(50)

FROM SKETCH TO STRUCTURE: A UNIFIED AND EFFICIENT FRAMEWORK FOR OPTIMAL DESIGN WITH ISOGEOMETRIC ANALYSIS

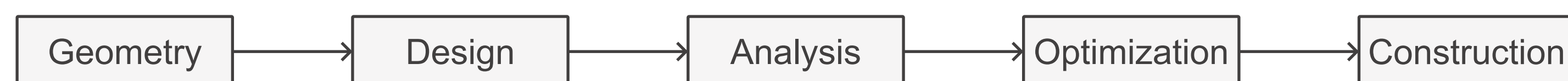**Philip Luke Karuthedath*[1], Abhinav Gupta[2], Bhagath M[1], Rajib Chowdhury[1]**
[1] Indian Institute of Technology Roorkee, Roorkee, India
[2] Avkalan Labs Pvt. Ltd., SN, HP, India.

AVKALAN

MOTIVATION

Geometry → Design → Analysis → Optimization → Construction

Due to the difference in the simulation environments utilized in the design, engineering, and manufacturing industries, there exists a practical problem of information transfer between the designer, engineer, and construction professionals.

This might lead to conversions errors and significant rework that adds up to the time and financial cost of the project.
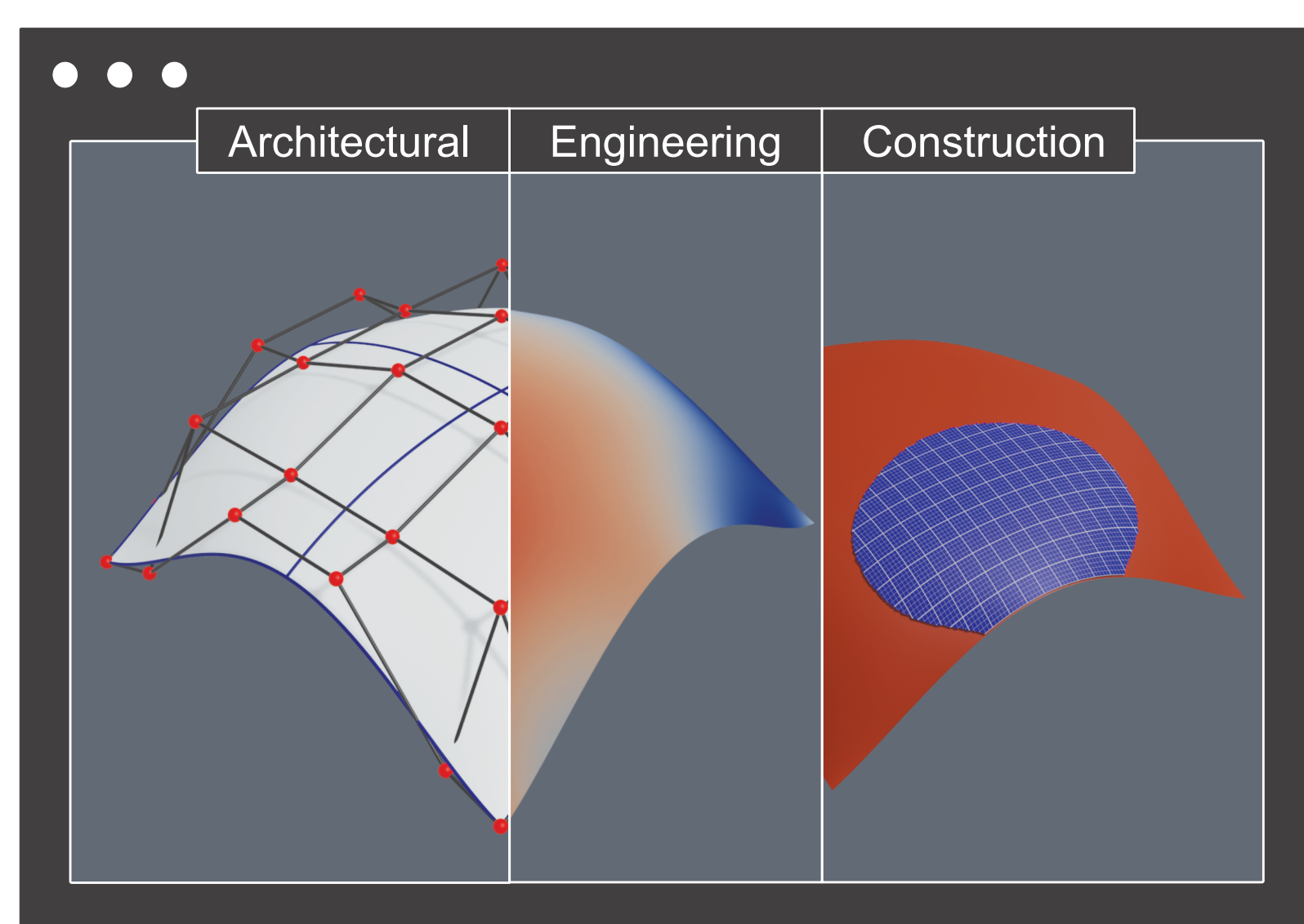

RESEARCH AIMS

This research aims to develop a unified and geometry-preserving framework that seamlessly integrates design, analysis, and structural optimization[4] using Isogeometric Analysis (IGA)[3].

The goal is to enable adaptive, efficient, and manufacturable solutions directly on CAD geometries across a wide range of structural models, including plates, shells, and 3D continua.

METHODOLOGY

We use the Geometry Independent Field approximaTion (GIFT)[2] framework, which decouples geometry and analysis by enabling the use of different basis functions for geometry representation (NURBS) and solution approximation (PHT-splines).
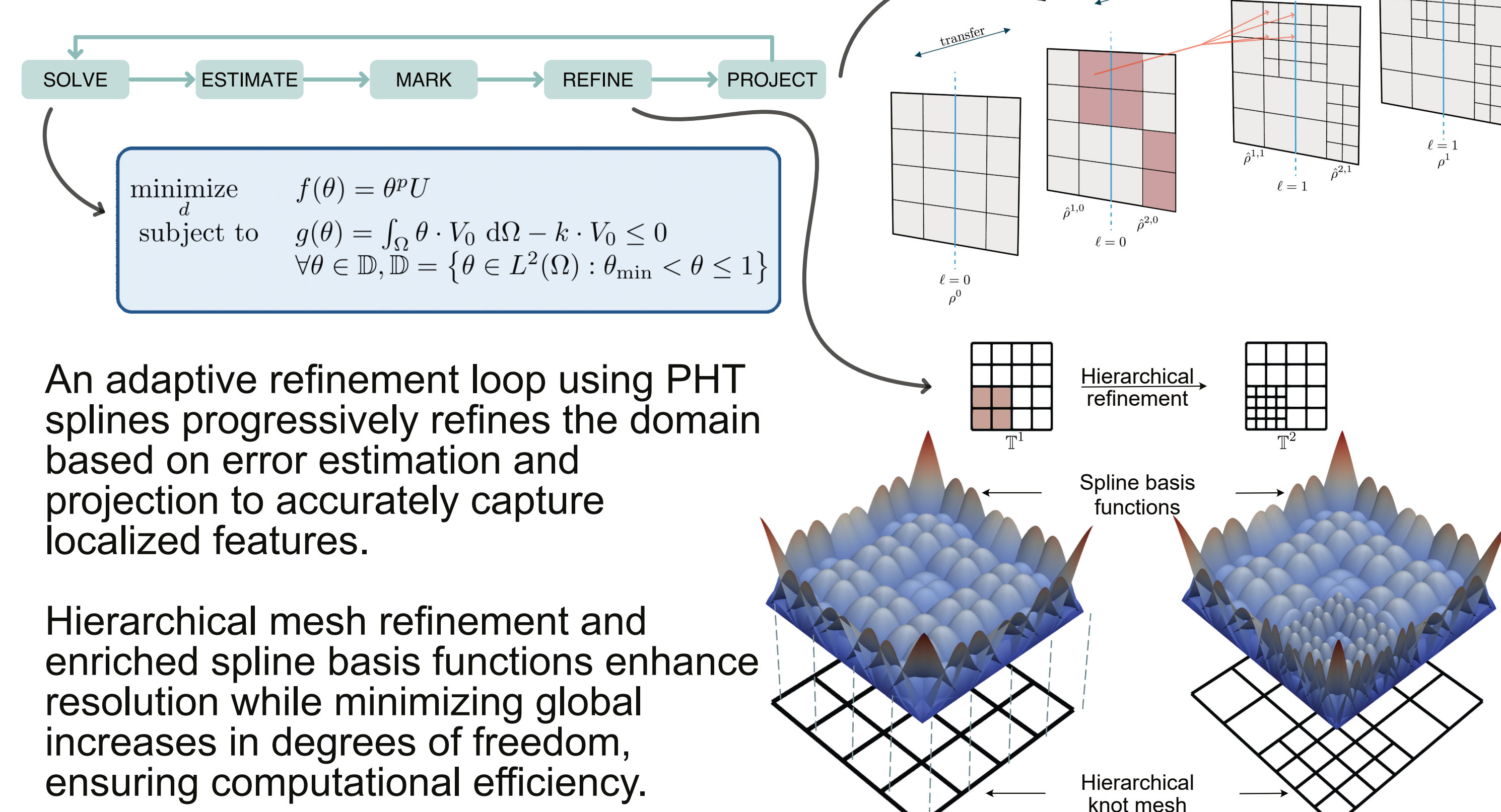
This allows for adaptive refinement and optimal field representation while preserving the exact CAD geometry throughout the analysis.

PHT-Spline mesh (p = q = 3)

NURBS mesh (p = q = 3)
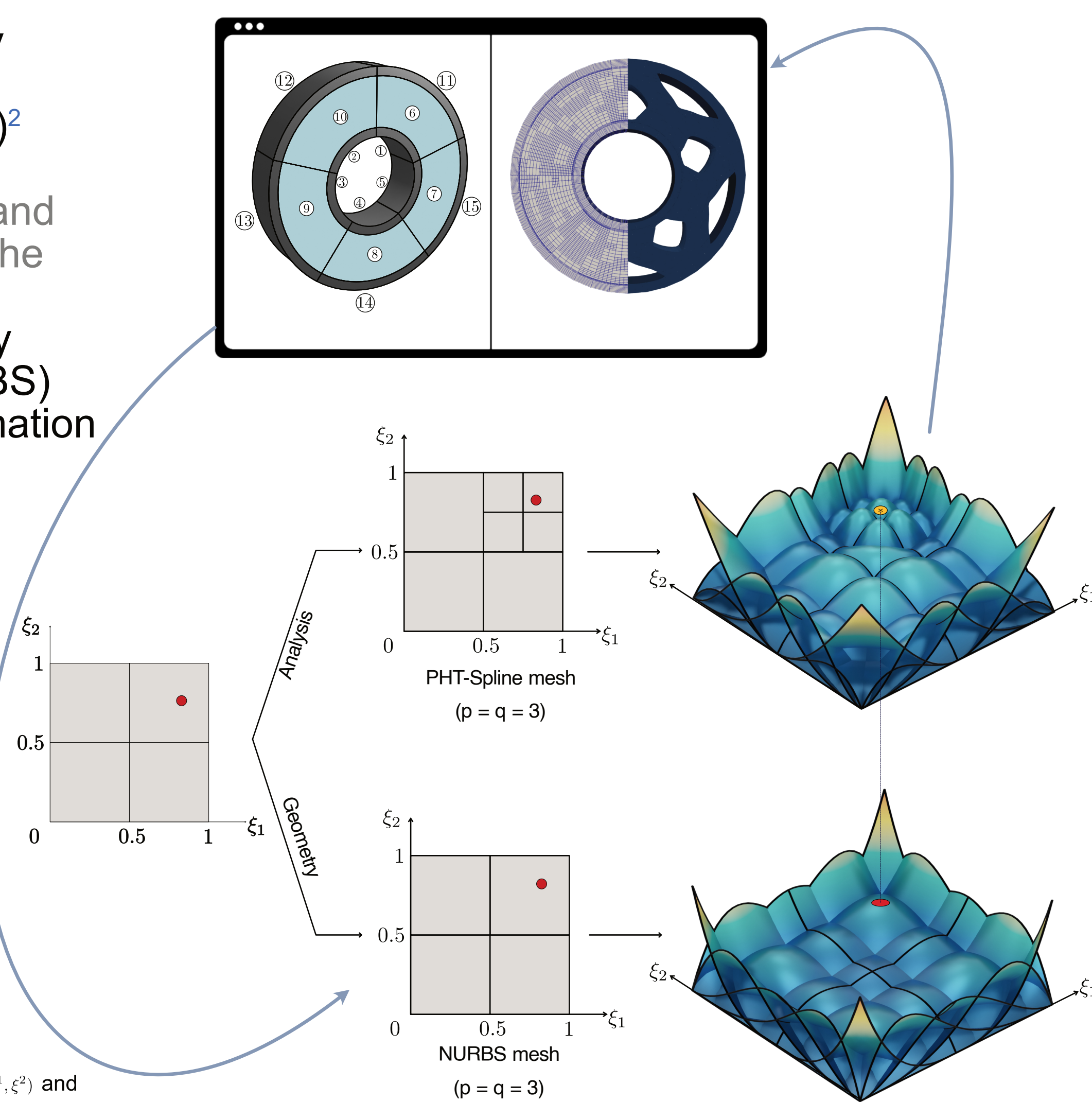
● Point with parametric co-ordinates (ξ^1, ξ^2) and physical coordinates (x_1, x_2)

⊙ Field variable evaluated at point ●

RESULTS

82.2%
REDUCTION IN DoF

scan to interact with the results
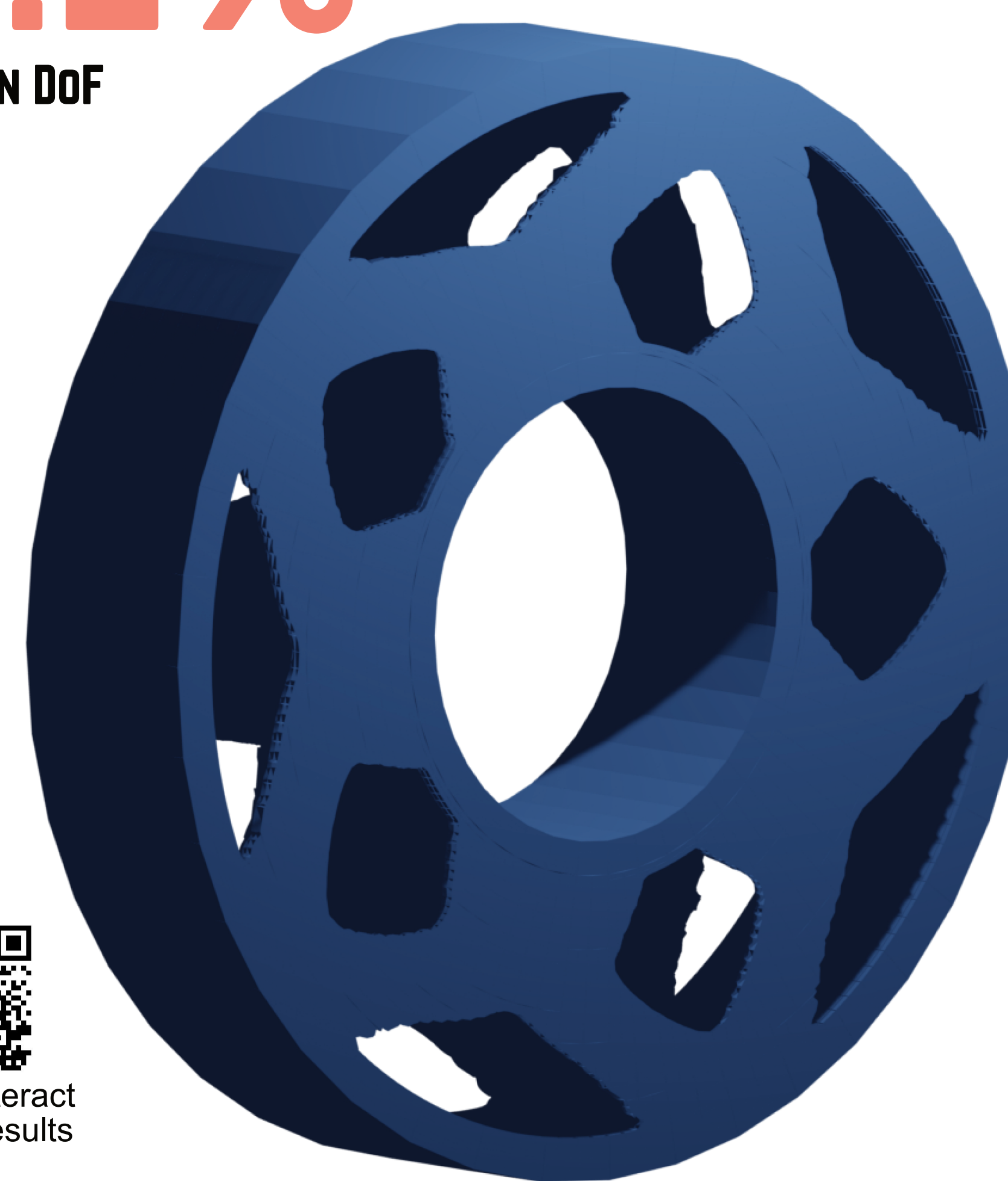
Optimization
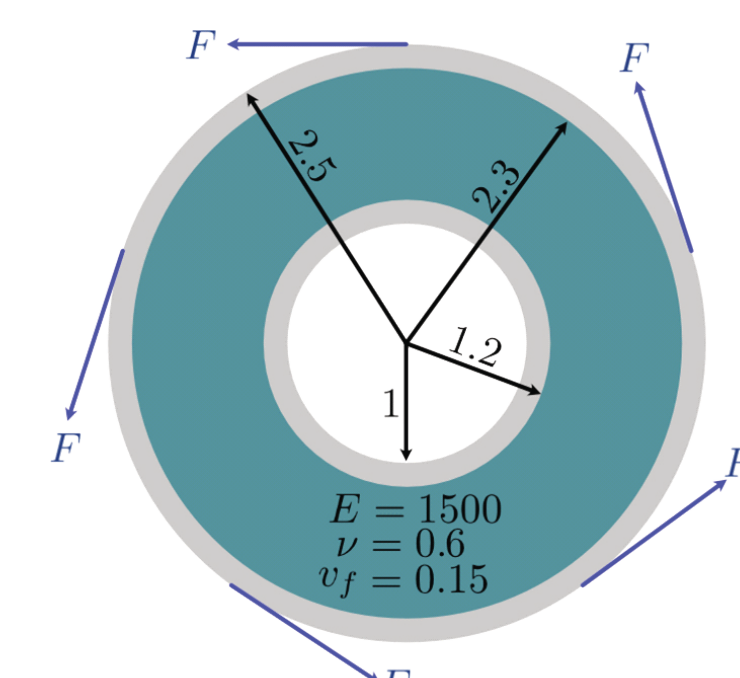
Geometry
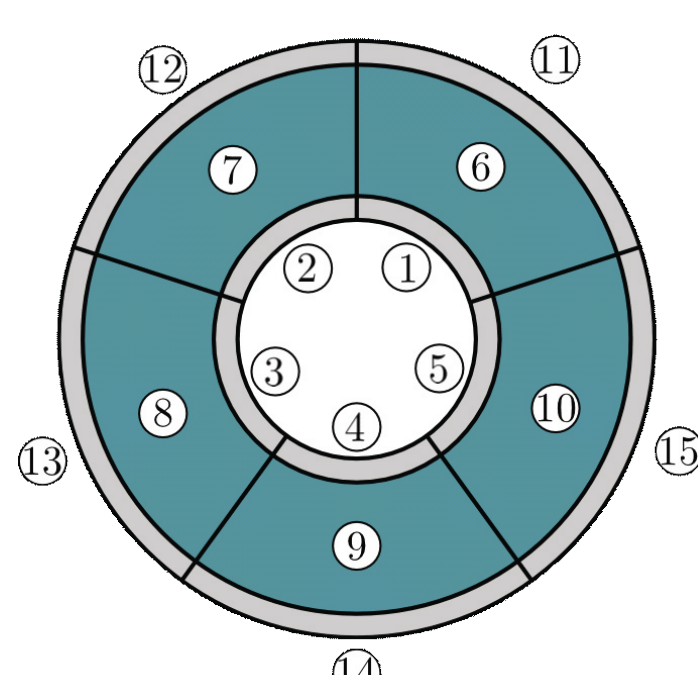
Design
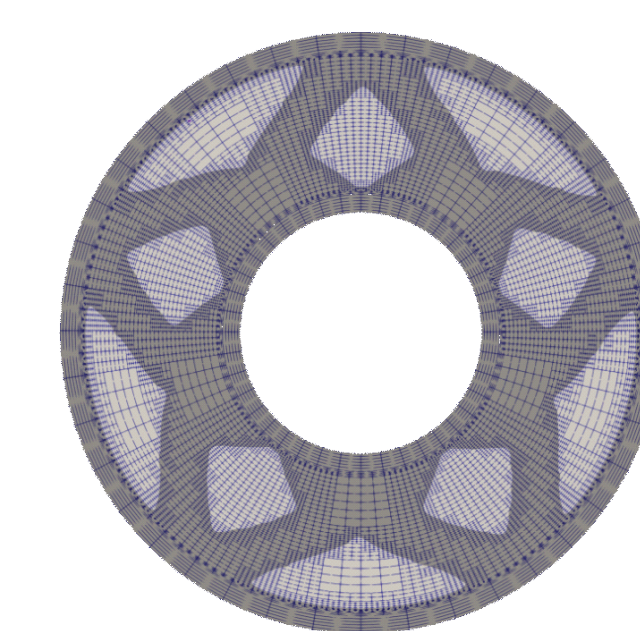
Analysis mesh
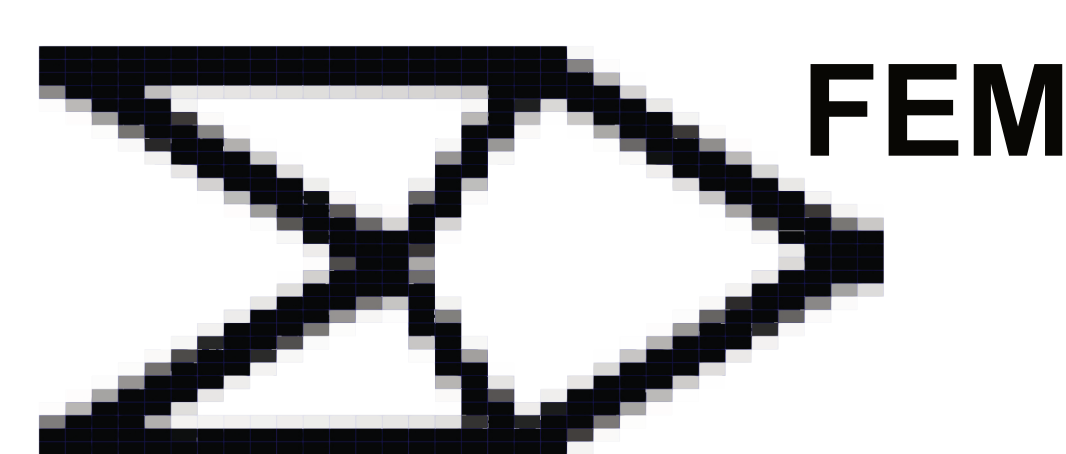
FEM
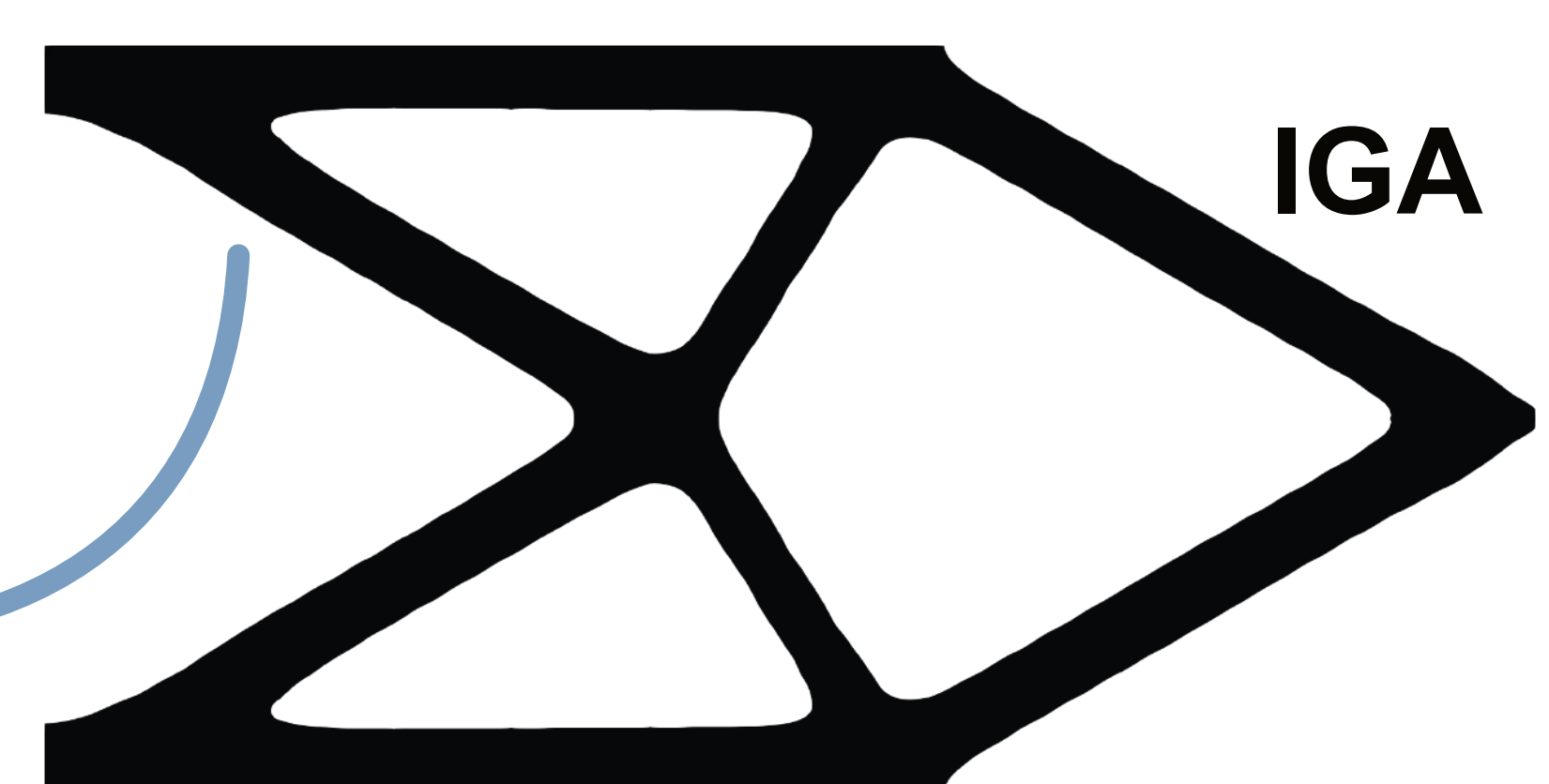
IGA

In comparison with discrete-density FEM, continuous density function with IGA provides a smooth, manufacturable design for the same mesh.

shape optimization of shell structures

ADAPTIVITY

SOLVE → ESTIMATE → MARK → REFINE → PROJECT

$$\begin{aligned} \underset{d}{\text{minimize}} \quad & f(\theta) = \theta^p U \\ \text{subject to} \quad & g(\theta) = \int_\Omega \theta \cdot V_0 \, d\Omega - k \cdot V_0 \le 0 \\ & \forall \theta \in \mathbb{D}, \mathbb{D} = \{\theta \in L^2(\Omega) : \theta_{\min} < \theta \le 1\} \end{aligned}$$

An adaptive refinement loop using PHT splines progressively refines the domain based on error estimation and projection to accurately capture localized features.

Hierarchical mesh refinement and enriched spline basis functions enhance resolution while minimizing global increases in degrees of freedom, ensuring computational efficiency.

Hierarchical refinement
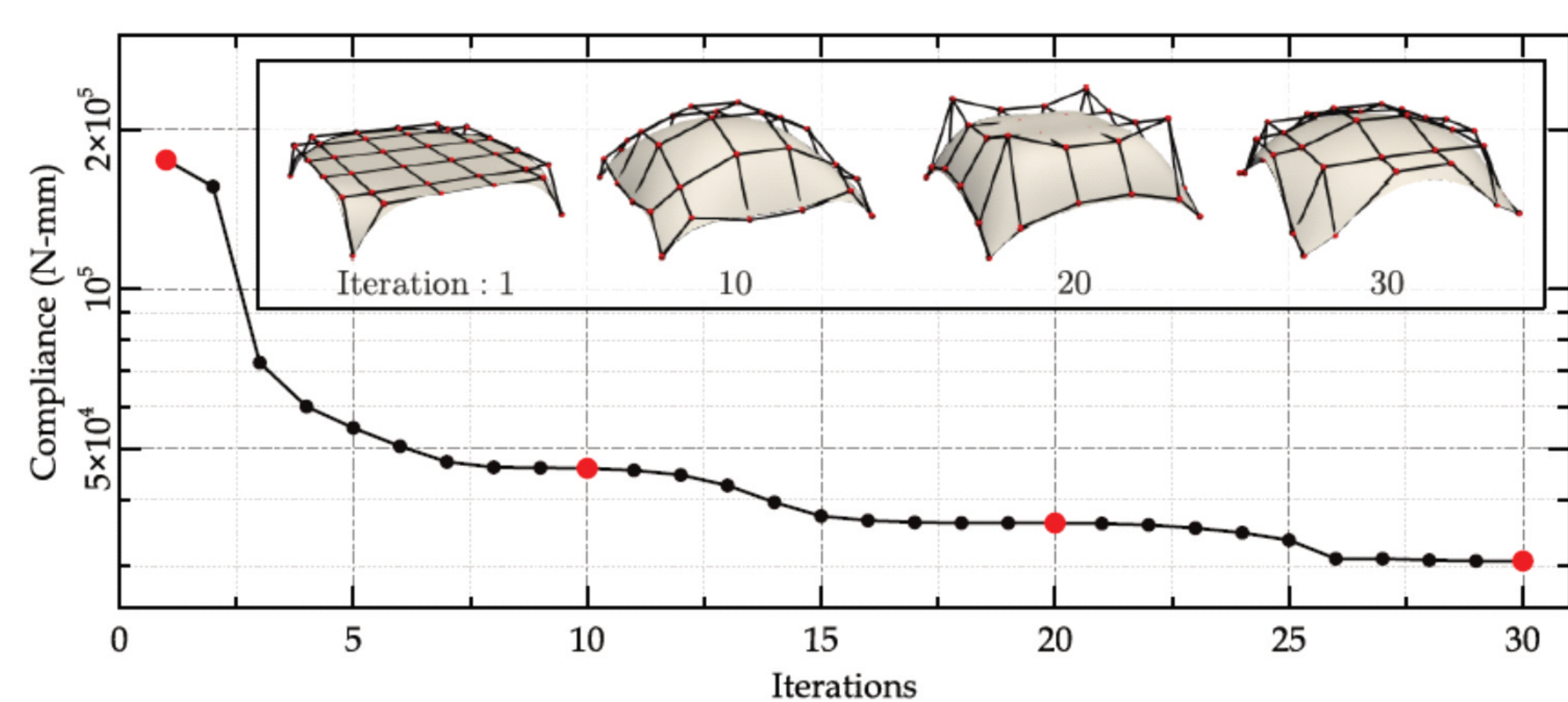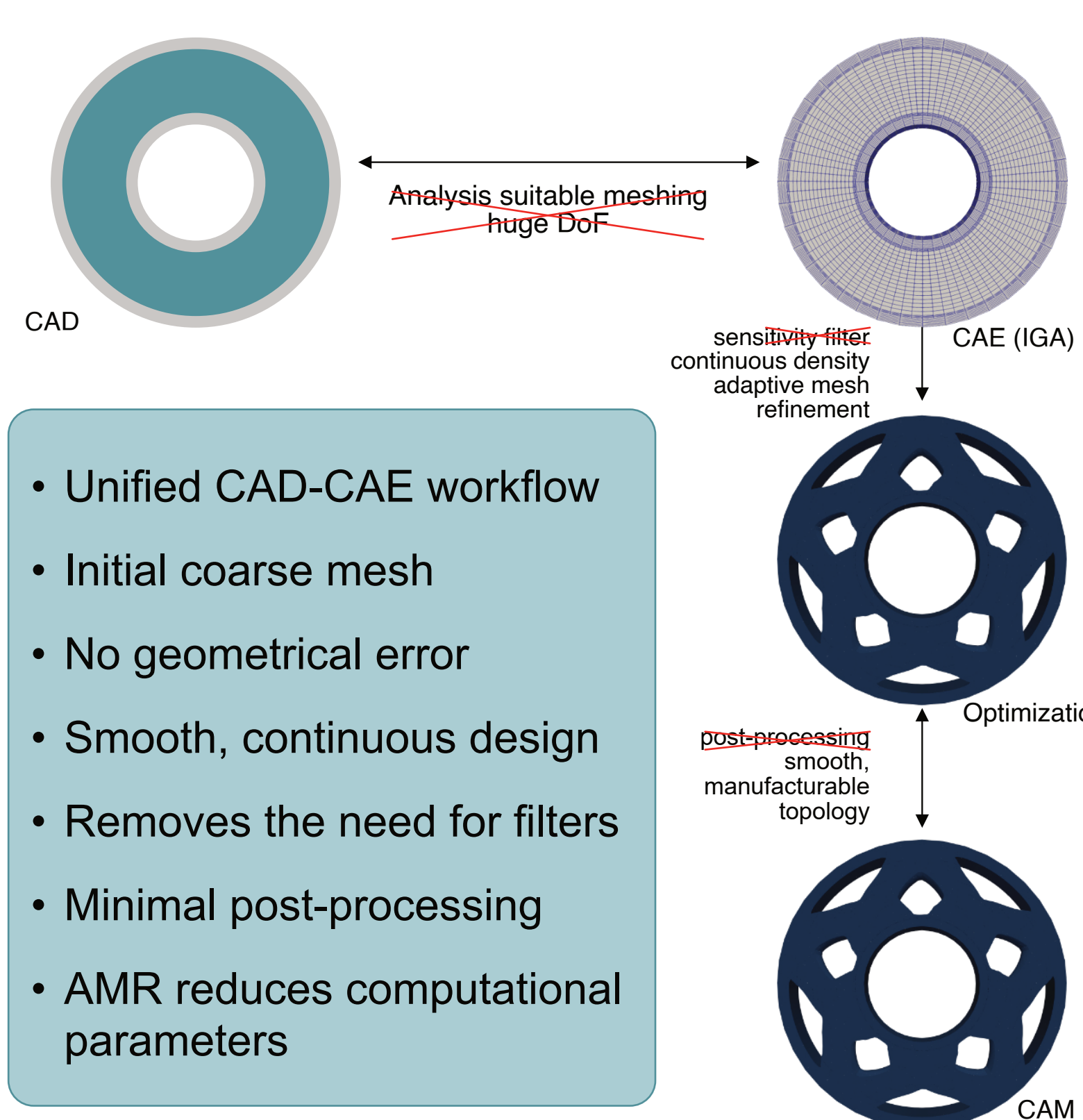
Spline basis functions

Hierarchical knot mesh

CONCLUSION

CAD — Analysis_suitable_meshing — huge DoF — CAE (IGA)

sensitivity filter continuous density adaptive mesh refinement

post-processing smooth, manufacturable topology

Optimization

CAM

- Unified CAD-CAE workflow
- Initial coarse mesh
- No geometrical error
- Smooth, continuous design
- Removes the need for filters
- Minimal post-processing
- AMR reduces computational parameters

REFERENCES

1. Karuthedath, Philip Luke, et al. "A generalized framework towards continuity and computational efficiency in topology optimization using multi-patch isogeometric methods." *Engineering with Computers* (2025): 1-50.
2. Xua, Gang, et al. "Geometry-Independent Field approximaTion (GIFT) for Adaptive Spline-Based Finite Element Analysis." in: *Proceedings of the 11th World Congress in Computational Mechanics*, 2014, p. 30.
3. Hughes, Thomas JR, John A. Cottrell, and Yuri Bazilevs. "Isogeometric analysis: CAD, finite elements, NURBS, exact geometry and mesh refinement." *Computer methods in applied mechanics and engineering* 194.39-41 (2005): 4135-4195
4. Bendsøe, Martin Philip, and Noboru Kikuchi. "Generating optimal topologies in structural design using a homogenization method." *Computer methods in applied mechanics and engineering* 71.2 (1988): 197-224.

FUNDING SOURCES

CONTACT

🌐 https://computationalmechanics.in
✉ philip_luke@ce.iitr.ac.in
📱 +91-8547082517

scan for more details on the project