The functionality of form: exploring traditional shell structures to supplement modern engineering design

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Summary

There is a growing need for increased knowledge in the development of new and challenging structures in an ever changing society. Engineers must handle complex functional and contextual parameters in addition to traditional structural design, presenting an educational challenge in which skills of numerical tools merges with the relationship of load-bearing elements and architectural form used in best practice of structural engineering. The focus of this paper is the educational challenge demonstrated by the case of shell structures as a structural element and architectural form mediator. The interdependence between architectural form by architects and the structural design by engineers is important and thus especially considered. The goal is to assist and explore the desire of structural engineers to fulfil both architectural requests and engineering requirements and to suggest how this urge can be implemented to enhance the current theoretical-intensive educational pathway.

Keywords: Engineering education, Shell structures, Structural analysis, Architectural design

Functionality of form; methodology for exploring structures

This paper presents an educational approach to structural knowledge and structural design. It’s based on the collaboration between structural engineering and architectural design at the Norwegian University of Technology. The intention is to provide a platform for students to better understand the structural engineering potential of contemporary architecture. Structural engineering and architectural design are closely related professions but nevertheless very different practices. To successfully realise irregular or complex-shaped buildings, the engineer should look for the structural potential of the actual architectural proposal and suggest improvements, which may concern the shape and materials, all in accordance with architectural intentions. In early phases of the design process, a good engineer should be proficient in assisting the architect as to what extent shape and material can be structurally improved without having to use detailed models and calculations. We argue for three steps: structural and architectural knowledge of key buildings, to grasp the architectural essence of architects’ building proposals and to “read” or interpret complex shapes as combinations of underlying basic shapes. The emphasis in the current paper is based on our realisation and reaction to subjects as taught. Hence, want to we further explore the idea of added value for all newly qualified structural engineers that are already theoretically highly skilled.

Why functionality of form?

Form inspires both architects and structural engineers to accomplish elegance in structures. The expression “form follows function” is a well-known phrase, an idiom sometimes described as an axiom credited to Louis Sullivan in 1896 [1]. Later, this view of form and function and their role in the design of structures has been followed up by Moussavi [2], who stated the expression “the function of form” by so rightfully asking, “But, if not function, what does form follow?”. This train of thought is, in all modesty, here followed by a small but significant clarification of “the functionality of form” to also capture the leading engineering perspective of structural integrity.

Methodology for exploring structures

To highlight the importance for students to further explore structures, we propose a knowledge-based educational concept of structural design. This educational tool simply is based on the recognition of the importance of understanding key structures, an approach to acknowledge structures of excellence in the education. The tool is to be applied by establishing a *hypothesis* of functionality (component or overall), do necessary *evaluations* at appropriate level, rendering a discussion and c*onclusion* of the lesson learned. The final product is a purpose-based conclusion.

Examples: student investigations into modern shell structures

The presented methodology is exemplified by two student investigations of traditional shell structures [3]. Both are good examples of how students may use their structural understanding after previously have been working with basic 2D and 3D shapes. The first structure is a corner-supported barrel vault and the second is a cross vault and the potential effects from overhangs.

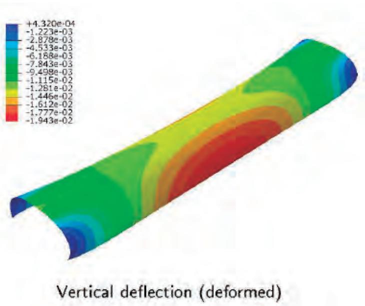

Fig. 1 Corner-supported barrel vault vertical deformation

Corner-supported barrel vault as a simple supported beam

For the barrel vault, some preliminary considerations were discussed. If subjected to self-weight only, the shell exhibits compressive forces as well as bending forces depending on the geometry, as shown in Fig. 1. At the ends of the shell, the force and stress distributions will be complex due to edge effects, but, in the main body of the shell, the distribution is more beamlike, but with clear deviations.

Cross vault: effect of overhangs

A simple cross, or groined, vault may be constructed from two intersecting barrel vaults oriented perpendicular to one another. Groined vaults permit larger open areas than barrel vaults on the same footprint, allowing more light into the interior as well as providing increased stiffening compared to the barrel vault. Unlike barrel vaults, these cross vaults may serve as both roof and wall, defining the entire interior space with one structure. However, like barrel vaults, the forces may be envisioned as traveling along the line of largest gradient, as shown in Fig. 2.

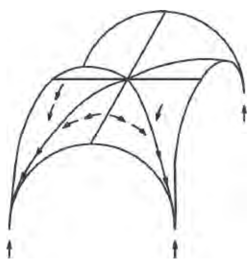

Fig. 2: Cross vault: force flow of a simple groined vault. Reference building/key structure: The Bacardi Rum Factory, Cuautitlan, Mexico, by Félix Candela, 1960, expanded 1971

Conclusion

An educational knowledge-based structural design concept is suggested based on recognition of the importance of understanding key structures, building a library of knowledge applicable to a wide range of cases. The methodology is applied by establishing an overall or by-component functionality hypothesis, conducting analyses at appropriate levels from calculations via flowcharts to FE-analyses and rendering a discussion of the lesson learned.

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