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Deployable textile hybrid structures: design and modelling of kinetic membrane-restrained bending-active structures

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Abstract

By rapidly expanding from a compact, stowed bundle to a functional space enclosure, deployable structures can address temporary needs in a minimum amount of time. Using the intrinsic elastic behaviour of flexible elements — active bending — in the design of transformable or deployable structures leads to a wide range of kinetic concepts. This component transformation can decrease the complexity that often comes with rigid-body mechanisms. This paper presents one principle for deployable bending-active structures, based on the interaction between a deployable grid and a restraining membrane: deployable textile hybrid structures. A case study illustrates the design concept and the deployment and assembly processes that allow multiple structural transformations. The large interdependency of the form and material behaviour of bending-active structures, contrary to conventional form-active structures, requires a specific modelling approach. The approach presented in this paper allows feedback between the parametric input of starting geometry and material characteristics, and the output geometry and internal stress. Working with a high-strain fabric without cutting pattern, balancing the stresses and strains between the bending elements and tensile fabric becomes the prime focus. Although the preliminary results are acceptable in theory, a more detailed structural analysis and real-scale models should validate the assumptions of rapid assembly and the structural behaviour on a realistic and practical level.

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Keywords: active bending; deployable structures; tensile structures; digital modelling; structural analysis; temporary structures

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1. Introduction

The principle of transformable structures entails a wide range of deployable and rapidly assembled structures [1]. Incorporating transformability in the design and construction of temporary structures, can greatly improve their reusability and reconfigurability and reduce their assembly time, thus not only avoiding excessive waste production, but also bettering their efficiency in responding to short-term or critical needs. Including active bending in the assembly of these structures leads to a wide range of structural concepts that owe their kinetic behaviour to the elastic deformation of the members [2]. This paper focuses on one principle of transformable active bending: the hybrid action of a deployable bending-active system with textile restraint. This reciprocal relation of restraint and pre-tensioning does not only improve the load-bearing behaviour, but can also be utilised during the assembly process. Moreover, the membrane restraint action allows creating a fully self-tensioning structure without grid distortions or incompatibilities in the deployable system, facilitating unrestrained rigid-body deployment when the fabric is not attached. Through a case study, this paper elaborates on the design and modelling of deployable textile hybrid structures. Though their conceptual design, easily supported by physical models, often occurs intuitively with a basic or experimental understanding of the bending and tensile actions, modelling these structures in a digital environment is rather complex. Since the form finding of bending-active structures depends largely on the starting geometry and material behaviour, the process differs noticeably from that of conventional form-active structures [3]. Therefore, we performed the form finding of the structure in an interactive environment between a parametric model of the flat starting geometry and the elastic formation of the structure through cable contraction in a finite-element environment. Using stretchable, high-strain fabrics eliminates the need for cutting pattern generation. Although this case study validates the approach and structural integrity of the concept, more detailed analysis and prototyping are necessary to facilitate the construction of these deployable textile hybrid structures.

2. Active bending transformation in deployable and rapidly assembled structures

2.1. Transformable structures

Transformable structures offer an efficient means to temporary and mobile use. The transformation process, of the components or the entire structure, facilitates rapid, reversible assembly and ensures a compact, stowed volume that can be easily transported [1]. Two main principles exist for the design of transformable structures: design for disassembly and deployability. Kit-of-parts structures or assembly kits contain a set of compatible components that can be combined and re-combined into, often multiple and different, structural configurations. Conversely, deployable structures rely on an instantaneous transformation process, from a fully compacted to a fully deployed and functional configuration. Some examples, such as most deployable scissor structures, are rigid body mechanisms, whereas others entail a structural stress development during the deployment process, e.g. the pre-tensioning of a tensile membrane. Although both principles of transformability — deployment and rapid assembly — involve different types of erection, a combination of both can further increase a structure's transformational capacity, e.g. the universal scissor component [4].

2.2. Bending-active structures

Active bending is the utilisation of large elastic deformation to create curved structures from initially flat or linear elements [5]. Essentially a structural formation process, active bending can result in and be applied to a myriad of structures and structural types. Introducing the curvature only during the assembly of the structure, limits its pre-fabrication to creating the flat layout of the components, evidently simplifying the production and transportation. Although managing the internal bending stress in the structures in a stable and structurally efficient equilibrium can be a complex process, this often results in a significant improvement of the structures' load-bearing behaviour. Shortcutting the bending forces internally in a self-restraining system is an efficient means to avoid external restraints and employ the stress-stiffening effect. This self-restraint can be induced by creating topological incompatibilities, between the coupled bending elements or by adding tensile elements, such as cables or a membrane.