

# Computation and Design of Bending-active Structures

In the context of lightweight structures, material properties still have a predominant role: while in industrial design, fiber-composite materials like CFRP gain more and more importance, the advances in civil engineering lie mainly in the use of “engineered” materials like lightweight concrete and – increasingly – fiber reinforced materials. This approach allows for advances, but often tends to simply replace existing structural elements and construction techniques, and “plug in” new materials.

On the other hand, recent architectural examples reveal the need and the market for innovative architecture. Emphasized by the growing discussion about sustainable engineering, re-discovering the potential of lightweight structures like shell structures, membrane structures or grid-shells seems worth taking a chance. While these structures have all been built before, their combination with innovative material and modern architecture enforces the need for deeper insight in the geometry’s contribution to the structural behavior, mainly characterized by geometric stiffness.

## Bending-active Structures

In the context of lightweight structures, membrane structures have a predominant role due to their exclusive use of tensile forces. The introduction of bending active elements like beams can offer an important contribution to the structures shape and stiffness.

As these bending-active elements gain their stiffness and thus their contribution to the structures shape and behavior through the deformation process, they have to be integrated throughout the whole design-process.

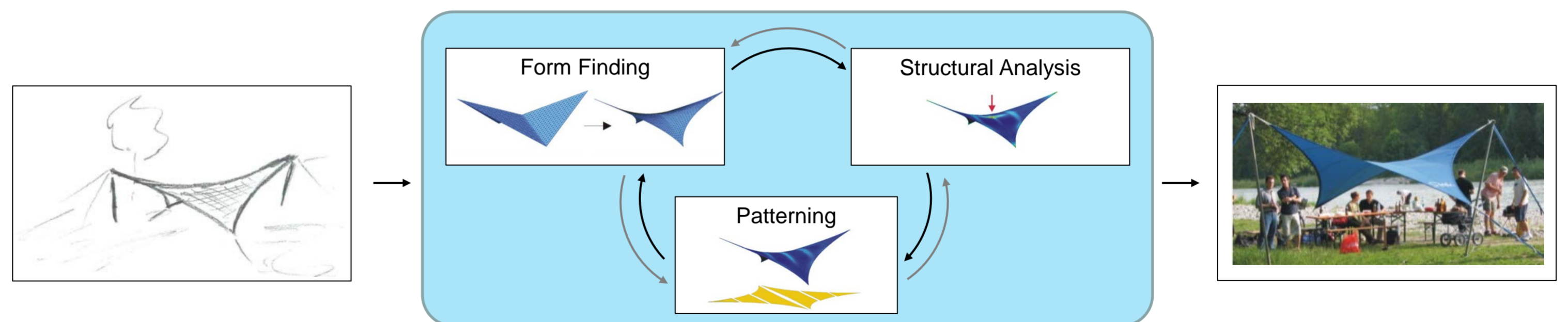
In contrast to the membrane, bending-active elements as elastic members change their internal stress-state during the form-finding process. The opposed behavior of these two types of members leads to the term “hybrid structures”.



Foldable umbrella spanning 28 m (A. Michalski, SL Rasch)



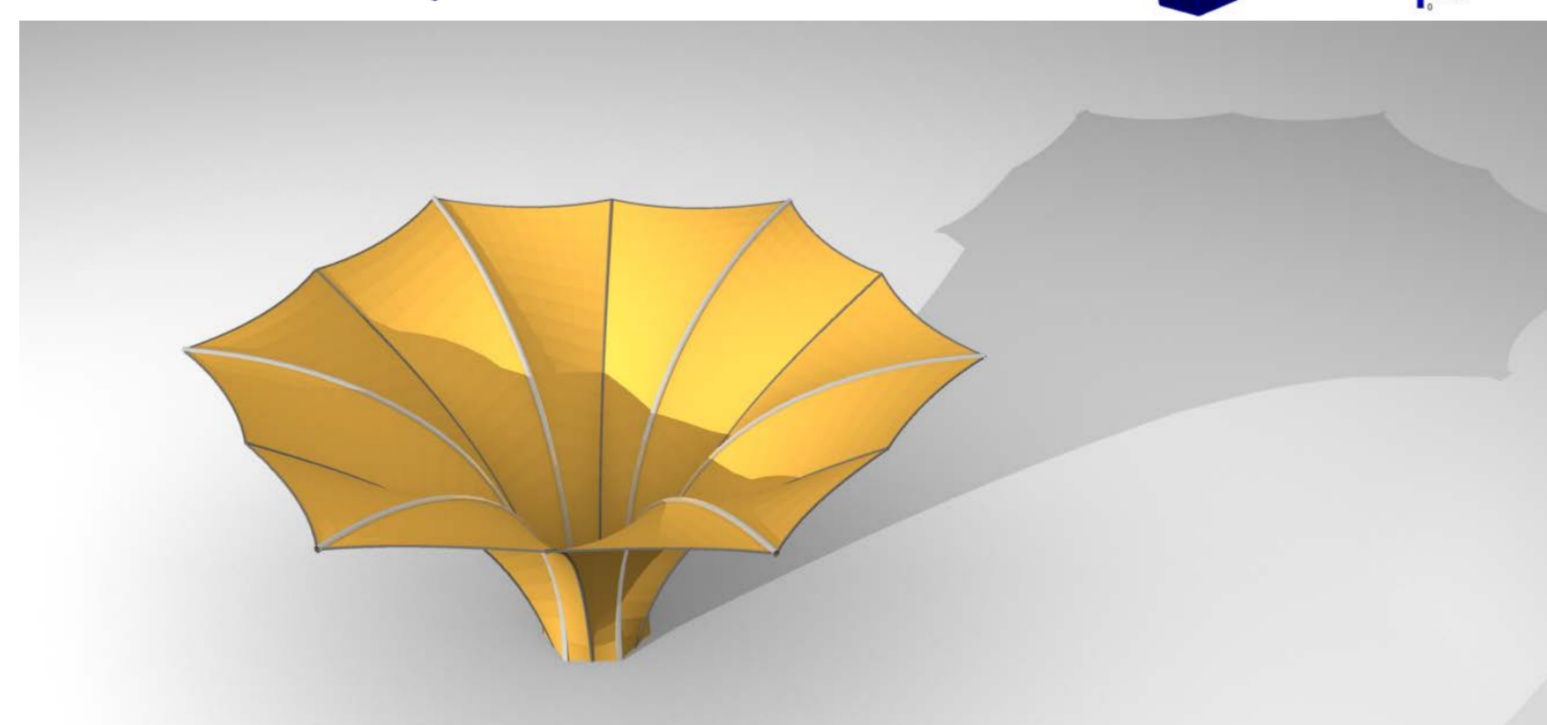
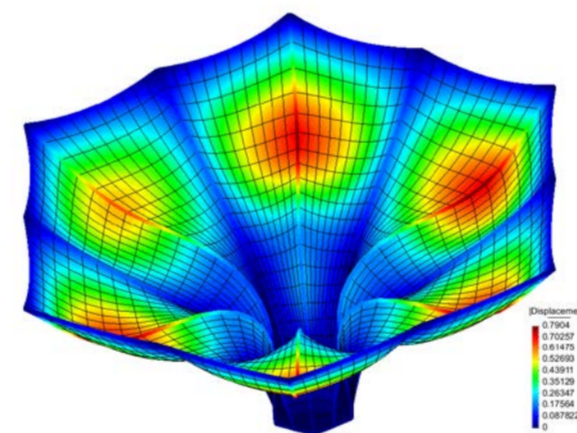
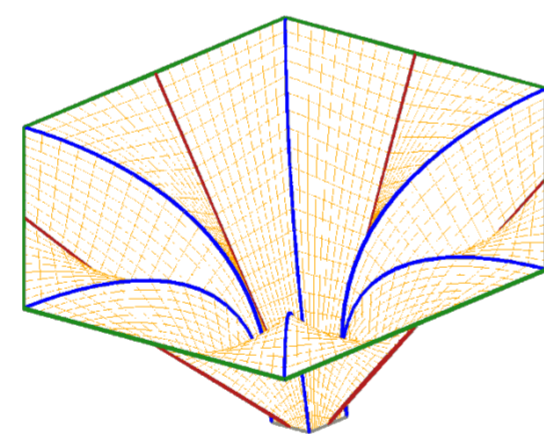
Self-stressed bow structure (J. Lienhard, ITKE Stuttgart)



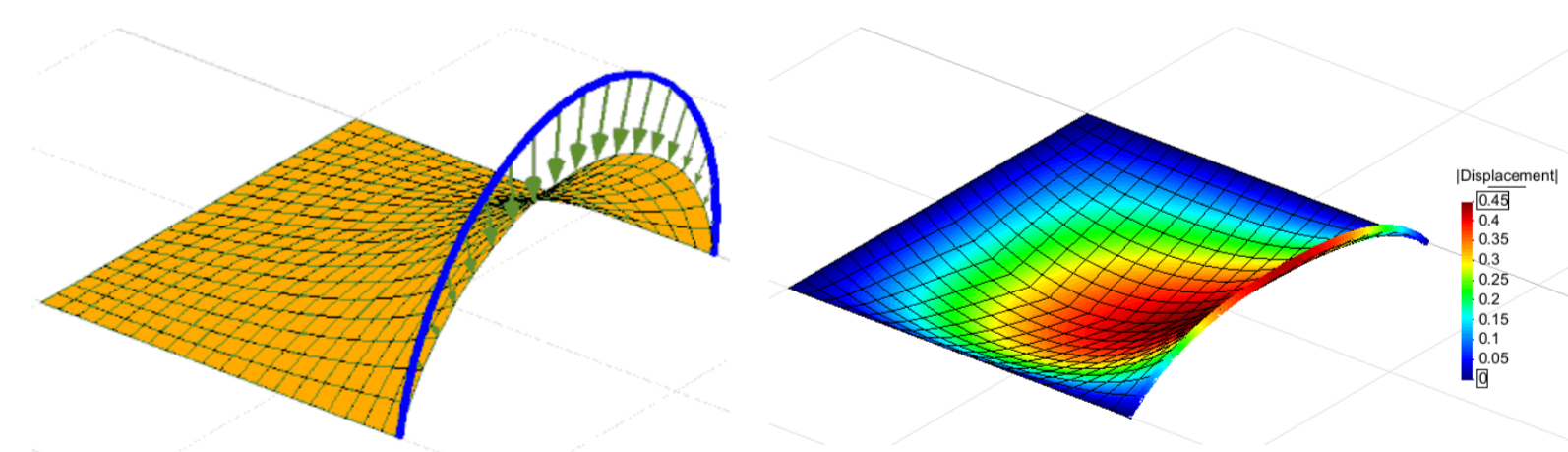
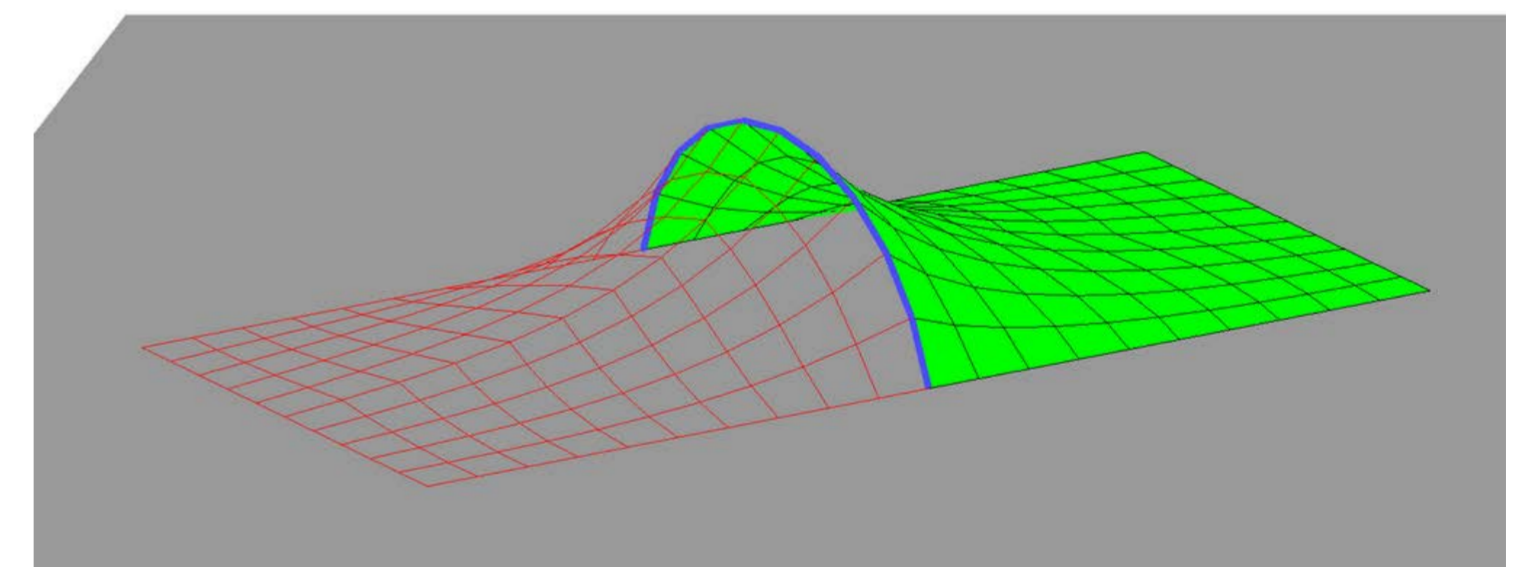
## Current development

The analysis of hybrid and bending-active elements motivates some lines of the current work:

- a non-linear beam element that allows for large rotations,
- integration of this element into the existing membrane analysis, especially form finding and further structural analyses,
- analysis of stiffness-contributions from pre-bending of the beams.



“Blossom” with bent beams and cables

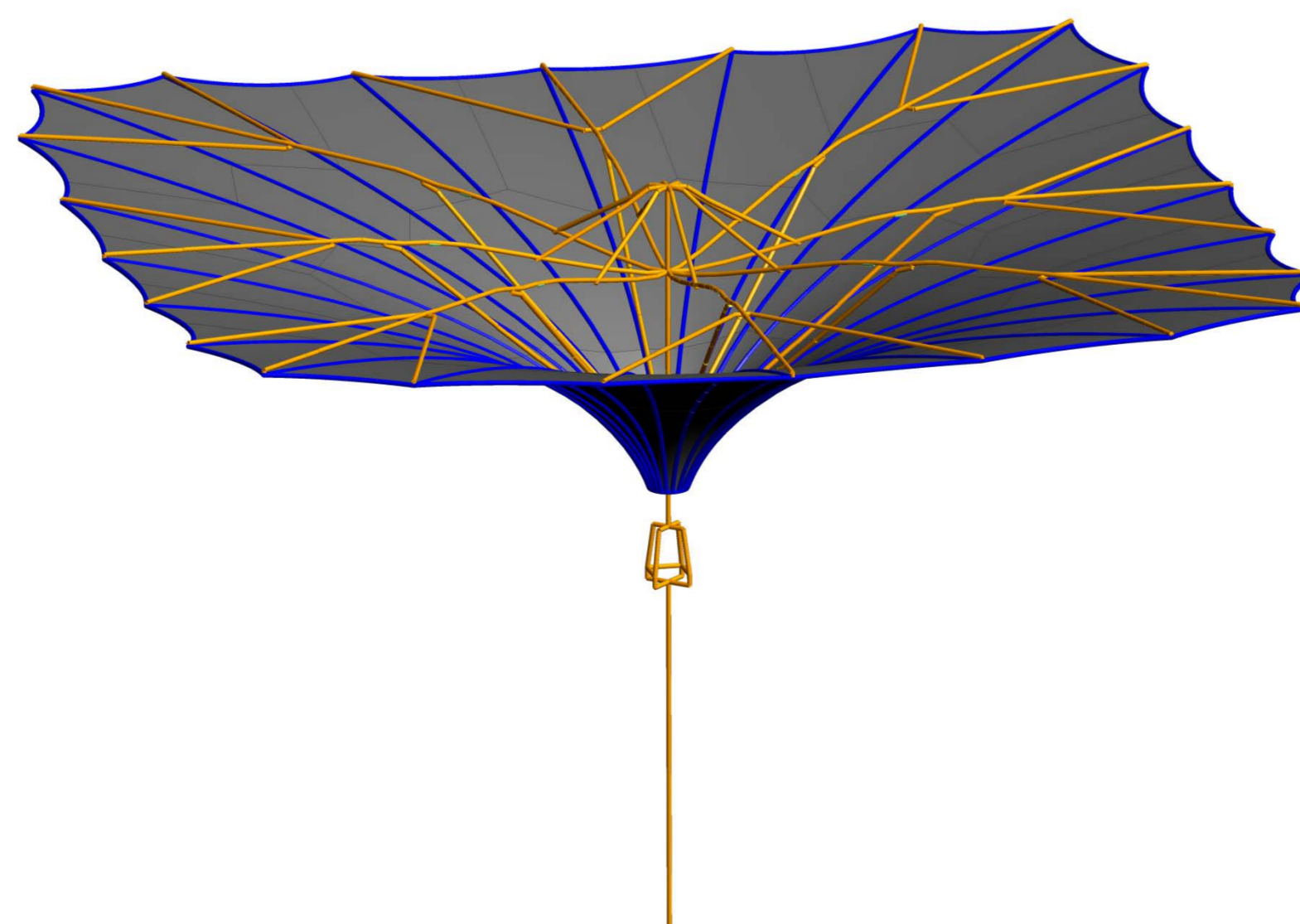


Application of the form-found configuration to the structural analysis

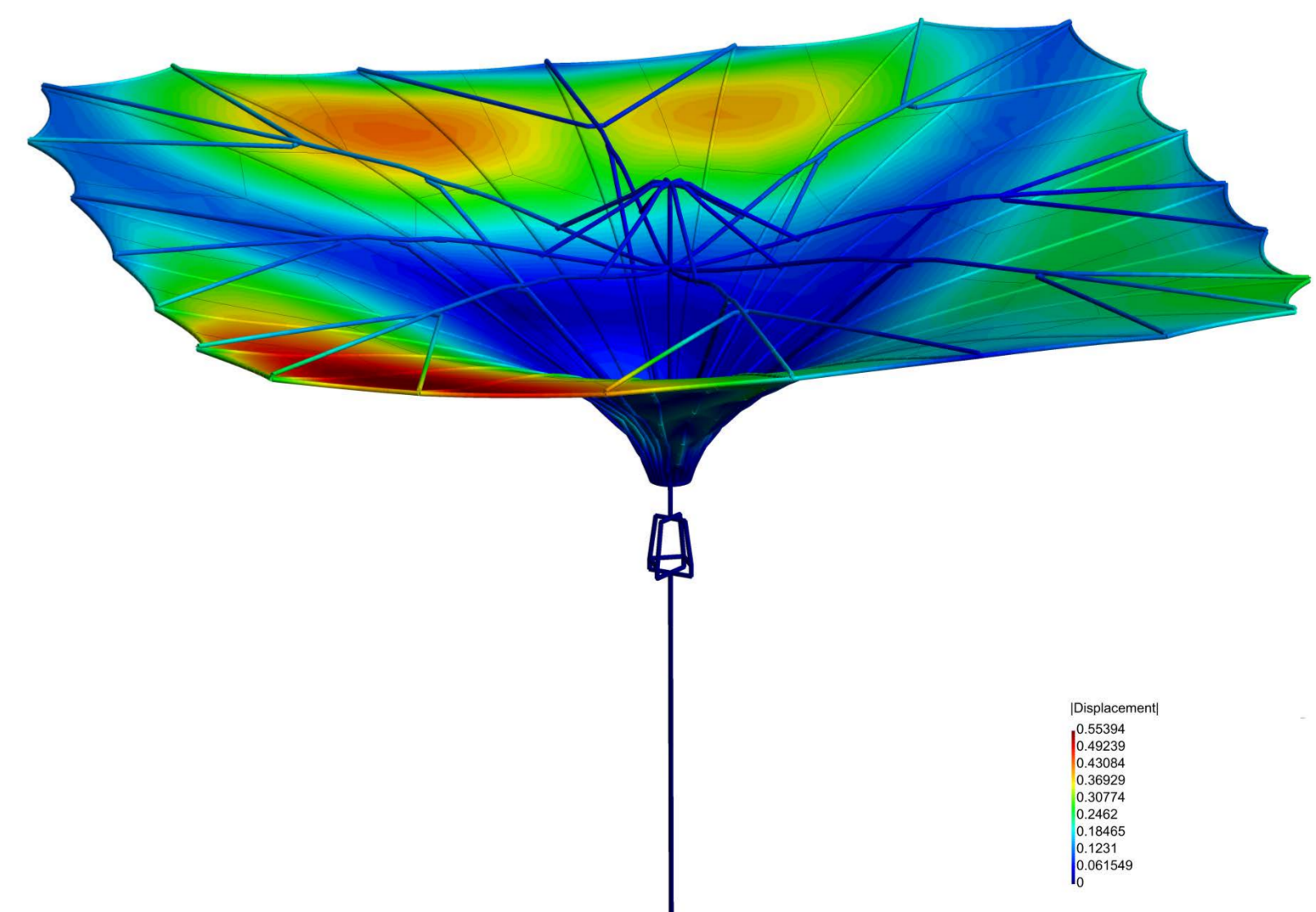
## Application to a 28 m Umbrella

The example of a foldable umbrella spanning 28 m (collaboration with A. Michalski, SL Rasch) demonstrates the possibilities that lie in the combination of bending-active elements and “classical” membrane structures.

The umbrella is part of an ongoing research program that includes *in-situ* real-scale measurements of wind impact on and structural response of the umbrella.



Foldable umbrella spanning 28 m



Deformation during dynamic analysis