A variational formulation for motion design of adaptive structures

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Abstract
In contemporary architecture and structural engineering, energy efficiency and sustainability play an important and steadily growing role. Beyond lightweight design, adaptivity offers a possibility to design even more efficient structures. One idea of adaptive structures is to adjust the geometry to varying loading. Optimal geometries for different dominating load cases can be provided by classical structural optimization. The transition between these geometrical configurations is mostly characterized by small displacements where linear analyses are sufficient.

Another purpose of adaptive structures is the adjustment to changing requirements that occur during the usage of the building. Examples for this are deployable and retractable façades or roofs, where the geometries of the different configurations differ significantly from each other. Here, not only the geometry itself needs to fulfil specified requirements, but also the shape transition has to be designed to satisfy the condition of efficiency. These motions include large displacements and therefore geometrically nonlinear analyses need to be considered. This contribution deals with such shape transitions as a motion design between geometrical configurations, based on a variational formulation.

As an illustrating example, we first refer to the Brachistochrone curve, which represents one of the first problems solved by variational principles. For motion design, the functional is defined as a particular quantity that needs to be minimized related to the motion. The method is developed with the exemplary condition of minimizing the strain energy during the whole deformation process. By a discretization of the motion path with finite elements, additionally to the spatial discretization, a linear system of equations is obtained.

The proposed method is verified by means of applications with known exact solutions, for instance the motion of a kinematic system with zero strain energy throughout the entire process. In addition, we take into account the results of the biomimetic analyses that were carried out in the Collaborative research center SFB-TRR 141.