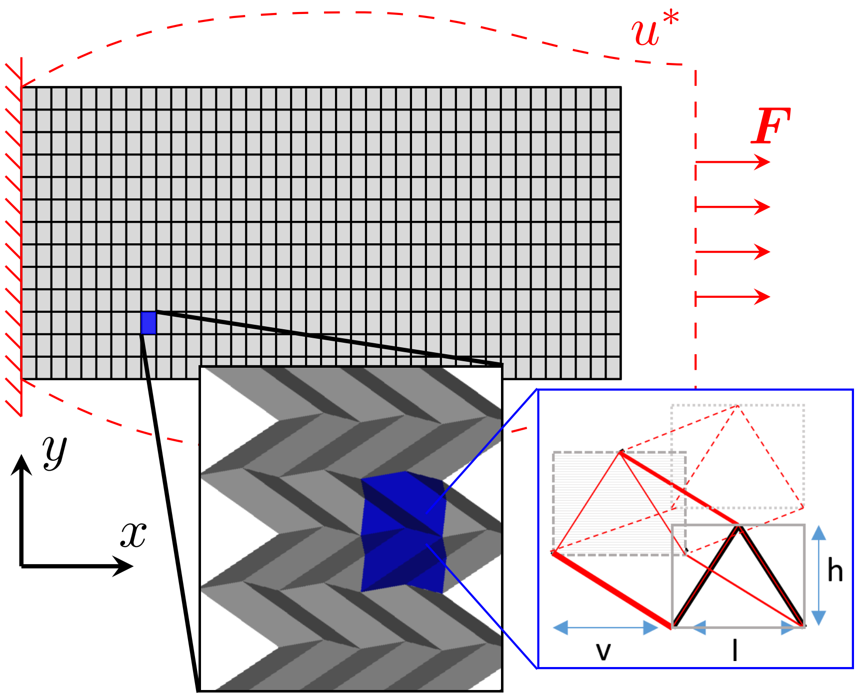


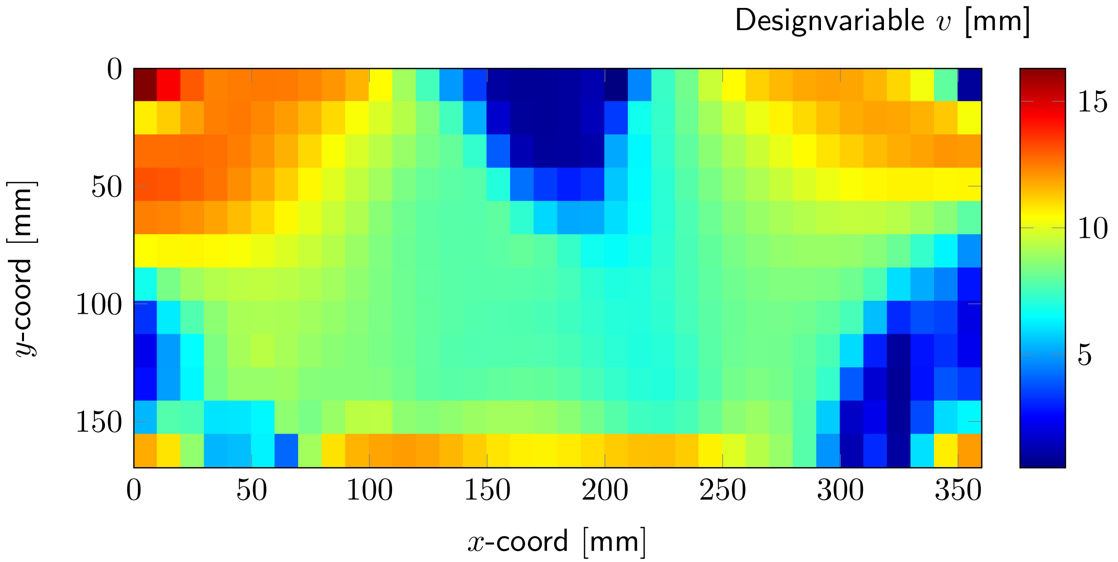


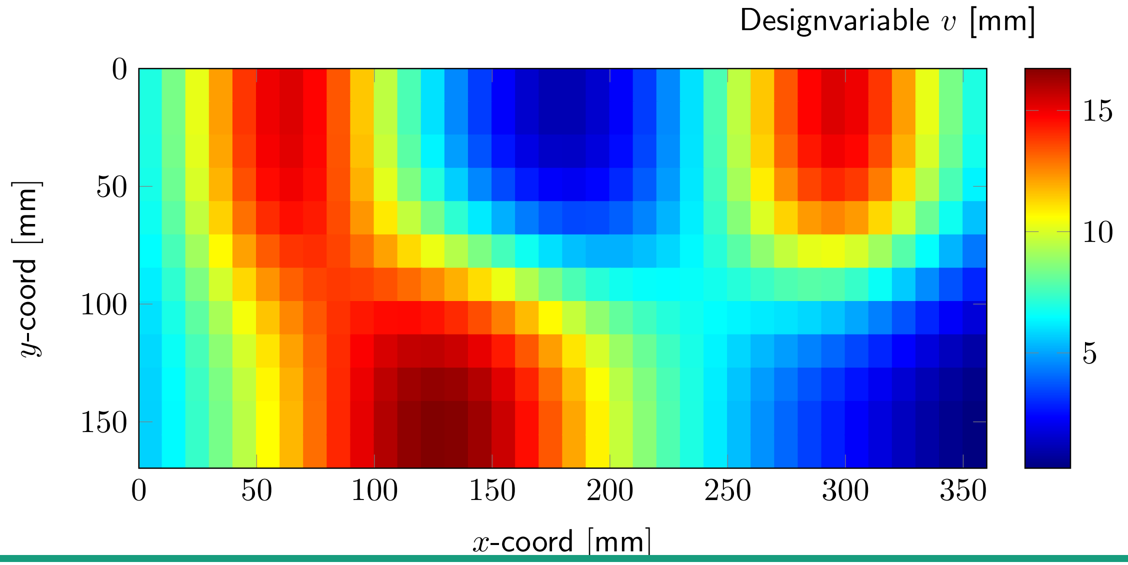


Foil Unit Cell - Diverse Solutions

- Example for optimization
- Targets:
  - Asymmetric deformation
  - Different solutions possible

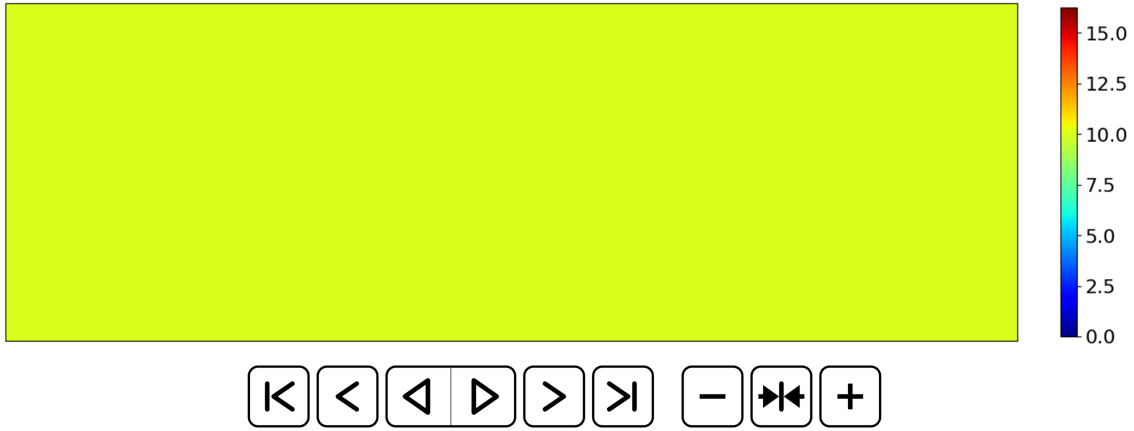




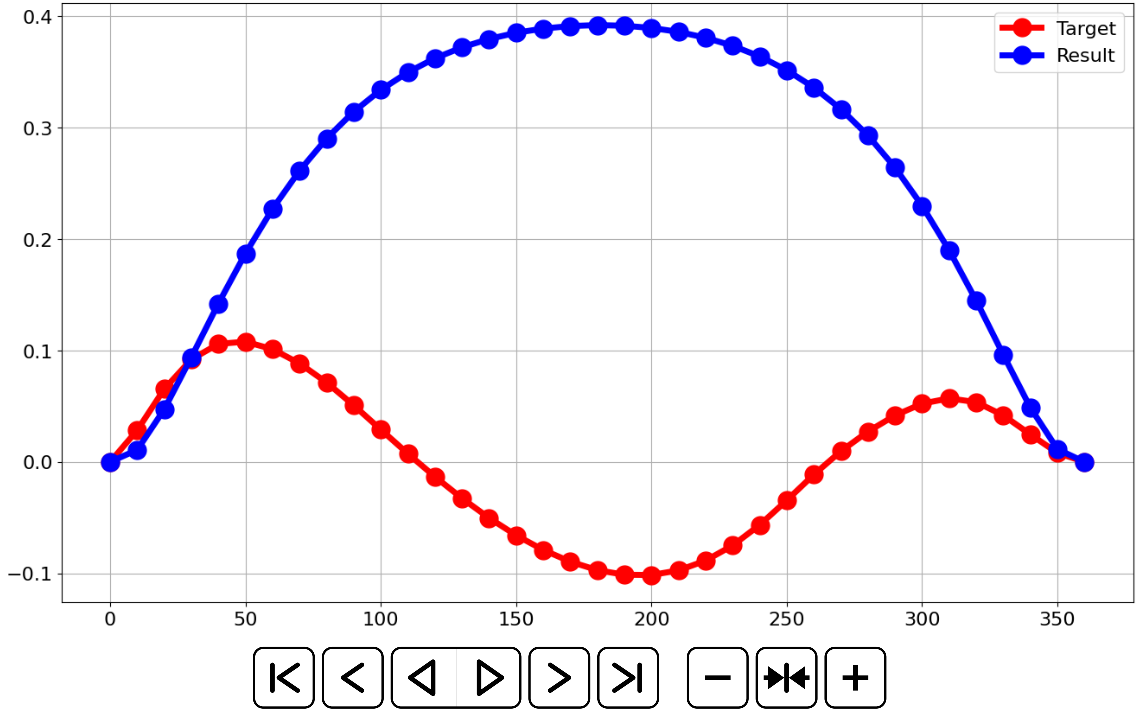


Foil Unit Cell - Optimization Performance

- Intermediate results during the optimization iterations
- Simultaneous comparison between
  - Parameter distribution within geometry
  - Difference between target and computed data



Distribution of design parameter

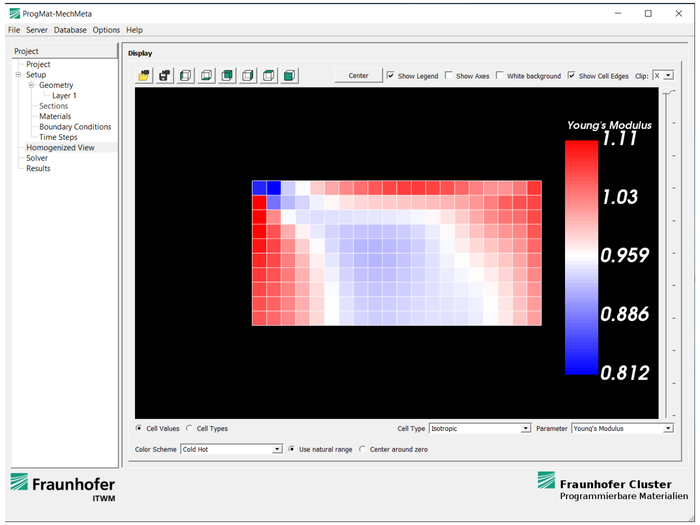


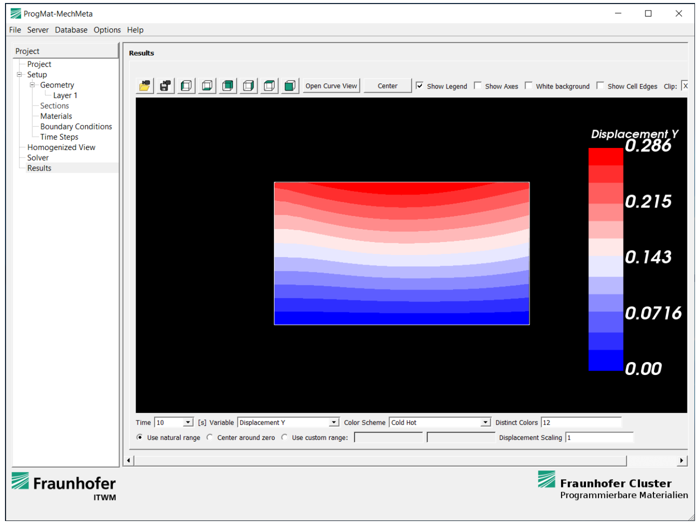
Comparison between target and computation at upper side

Fraunhofer CPM

Conclusion and Outlook - Summary

- Status quo of the Fraunhofer Cluster with respect to optimization
  - Interdisciplinary work of different institutes
  - Definition of programmable materials as subset of meta materials
- Computational framework for manufacturing programmable materials
  - Optimization method based on gradient descent iterations
  - Using FEA software for solving the primal and dual problems
- Processing chain for custom designed unit cells
  - Allowing arbitrary design of (periodic) unit cells
  - Mapping its mechanical behavior into a database for differentiation

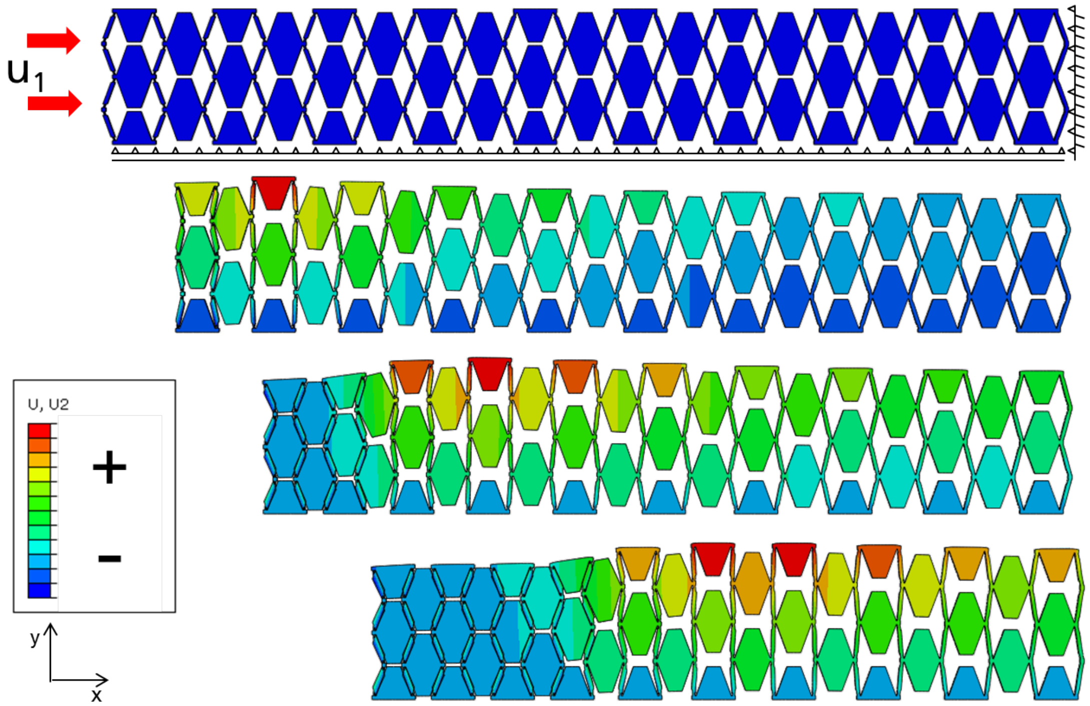




Fraunhofer
CPM

Conclusion and Outlook - Future Work

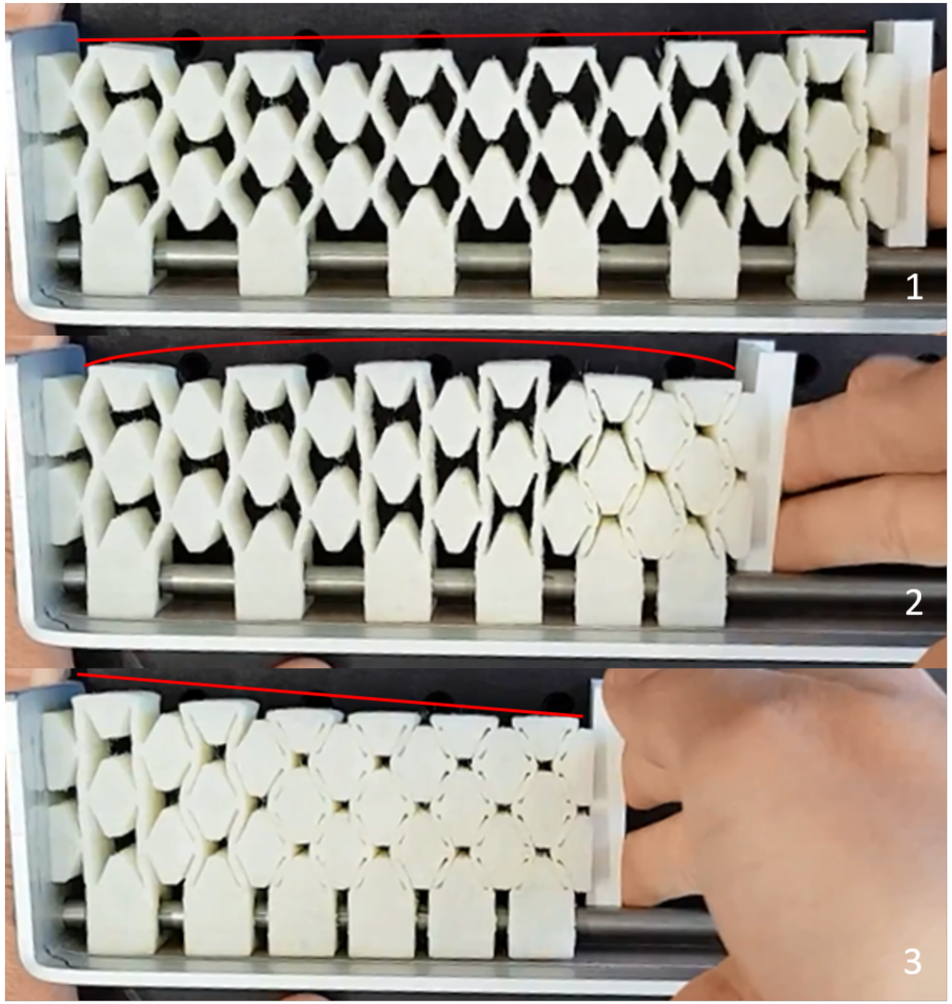
- Continue with
  - large deformations → Wave
  - history dependency → Honeycomb
- Combining different unit cells
  → Computational Vademecum
- Include manufacturing constrains
  → improving 3D printing
- Topology optimization of unit cells
  → bistable shapes
- Apply neural networks & machine learning
  → replacing tensor learning



Fraunhofer CPM

Conclusion and Outlook - Future Work

- Continue with
  - large deformations → Wave
  - history dependency → Honeycomb
- Combining different unit cells
  → Computational Vademecum
- Include manufacturing constrains
  → improving 3D printing
- Topology optimization of unit cells
  → bistable shapes
- Apply neural networks & machine learning
  → replacing tensor learning



Fraunhofer CPM

For further information visit our website:
https://cpm.fraunhofer.de

Fraunhofer Cluster of Excellence Programmable Materials

Fraunhofer
CPM