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DESIGN OF ARCHITECTURAL MEMBRANES WITH ISOGEOMETRIC ELEMENTS

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Architectural membranes offer a unique language of shapes, mainly characterized by their curved silhouette, underlining the light-weight, efficient nature of these structures. One of the core characteristics of architectural membranes is their load-bearing behavior: external and internal loads are transferred to the supports exclusively via tension. To ensure this load-bearing behavior, prestress in the membrane is required. Form-finding has the task to determine the shape that fits the prescribed prestress state and the given boundary conditions. Since form-finding usually is an iterative approach towards an architecturally desirable structure, the interlacing between design and structural engineering is extremely close. In this context the gap between computer-aided design (CAD) and computer-aided engineering (CAE) presents a major obstacle, since conversion and adaption between different "parallel" geometric models require considerable amounts of resources and obviously is prone to errors and deviations.

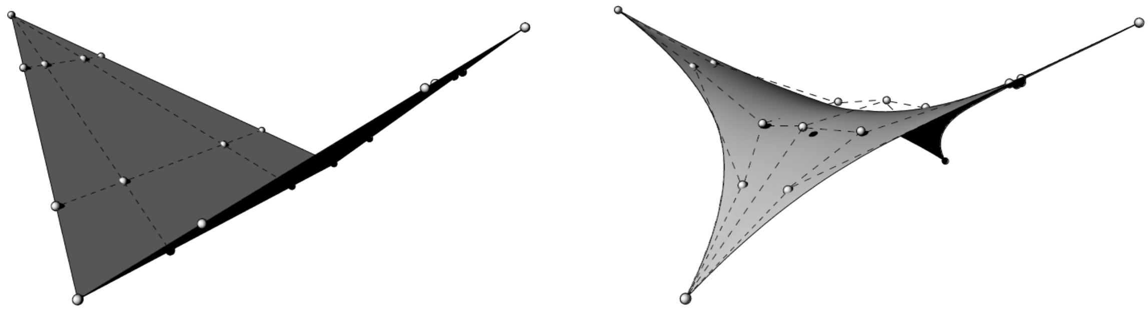

Figure 1: Form-finding of a four-point sail with isogeometric membrane and cable elements. Both the starting geometry (left) and the form-found geometry (right) are described by the control points [2].

The isogeometric analysis (IGA) is a rather recent technique in the context of finite element analysis (FEA) that uses the Non-Uniform Rational B-Splines (NURBS) from CAD as basis for discretization. Therefore the model conversion can be omitted and the same geometric basis is used for both, the design and the structural analysis, which allows for an impressive CAD-CAE-integration.

In this context, membrane structures with their smooth and double curved shape are ideally suited for IGA. From a geometric point of view they are – with the exception of edge and valley cables – formed without kinks.

In the proposed contribution, the form-finding of architectural membranes at the basis of the Updated Reference Strategy (URS) [1] is presented. The URS stabilizes the originally singular problem of form-finding with the help of a non-singular regularization term, which can be written in a virtual work formulation, introducing the so-called homotopy factor λ:

$$-\delta W_{\text{URS}} = -\lambda \cdot \delta W_{\text{original}} - (1-\lambda)\cdot \delta W_{\text{regularization}}$$

Assuming convergent behaviour – which is the case for solvable problems – the regularization problem can directly be solved in each iteration step. The geometry is updated and the desired prestress is reapplied to the “new”, resulting geometry until convergence is achieved, *i.e.* until the stresses in the actual configuration fit the desired prestress state.

For the form-finding of membrane structures, a geometrically non-linear membrane and a cable element have been formulated in the IGA-framework [2]. While the membrane element is formulated as a classical element, close to successful shell formulations, the cable element is based on the recently developed IBRA-technique, proposed in [3].

An extensive series of benchmarks from patch-test level up to real scale architectural membranes underlines the reliability and advantages of the presented approach of design and form-finding with the isogeometric analysis. The assessment of membranes against geometry-related phenomena is more straightforward due to the closed description of the geometry.

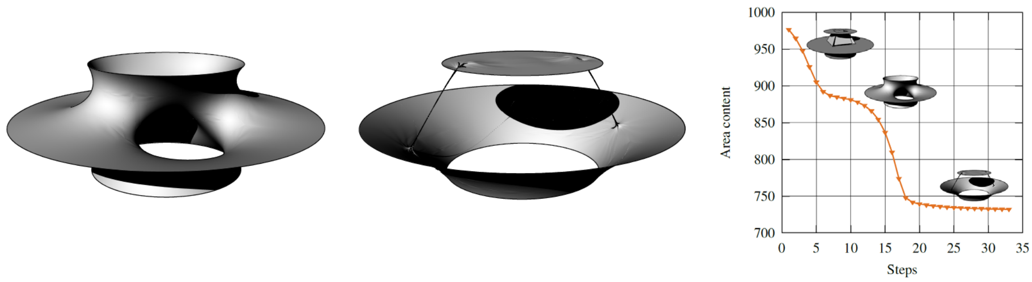

Figure 2: Form-finding of Costa’s minimal surface. Intermediate stable solution (left), “collapsed” final solution (middle), development of the surface area during the form-finding (right) [2].

Especially in the form-finding of tensile structures a close design-through-analysis approach could provide substantial advantages by omitting the facette-type discretization of classical FEA. Future work shall try to exploit further promising approaches for even closer CAD-CAE-integration or the use of the geometry description from IGA for cutting pattern generation.

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