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Computation and fabrication of scaled prototypes

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ABSTRACT

The formal, functional, and material attributes of design are routinely investigated through the construction of physical models and scaled prototypes. With the increasing adoption of computational workflows, the digital to physical translation process is central to the construction of scaled prototypes. However, the choice of methods, tools and materials for computational prototyping is a developing area. Therefore a systematic body of knowledge on the benefits and costs of multiple methods of computational prototyping for the construction of physical prototypes need to be identified. This paper addresses the prototyping process through the comparison of three computational methods of fabrication through the modelling, analysis and construction of a Gaussian Vault. It reports on the process of digital to physical construction using additive manufacturing, surface fabrication and structural component models. The Gaussian Vault offers a unique set of geometric, structural and physical characteristics for testing all three methods of prototyping. The size, shape and proportion of vault prototypes are rapidly generated and tested. The design geometry, material properties and physical construction of the Gaussian Vault are realised using commonly used practice workflows comprising parametric modelling and analysis of geometry, model rationalisation with material characteristics and finally the use of digital fabrication methods. Comparison of the results identifies the characteristics, benefits and limitations of the three approaches. Finally the paper discusses the digital to physical translation processes and summarises the characteristics, benefits and issues encountered in each.

1. Introduction

Physical models and scaled prototypes of architecture play an important role in design. Physical prototypes enable architects and designers to investigate the formal, functional, structural and material attributes of the design. New advances in the computation of architectural geometry combined with advances in the field of digital fabrication now permit sophisticated digital to physical workflows for constructing prototypes. The increasing importance of digital workflows in the design of buildings has led to a renaissance in the use of scaled prototypes, or “mock-ups”. Understanding new workflows for realising scaled prototypes is an important area of emphasis in design practice. Using computer-aided modelling functions, the design, representation, and fabrication methods of scaled models can be significantly enhanced. The paper discusses the possible methods of digital fabrication for scaled prototypes. With the increasing proliferation of methods and techniques supported by a proliferation of digital tools, multiple workflows are now possible. it is therefore necessary to identify and quantify the relative benefits, strengths and limitations of these methods and workflows.

2. Background

The digital-to-physical prototyping process can be largely categorised as iterative process of digital modelling of the design geometry or *design exploration* [5,13,19], integrating material constraints with the final geometry or *fabrication planning* [8], and finally setting out a protocol for manufacturing the physical realisation [9]. Digital translation methodologies have been widely studied and reported in the literature. For example, modelling the building envelopes [4,14] allows for a detailed consideration of the interrelationships between the geometry, material and structural configurations. In particular, digital translation tools offer a better rationalisation process in the case of complex non-standard architectural forms [3,6,7,16].

Furthermore, the capabilities of parametric software allow for experimentation with variable changes to the fundamental aspects of size, shape and degree of curvature in the geometry [1,18].Subsequently, the digital fabrication approaches

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allow for the physical reformation of the intended prototype form [9]. More recently, a better integration between structure and skin through node connections, their implications for full-scale modelling and exploration of architectural and structural reticulated components [17] and multi-layer meshes [11] have been proposed. The rapid advances in modelling tools and the translation of material constraints suitable for fabricating prototypes offers new workflows for architects and designers in the construction of scaled prototypes. Parametric modelling and digital fabrication workflows are focussed the design and construction of new, mostly iconic one-off buildings. Therefore, it is necessary to look at how the digital sophistication can be applied to routine tasks. Secondly, almost all reported workflows in the literature, cover a single method or technique for digital to physical translation. Therefore, there exists a potential scope to research the same task using differing methods for translation. To achieve these goals, a systematic body of knowledge on the benefits and costs of multiple methods of computational prototyping for the construction of physical prototypes is needed.

3. Motivation

Despite the ongoing impact of these new mockups, there remain several gaps in the literature. First, the literature on scaled prototypes is focussed on the deployment of workflows for the translation of a single digital model into a physical prototype. With the increasing proliferation of methods and techniques supported by an explosion of tools, multiple workflows are now possible. it is therefore necessary to identify and quantify the relative benefits, strengths and limitations of these methods and workflows. The intention of the paper is to understand the different computational processes for translating the same digital surface geometry of Gaussian Vaults into physical prototypes. This is achieved through three experimental methods: solid rapid prototyping, surface model and structural models. This paper addresses the prototyping process through the comparison of three computational methods of fabrication through the modelling, analysis and construction of a Gaussian Vault. It reports on the process of digital to physical construction using additive manufacturing, surface fabrication and structural component models. The Gaussian Vault offers a unique set of geometric, structural and physical characteristics for testing all three methods of prototyping. The size, shape and proportion of vault prototypes are rapidly generated and tested. The design geometry, material properties and physical construction of the Gaussian Vault are realised using commonly used practice workflows comprising parametric modelling and analysis of geometry, model rationalisation with material characteristics and finally the use of digital fabrication methods. Comparison of the results identify the characteristics, benefits and limitations of the three approaches. Finally the paper discusses the digital to physical translation processes and summarises the characteristics, benefits and issues encountered in each method.

4. Gaussian Vault: prototyping workflow

The focus of the paper is to understand how different processes for translating digital surface geometry of Gaussian Vaults into physical prototypes.The forms used for the experimentation in design and fabrication of scaled prototypes are based on this full scale experimentation by Eladio Dieste in masonry vaults and shell structures. In an earlier paper [15], we reported on the simple approximation of the gaussian geometry as ruled surfaces. In this paper, we develop the concepts using planar mesh approximation approaches. Of Dieste's developed forms, the paper focuses on the geometry of the Gaussian Vault. The Gaussian Vault is an innovative structural form developed during the fifties by Eladio Dieste, an Uruguyan structural engineer [2,10]. Dieste's experimental projects resulted in the full-scale construction of masonry vaults and shells based on structural minimalism and the use of gaussian curvature. His built projects elegantly integrate the principles of structural form through the use of curvature and geometry. Since the formal properties are derived from structural and geometric principles, his work has received a revival in the field of digital fabrication. The choice of the Gaussian Vault as a prototype was motivated by two qualities of the form

- Structural innovation. The structural basis of the form, the use of double curvature and the possibility to represent the vault using discrete, repeatable component geometry.
- Material experimentation. With the surface realised as a digital object, material experimentation is undertaken through the investigation of additive manufacturing, fabrication planning based on surface geometry unfolding and structural models based on gridshells.

4.1. Geometric complexity

The capabilities of parametric software allow for design exploration with variable changes to the fundamental aspects of size, shape and degree of curvature in the geometry [1,4]. These tools also support the planning and fabrication of digital surface geometry into scaled prototypes Three methods are examined using both known and experimental processes based on the parametric manipulation of the Gaussian surface geometry (Fig. 1).

The surface geometry of the Gaussian Vault is based on two catenary curves of differing heights that sweep across the span of the form. Profiling the progression (perpendicular to the span), the vault starts and ends with straight line profiles. However, as the profile reaches the apex of the span curves, the shape transforms into an S-curve and creates the degree of double curvature in the form. The surface is an outcome of the development of this geometry (Fig. 2).

5. Material experimentation

The computation and construction of Gaussian Vaults provide a unique insight into the digital-to-physical translation process covering geometric complexity, structural innovation and material experimentation. These results were gathered through three prototyping experiments using additive manufacturing, surface models and structural models (Table 1). The first method is through the

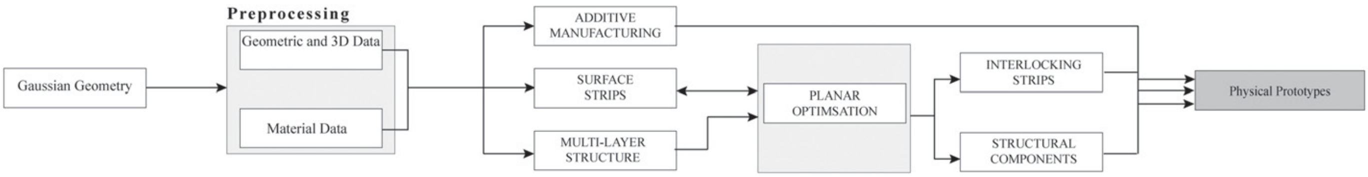

Fig. 1. Scaled Gaussian Vault prototypes: the digital to physical translation process.