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NURBS BASED FORM FINDING OF EFFICIENT SHAPES FOR SHELLS

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Summary. This paper presents ongoing research on using non-uniform rational b-splines (NURBS) based isogeometric analysis for form finding of efficient shapes for shells. The form finding is made using dynamic relaxation together with NURBS based membrane elements. The method is employed directly to design geometry, without the need for any further discretization. The method is implemented in two plug-ins for Rhinoceros 3D and Grasshopper 3D. The method describes form found geometries well with very few elements and can be used to find efficient shapes very rapidly and directly in design software, and is thus suited for design explorations.

1 INTRODUCTION

Conceptual design is the first phase in the design process in which all the requirements and design objectives are synthesized into conceptual alternatives. In practice today, major decisions regarding the buildings geometry and overall form are usually made during the first phase, while structural performance considerations are postponed. To include structural performance in conceptual design requires, amongst other things, the availability of tools such as simulation software, suitable for conceptual studies.

Shell structures with small thickness to span ratios are a subset of lightweight structures where occasionally the shape is defined through form finding processes. The form finding consists of finding shapes which carry a form-defining load primarily through membrane action, maximizing the shells efficiency. The form finding can be performed using physical hanging models, if the form defining load case is the self-weight. Several computational tools exist to explore designs using hanging models, however, they all rely on translating computer aided design (CAD) geometry to traditional polynomial based FEM, see Fig. 1. This leads to limited workflow and interactivity in design situations.

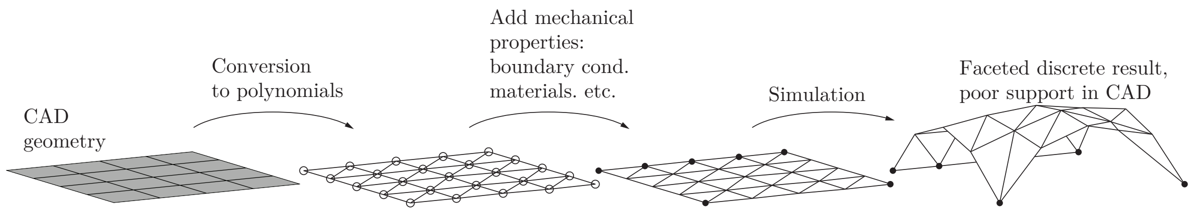

Figure 1: Traditional work flow for form finding, starting with a NURBS geometry and ending with a FE-solution with discrete geometry.

1.1 Present research

In here, ongoing research on using non-uniform rational b-splines (NURBS) based isogeometric analysis[1] for form finding of efficient shapes for shells is presented. The dynamic relaxation method[2] is used together with NURBS based membrane elements for finding the static solutions. The method is employed directly on design geometry, which is described by NURBS, without the need for any further discretization. Efficient solution methods are obtained by selection of mass and damping for the dynamic relaxation method[3]. The results are used to implement two plug-ins for the CAD applications Rhinoceros 3D and Grasshopper 3D. The method describes form found geometries well with very few elements[3] and can be used to explore different efficient shapes for shells very rapidly and directly in design software, and is thus suited for design explorations.

2 RESULTS

Conceptual design is an iterative procedure, and performing form finding often requires several iterations in order to get satisfactory results. To simplify this work flow, it is favorable to perform the form finding directly in the design software. The use of a design software can simplify the modeling of the related parameters, such as the initial geometry, the boundary conditions, material parameters etc. Buildings are generally designed in CAD software, and it is therefore of interest to include form finding directly into the CAD software. To study the possibilities of performing form finding directly in CAD software using NURBS, which are well supported by the CAD software, two demonstrator plug-ins for Rhinoceros 3D and for Grasshopper 3D for form finding with dynamic relaxation are developed.

2.1 Grasshopper 3D plug-in

The Grasshopper 3D plug-in provides form finding capabilities trough the Grasshopper visual programming environment (VPE). The interface to the form finding is done trough the use of custom Grasshopper components. The inclusion of form finding into Grasshopper makes it possible to create parametric architectural models, where the form finding is a part of the parametric model. Since the form finding is performed using NURBS all of the existing components and functions in Grasshopper can be applied after the form finding process.

2.2 Form finding example

The ability to perform form finding with very few elements is favourable in design situations as it allows the designer to quickly explore alternative shapes. In the form finding exploration the first step is to define an initial shape, boundary conditions, material parameters and applied loads. Once this is done the the dynamic relaxation is run with a coarse mesh and the form found shape is computed.

Fig. 2 shows the setup in Grasshopper for a simple form finding with an initial geometry with a single patch, consisting of one element which is subdivided twice into 4 X 4 elements. The building geometry is included in the design process, and the form finding results are viewed in this context.

To fulfill the design criteria it is often necessary to iterate the form finding process by

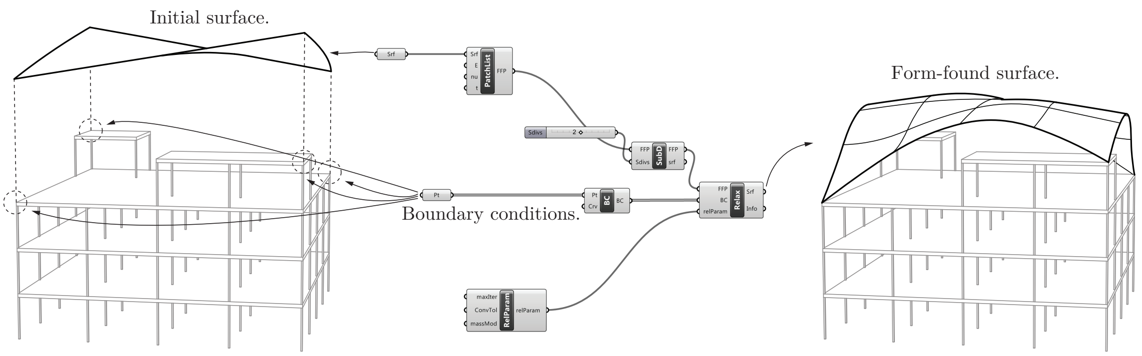

Figure 2: The combination of Grasshopper components for a simple form finding.

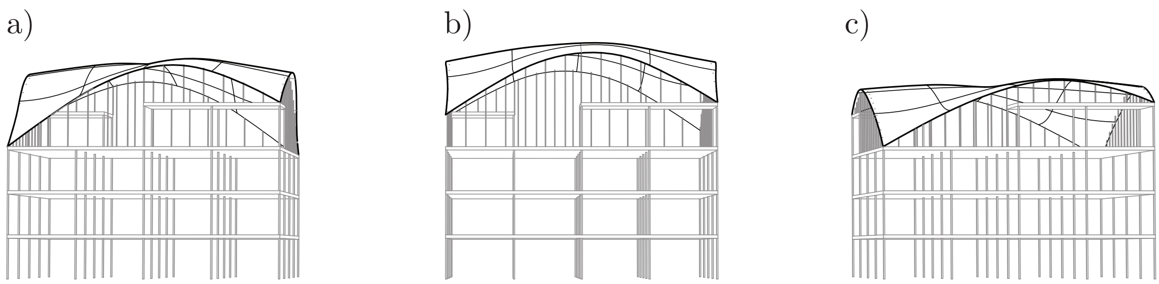

Figure 3: Different examples generated by changing the boundary conditions or initial geometry of the example shown in Fig. 2. a) added vertical bars. b) changed position of corner points. c) increased Young's modulus of roof.

experimenting with initial parameters such as the initial geometry, boundary conditions, and loads. Fig. 3 shows a few design explorations of the simple geometry that is shown in Fig. 2 with a uniformly distributed load. Variations of the boundary conditions and geometry generates different shapes, all approximated with a coarse mesh. Since the resulting geometry is still represented by NURBS it can be used with a parametric model in Grasshopper, this is exemplified by the length of the vertical bars between the building and roof, which are automatically updated if the roof shape is altered.

Integrating the process into Rhinoceros simplifies several parts which are often included in the design process. The form finding can be performed within the architectural context, and thus simplifies considerations related to the surrounding buildings, such as e.g. shading and reflections. Since the form found shape is defined in the design software and being represented by the complete curved geometry description it is straight forward to do architectural renderings to present to clients. Further detailing operations in CAD can be performed after the form finding since the geometry is still NURBS, and is well supported by the CAD software.

3 CONCLUSIONS

The use of NURBS based elements for architectural form finding was presented in this paper. The core concept of the approach is that it allows for interactive form finding of shells in a well suited CAD environment.

ACKNOWLEDGMENTS

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