Chapter 4

Architectural Morphogenesis Through Topology Optimization

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ABSTRACT

This chapter illustrates the main approach for a generative use of structural optimization in architecture. Structural optimization is very typical of sectors like mechanical, automotive engineering, while in architecture it is a less used approach that however could give new possibilities to performative design. Topology Optimization, one of its most developed sub-methods, is based on the idea of optimization of material densities within a given design domain, along with least material used and wasted energy. In the text is provided a description of TO methods and the principles of their utilization. The process of topology optimization of microstructures of cellular materials is represented and illustrated, emphasizing the all-important criteria and parameters for structural design. A specific example is given of the research at ACTLAB, ACB Dept, Politecnico di Milano, of performative design with lattice cellular solid structures for architecture.

INTRODUCTION

The development of computational tools and design methods nowadays influence highly the development of new forms of architectural design. Designers are accessing easily tools which allow to impregnate their design decisions with an overlook on technical questions. Integrative design approaches are in a process of consolidation and design thinking has moved gradually towards the idea of form-finding, where performances are integrated not merely into an evaluative discourse, but as generative parameters.

Among the vast proliferation of available tools, there is a plethora of algorithmic-based solutions for including structure-related enquiries in the design process. Among them, Topology Optimization (TO) methods have emerged as an interesting approach to evaluate form and structure jointly, following the example of aerospace and automotive industry, where the optimization of mechanical parts is

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performed in connection with an efficient material usage. In civil engineering, TO is a known approach for the optimization of structural elements, such as beam, columns, or truss layout, with an emphasis put on structural and material optimization (Amir and Bogomolny, 2011). In this chapter is discussed how TO can be applied conveniently for the morphogenesis of a structural design, in an effort to look at this technique not only under the perspective of the material optimization, but with an accent put on the potential of creating shapes which can complement and inspire the generation of architecture.

**BACKGROUND ON STRUCTURAL OPTIMIZATION**

In structural engineering, a main goal is developing load-bearing systems which satisfy economically the design performance objectives and safety constraints. Economical consideration is often the main driver for developing a design process that enables the minimization of resource consumption. In doing so, an important concept is the one of optimization, that refers to the selection of the best element from some set of available alternatives (Radman, 2013). Optimality conditions of structural systems have been introduced first in 1901 by Anthony Michell in his theoretical study *The Limit of Economy of Material in Frame-Structures*” (Michell, 1904). What Michell claimed is a continuous displacement field with equal and opposite principal strains, considered as limit strains of the material in compression and tension. If in a particular problem it is possible to design a structure all of whose members are in tension, or alternatively compression, then the optimum design is achieved, since all the members of a truss are laid along these principal strain lines. Also, the tension and compression members that meet at a node must be orthogonal, since they lie along principal directions with unequal principal strains $e$ and $-e$.

The work of Michell was remarkable because he achieved these results without any prior work on optimization theory, but largely based on intuition. However, it suffers some limitations: it is limited to planar structures, distributed loads are not included, loads are applied only on the boundary, the manner by which a truss approaches the infinitely refined limit is not addressed, and consequently the exact relationship between the limit and the underlying discrete truss structures is unclear.

Wider access to computational work in 1990s justified the development of numerical procedures for the TO of structures, aimed at finding the best layout, configuration and spatial distribution of materials in the design domain of the continuum structure (Bendsøe and Kikuchi, 1988).