Curved Bridge Design

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Abstract. This paper presents a novel approach for the interactive design of linear structures in space. A method is introduced, that provides a maximum of formal freedom in the design of funicular, hence efficient, structures. For a given deck geometry, defined by a design driving NURBS curve via parametric modeling techniques, a tailored relaxation routine allows for controlled, real-time form-finding of the spatial funicular. Subsequently, the equilibrium of the deck is constructed using techniques from graphic statics, combined with a least-square optimization technique. Finally, the method is applied to a design example.

1 Introduction

The role of computation in architecture has undergone a shift in the last few years: from the promise of novel, unlimited freedom in form, enabled through digital design and fabrication processes, to a more critical attitude, questioning the complexity and cost of this freedom [15]. This change of focus is one reason for recent ambitions of the integration of structural and fabrication constraints into architectural design practice [14]. An engineering practice is emerging, that blurs the role of the engineer in the design process between problem-solver, and creator of ideas and design concepts [5].

One basis for this new model of collaboration between architects and engineers is an upcoming set of shared computational concepts and interfaces as common language in the design practice [16]. The integration of structural constraints with fabrication data in a tailored, real-time design environment has been described for the case of a digital hanging chain modeler [6]. Recently, a method for the setup of an associative model of an efficient structure for a freeform roof, using techniques from graphic statics, has been reported [7].

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In this case study, a new computational strategy is introduced, that allows for real-time design of spatial bridges in early design stages, between the conflicting priorities of exciting spatial expression and efficient material use. Using concepts derived from form-finding methods for cable nets [1], and graphic statics [17][13], a set of funicular polygons is generated, that are in equilibrium with the dead-load of a given deck geometry. These structures are highly efficient for the design load, due to the funicular form of the equilibrium solution.

The structure of this paper is as follows: first, the basic concepts of the technique are briefly summarized. Second, the design method and its implementation in a parametric setup are described. Finally, the design of a footbridge is shown, demonstrating the effectiveness of this approach.

2 Concepts

2.1 Equilibrium Solutions

The approach presented here is suited for form-finding in early design stages, on the basis of dead-load. The method is considering the equilibrium of axial forces in all structural members, while neglecting material stiffness and deflections. This is valid based on the assumption of the rigid-plastic material model and the lower bound theorem of the theory of plasticity [4]. In later stages of the design process, after member dimensions have been assigned to the structural axes, further structural analysis has to ensure that the deflections stay small, and that no elements are in the danger of buckling. Since funicular structures are instable systems, additional stiffening means against collapse in the case of asymmetric load have to be introduced.

2.2 Curved Bridges

In what follows we will exemplify the method by dealing with the design of a typology of bridges, consisting of a curved deck in plan, and a funicular structure, a cable or an arch, supporting the deck. Prominent build examples of this typology are the suspension bridge in Kehlheim, Germany, and the arch bridge in Oberhausen-Rippenhorst, Germany, both designed by Schlaich, Bergermann and Partner [2], and the Campo Volantin footbridge in Bilbao, Spain by Calatrava [3]. For the general case of a bridge in equilibrium, with its deck following an arbitrary space curve, it is always possible to find two funiculars, balancing the dead-load of the deck [9]. For this paper, a specific case is discussed: the geometry of the deck is arbitrarily curved, but lying within a horizontal plane. In Fig. 1, the main concept for the form-finding of the funicular is described for a suspension bridge: the goal is to achieve a