Bending incorporated LIGHTWEIGHT

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What if no tools are available for the design and analysis of novel lightweight structural systems? Well, develop then your own tools! That is exactly what researchers of the æ-lab did in collaboration with the BLOCK Research Group (ETH-Zürich) to explore and investigate novel tension structures with integrated bending-active elements.

Introduction

Doubly curved membrane structures are typically tensioned between high and low anchor points, attached to the ground, buildings or poles. By integrating elastically bent, linear elements in the membrane surface, an internal supporting and shape-defining system is created that provides more freedom in design and reduces the required amount of external supports.

These elastically bent elements are often referred to as 'spline' or 'bending-active' elements. The latter term was introduced to describe "curved beam or surface structures that base their geometry on the elastic deformation of initially straight or planar elements". Combining bending-active elements with a membrane structure creates a hybrid construction with interacting components. The 'igloo' camping tent or the umbrella are probably the best-known examples of this kind of structural system.

Currently, an integrated tool for the form finding of bending-active tension structures in which the interaction between tension and bending elements can be properly modelled and calculated is not available. Therefore, researchers of the æ-lab and the BLOCK Research Group (ETH-Zürich) jointly developed a design tool with a flexible and easy-to-use graphical interface that allows the potential of bending-active elements for shaping tension structures to be fully explored.

Interactive form finding

The presented tool is written in Python and implemented in Rhinoceros, providing a familiar and comprehensive user interface. Building upon the framework for form finding of tension structures using discrete networks, the equilibrium problem of the hybrid system is solved with the dynamic relaxation. Results can be easily visualised and inspected in the Rhinoceros 3D model space.

In addition to changing the node fixity and adding or deleting cable-net elements, various attributes of the structural components can be changed during form finding. The user can, for example, decide to make the boundary edges force-controlled, define a set of links as cable and/or change the initial length or section properties of the bending element. The latter is illustrated in the next example.

Three alternatives of the same structure, but with different properties of the bending element are generated. Figure 1a is the reference figure, figure 1b has a bending element with a Young's modulus that is three times lower, and the bending element of the structure in figure 1c has a diameter twice as large. It is clear that this form finding tool allows intuitive and fast exploration of the influence of different properties on the equilibrium shapes of the hybrid structure.

Design examples

The potential of integrating bending-active elements in a membrane structure with the design tool is demonstrated with the following cases. The first two consist of multiple cantilevered bending elements (Figure 2 and 3). They clearly show the supporting and shape-defining function of the elements. The following two examples are a combination of an elastically bent arch with a 'suspended' bending element (Figure 4 and 5). Figure 6 illustrates a bending element suspended to two cables, e.g. connected to an adjacent building.

Conclusions

Integrating bending-active elements in tension structures is a powerful and interesting way to support and shape them. Various design configurations and applications of these hybrid constructions are feasible. To allow full exploration of the design possibilities, a form finding tool has been developed and subsequently demonstrated through a series of case studies.

Future development of the tool will be focused on the use of different solving strategies and the integration of a statical analysis module.

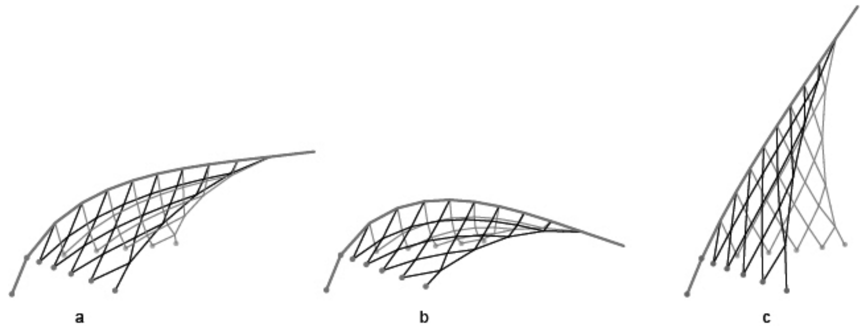


FIG 1: Exploring different equilibrium shapes by changing the attributes of the bending element

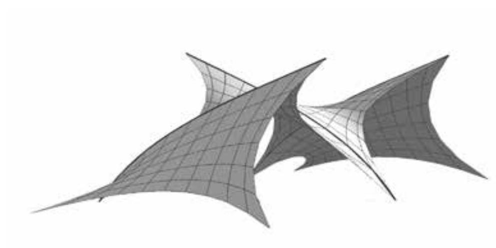


FIG 2: Multiple cantilevered bending elements positioned alternating at the opposite side of the structure generate a concatenation of modular four-point 'hypars'

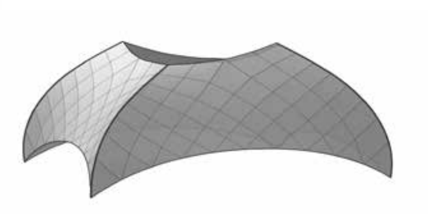


FIG 3: Bending the cantilevering, linear elements towards the middle generates a tent-like structure

FIG 4: Combination of two elastically bent arches with two integrated suspended bending elements

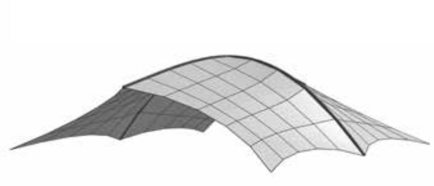
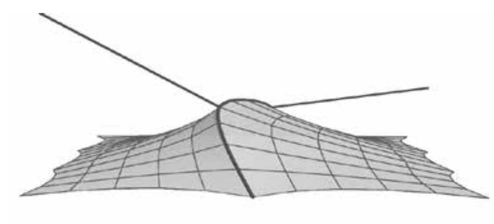


FIG 5: The simplest combination consists of one elastically bent arch with one suspended bending element.



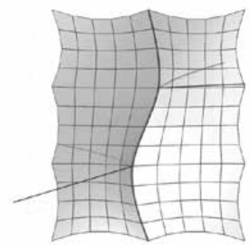


FIG 6: A bending element suspended to two cables e.g. connected to an adjacent building