UNIVERSITÀ DEGLI STUDI FIRENZE

Mechanical modeling and optimization of ultra-lightweight structures

Nicolò Guiducci

Department of Civil and Environmental Engineering (DICEA)

PhD program in Civil and Environmental Engineering

Introduction and state of art

Lightweight structures, such as membranes, shells and composite, pleated, folded, inflatable, and lattice structures, are widely used in many advanced applications of different engineering fields such as structural, mechanical and aerospace domains, due to their outstanding structural efficiency and versatility. Among these, lightweight morphing and reconfigurable structures, such as textured materials, bistable auxetic metamaterials, origami- and kirigami-inspired structures, self-foldable and deployable systems, just to mention a few examples, have attracted increasing attention in the past few years.

To fully take advantage of the extraordinary mechanical performances of these structures and related materials, especially when their weight is taken to extremes (ultra-lightweight materials and structures), reliable and advanced theoretical models are needed, but they are not currently always available. These models are indeed necessary in order to setup design optimization strategies and algorithms to analyze such structures.

To achieve these ambitious and impactful goals, this research project proposes a feasible and comprehensive study aimed at developing advanced mechanical models for the design and optimization of one or more ultra-lightweight structures with a novel design concept inspired by existing ones, as for instance:

- flat flexible microstructured shells, Fig. 1a, [1];
- stiff inflatable shells from planar patterned fabrics, Fig. 1b, [2];
- tensairity structures, Fig. 1c, [3];
- pleated structures, Fig. 1d, [4].

Research objectives

After the deepen literature review, ultra-lightweight structures architectures with novel design concepts will be conceived, being inspired by existing ones.

The main purpose of this project will be then a general research advancement in several key aspects of modeling of these structures and their related materials, such as:

- the formulation of geometric and constitutive non-linear models for the conceived ultra-lightweight structures;
- the set up of a computational framework for the inverse design of such structures, starting from prescribed target shapes;
- the development of structural optimization algorithms;
- possibly, the realization of prototypical demonstrators to validate experimentally theoretical and numerical outcomes.

Methodology

Both modeling and optimization challenges will be addressed within a common theoretical framework, namely adopting variational approaches. Variational methods are based on energy minimization concepts, rely typically on intelligible energetic quantities, allow for rigorous analysis and offer a rational way for the development of numerical solution algorithms. In particular, they have turned out to be the natural way of analysis for the investigation of instability problems at both a material and structural level, and also for material microstructure and geometric shape optimization problems, for instance. Variational methods appear therefore the natural candidates to pursue the project aims [5, 6].

Fig. 1: different examples of ultra-lightweight structures that could inspire novel design concepts.

References

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