AMC TRR277

C02

3D structural puzzle – Numerical Multi Scale Shape and Topology Optimisation Methods to Additively Manufacture Optimal Structures from Optimised Pieces

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Project summary

The aim is to design optimal structures by incorporating the goals and constraints of additive manufacturing. To achieve this, we use efficient structural simulation and optimisation methods to fully exploit the design freedom offered by additive manufacturing. The results show significant improvements in design performance, cost efficiency and environmental considerations.

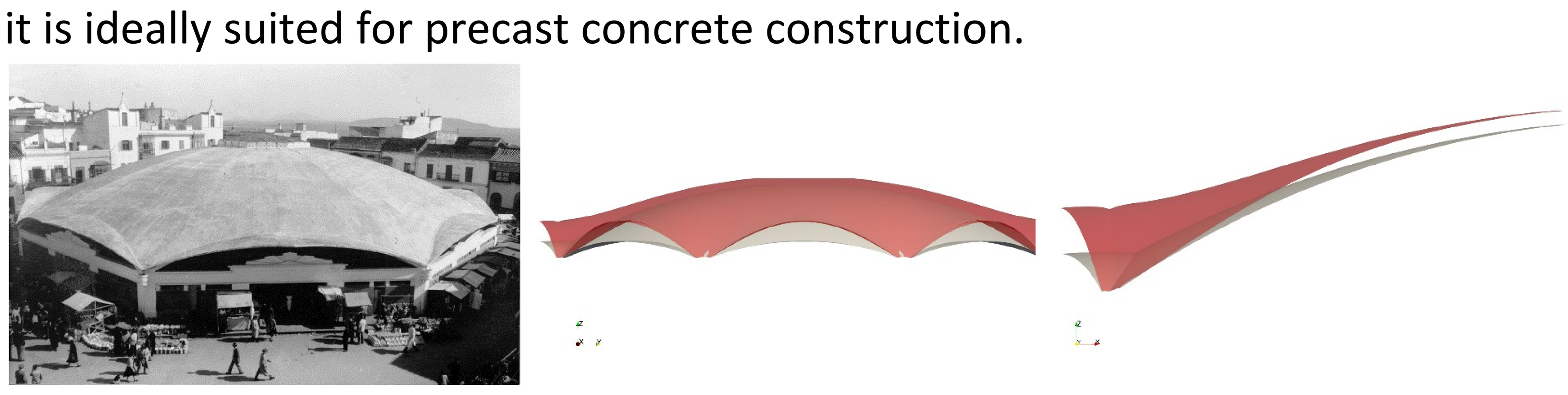
Main outcome of 1st funding period

The state of the art in free-form structure optimisation methods has been further developed, both in general and specifically for additive manufacturing. It is now possible to simultaneously address topology and shape optimisation for both thin and massive solid structures, while generating and controlling the highest standards of geometric surface quality. Specific topics are:

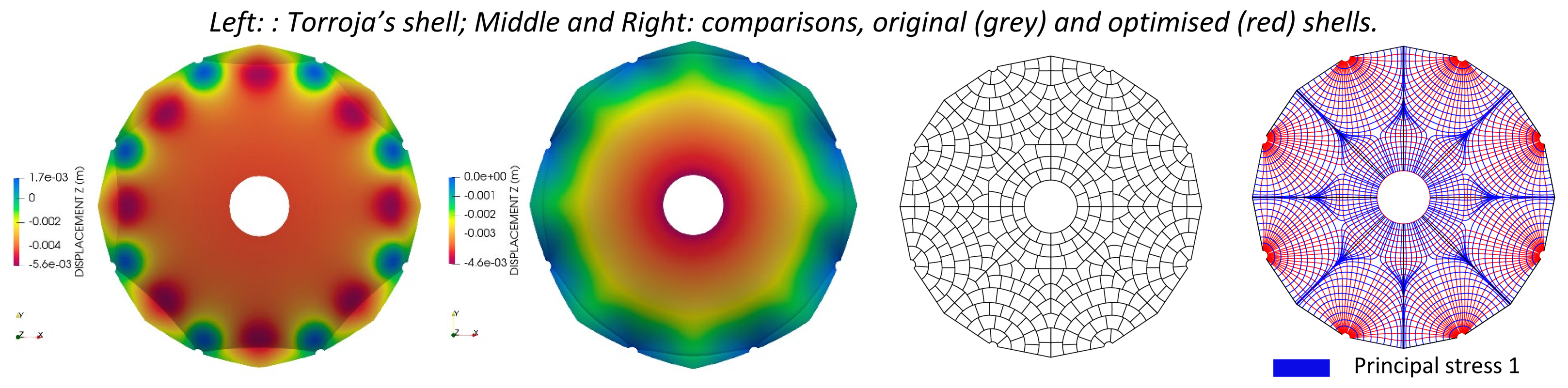
- **Implicit filtering**, to efficiently smooth and regularise the FEM design space. This is the richest possible design space.
- **Abstract problem formulation** that allows for concurrent and nested multi-level, multi-scale optimisation problems.
- **Additive manufacturing constraints** that ensure manufacturability.

Project status

The project significantly exceeds the requirements of the TRR in Phase 1 as a key design tool. The theory behind the optimisation method has been developed, the method has been established, validated and published. It is implemented in the open-source software KRATOS. The method has been successfully validated on selected benchmarks of famous design icons that are accepted as ideal, such as the Torroja concrete shell in Algeciras (see below). The result is an undulating form of exceptional quality in terms of geometric continuity and elegance. Mass is maintained, stiffness and load-bearing capacity are improved, and stress distribution is homogenised. In terms of AM, it is ideally suited for precast concrete construction.

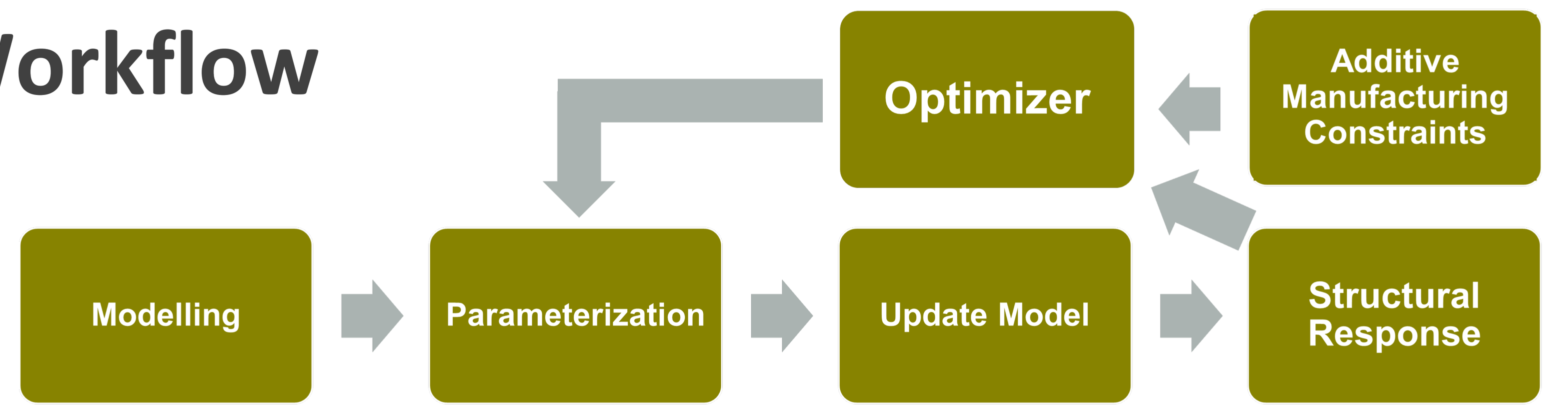


Left: : Torroja's shell; Middle and Right: comparisons, original (grey) and optimised (red) shells.



Torroja-shell: vertical deflections, the optimised shell, segmentation pattern, principal stress lines.

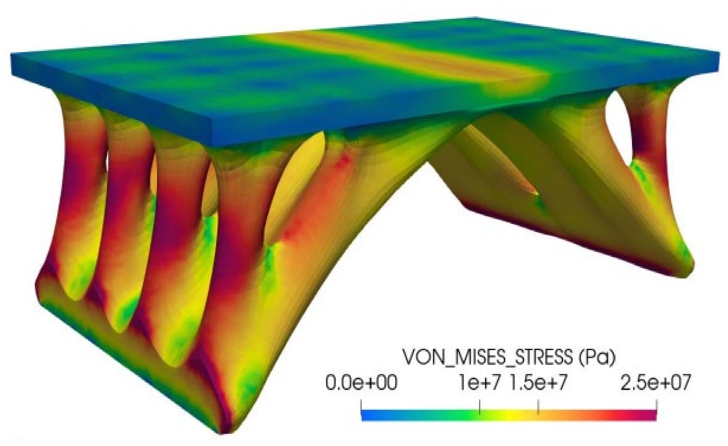
Workflow



Key collaboration in 1st funding period

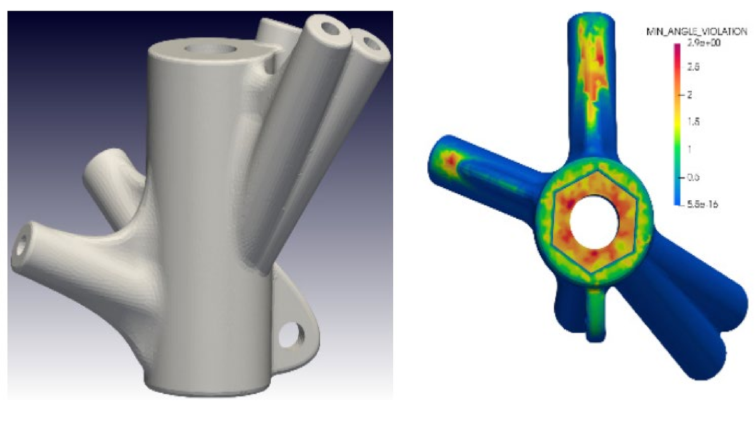
A01 **Topology Optimization**: A representative bridge was topologically optimized for the stiffest structure under prescribed material. The optimised design was then **directly** fabricated through the Selective Cement Activation (SCA) process of A01.

Printed geometry

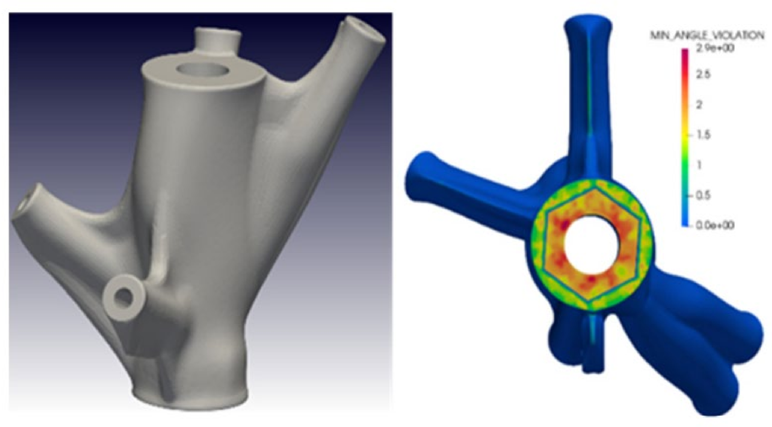


Simulation-based designed and optimised geometry

A06 **Shape Optimization**: A node of a five-meter tensegrity tower was shape-optimized, considering the supporting structure of LPBF. The mass and support structures were reduced by 20.38%, respectively.

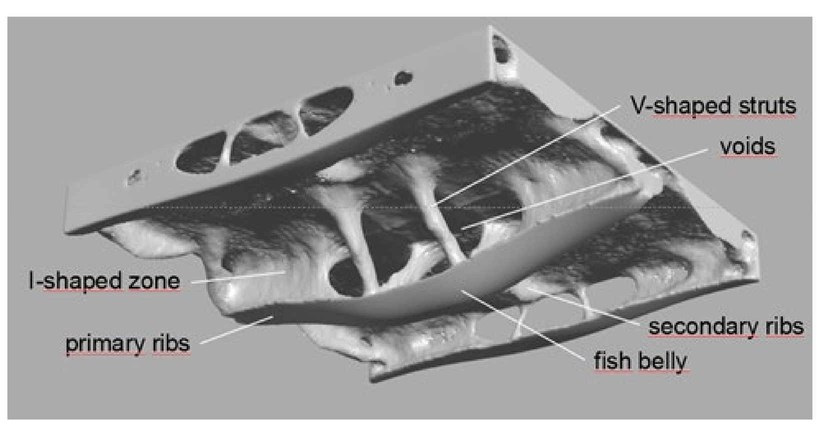


Initial tensegrity node



Optimised tensegrity node

A08 **Shape Topology Optimization**: Concurrent topology and shape optimization was used to reduce the mass of ILF-slab (demo) under a uniformly distributed load.



Concurrent shape and topology optimization

Printed structure after stiffness shape-topology and mass shape optimization

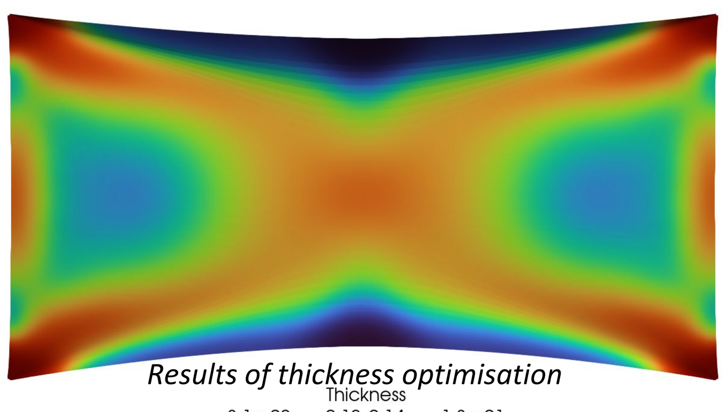
Large Scale Demonstrator

SPI Bridge

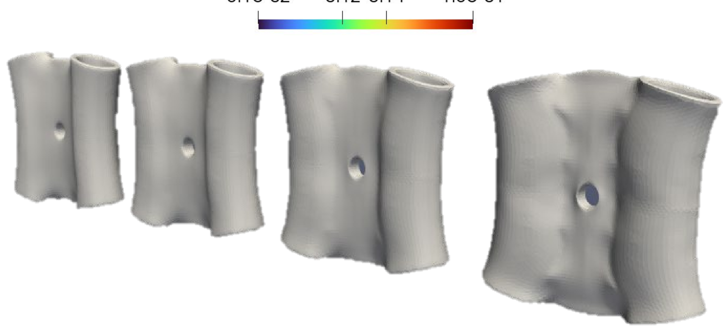
The thickness of a concept pedestrian bridge was specifically optimized to take advantage of 3D-printing. The concept bridge was designed by the CEM tool of group of Prof. D'Acunto. The optimal thickness distribution was found for the stiffest structure under the given mass constraint. Five loading scenarios were considered in the optimization process.

The steel node that connects the tension cables of the bridge is optimised in terms of its shape and the WAAM technique, which requires consideration of the maximum overhang constraint.

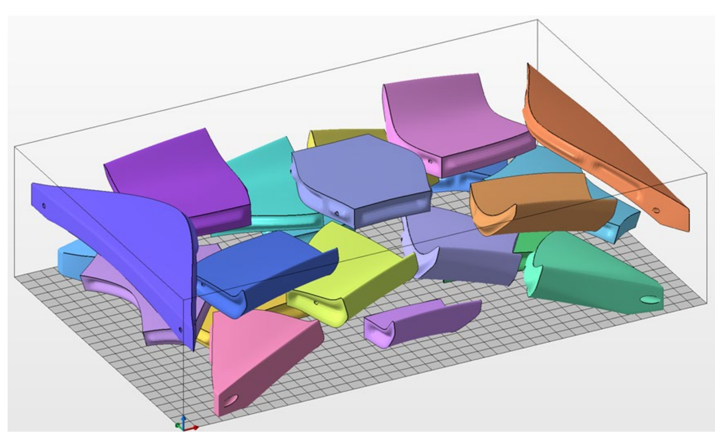
In order to additively manufacture such structure, the geometry is partitioned into pieces. The segmentation of is based on the principal stress line trajectories and consideration of the print box dimensions.



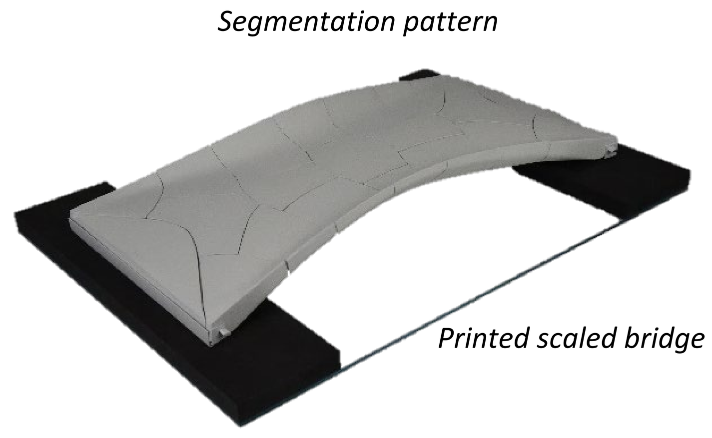
Results of thickness optimisation



Mass minimization of the connecting node under stiffness and overhang constraints. From left to right: mass minimization of 10%, 15%, 20%, and 27%



Segmentation pattern



Printed scaled bridge

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