Form Follows Force – On the Evolution of Form Finding for Shells

Ekkehard RAMM

University of Stuttgart
Pfaffenwaldring 7, 70550 Stuttgart, Germany
ramm@ibb.uni-stuttgart.der

Abstract

The present contribution addresses the historical evolution of the interaction between form and force in the design of thin-walled structures with an emphasis on shells. We reiterate the discussion on the interaction between form and force in [1], [2] where the notion *force follows form* is contrasted with *form follows force* in analogy to Louis Sullivan's famous phrase *form follows function.*

We briefly sketch exemplarily this evolution from the ancient to the present times. We start at the early vault type of structures in the Bronze Age, mention the advanced technology of the Romans and their followers and briefly describe the design concepts for the famous domes in the renaissance. Up to these times, the designs were apparently controlled according to the principle *force follows form*; i.e. a rational process in finding a physically optimal form was not a driving force in the design.

This situation changed in the transition to the modern era, when the question of an optimal shape for a structure was discussed following the concept of *form follows force*. This inverse concept asks for the form for a given objective, e.g. an optimal stress state. Robert Hooke's *Riddle of the Arch* was a landmark in this development. It was the start of modern form finding methods, applied by several master builders like Wren, Antonelli, Rondelet, Gaudi and later Frei Otto and Heinz Isler. Interesting to see that the old concepts of graphic statics experienced a renaissance in the last years leading to most interesting interactive design tools.

Finally, it is referred to recent developments on form finding by shape optimization and morphogenesis [3]. Thus, we will conclude this contribution with an extensive discussion on vertex morphing as a most powerful numerical tool with the largest design space and the least amount of effort, most effective already in the early stages of design.

References

[1] E.Ramm and R. Reitinger, "Force Follows Form in Shell Design" in *Innovative Large Span Structures: Proc. IASS-CSCE Intern. Congress*, Toronto, Canada, 1992.

[2] E. Ramm. "Force Follows Form or Form Follows Form- The interaction of form and force in surface structures" (in German) in *Prozess und Form – Natürliche Konstruktionen (Process and Form – Natural Structures)*, K. Teichmann and J. Wilke (eds.), Ernst & Sohn, 1996, pp. 68-74.

[3] K.-U. Bletzinger, "Form Finding and Morphogenesis", in *Fifty Years of Progress for Shell and Spatial Structures, 50th Anniversary Jubilee of IASS*, I. Mungan and J. Abel (eds.), 2011, pp. 459-474.