Research statement

Interests, Objectives and Goals

A substantial part of my current and past research is concerned with **smart materials** and **structures**. Smart materials exploit a *broad variety of physical mechanisms* to modify their response in a manner that can be controlled through appropriate physical stimuli. Nature has been long using such adaptive structures in essentially all life forms. In contrast, human-made structures often appear inefficient, static, and cumbersome.

In particular, my research is addressed to smart structures as devices resulting from the *combination* of *smart material behavior* with *slenderness*. Beams, plates and shells are examples of slender structures, as they have one or two geometrical dimensions (thickness or cross-section diameter) negligible with respect to their principal size (length and/or width). Geometrical features such as slenderness allow displacements to be large with moderate involvement of strain, which in turn results into a greater potential of mechanical actuation.

The most common physical mechanism exploited to achieve smart behavior are *piezoelectricity* and *magnetostriction*. Devices based on these principles are usually referred to as electro- or magneto-elastic. In particular, the use of a magnetic field to achieve actuation offers several advantages such as *remote and contactless control*, over other types of actuation, as well as the fact that it does not produce any polarization of the media nor chemical alteration. My most recent work in this direction is the development of theories of magnetoelastic beams composed of magneto-rheological elastomers. These are functional materials whose mechanical properties can be controlled upon the application of an external magnetic field by dispersing magnetic hard particles into a non-magnetic soft matrix. Such softness, when combined with slenderness, amplifies the overall deformation, giving rise to an effect called *huge magnetostriction*. This is in fact a hot topic in my current research. At present, I am indeed working on the *optimal design* of magnetic cantilevers to be used as actuators capable of *complex motion patterns*.

Material response can also be crafted to react to chemical stimuli. This is the case of gels, which have been within the focus of my most recent research. Gels are soft materials that can change radically change their shape when swollen with a solvent. For these materials, photolitographic patterning of the cross-linking density of thin gel membranes and, more generally, the fabrication of composite thin gel structures enable three-dimensional transformations through non-homogeneous or anisotropic swelling.

This work has also motivated further interest in theories of species diffusion in solids, most notably, the Cahn-Hilliard system. Results of this line of research have been, among others, generalized theories of Cahn-Hilliard type which find their application in model for *solid-state hydrogen-storage systems*. For these systems I have contributed to the development of an analytical model to capture *stress effects on the kinetics of hydrogen adsorption in nanoparticles*, and to the development and analysis of *PDE-based models to describe hysteresis in the absorption kinetics*.

The *non-linear, multi-physics, and three-dimensional character* of theories of smart materials demands for computationally intensive numerical methods which, when used alone, do not allow designers to gain insight about the key parameters and features that govern the response of these structures. This state of matters has motivated my research efforts to develop *systematic methods to derive and justify dimensionally-reduced theories* that can capture the mechanical behavior of thin structures with *minimal amount of mathematical complexity*. The availability and reliability of these models allow engineers to *gain insight from analytical or semi-analytical solutions* which are seldom found for three-dimensional models, and also to develop faster numerical approximation schemes. The problem, however, is that the extension to smart materials of the standard dimension reduction techniques, which engineers have long been using for conventional materials, is far from trivial, and requires sophisticated mathematical tools, typically asymptotic analysis and approximation. Yet, the guideline in these derivation is that the resulting models should, on one hand, capture the relevant physics and, on the other hand, be simple enough to provide engineers with immediate design formulas. As a matter of fact, the derivation of structural theories is a nice example of *sophistication* turning into *substantial simplification* at the end of the journey.

The complete list of my papers (including some unpublished manuscripts) can be found in [my Google Scholar account](#).

Methods and Tools

The *methods* I use in my research are theoretical, although I have some collaboration with experimentalists. In my work draw mostly *tools* from *continuum mechanics* with some ingredients from *applied mathematics*.

Continuum mechanics is usually referred to as that branch of mechanics that disregards the discrete nature of matter, treating a physical object as if a continuum collection of material points would fill its entire extent. It should be noted, however, that ignoring the detailed structure of matter at the atomic scale is typical of most branches of mechanics. What, I believe, distinguishes continuum mechanics from its siblings is the emphasis on *systematic procedures* that attempt to *unify*, as opposed to *ad hoc* constructions that tend to *differentiate*, an attitude that in my country finds its roots in the school of *Rational Mechanics*. This attitude has made it possible for scholars working in continuum mechanics to provide important contributions to other fields, such as physics, materials science, and even the behavioral sciences. Indeed, being an electrical engineering by training, it was the elegance and power of the methods of mechanics that made me interested in applications of structural theories to Micro-Electro-Mechanical Systems (MEMS), which I studied during my master thesis. From there, the leap to structural mechanics and mechanics of materials was quite short.

Applied mathematics is an area of mathematics that provides a common language and an unified way to understand and solve problems arising in a diversity sciences. Methods I have used from applied mathematics in include: asymptotic analysis, homogenization, and dimension reduction. The power of these methods is that they provide assistance in retaining, in a mathematical model, the essential features and the essential physics.

Finally, although this is not my main focus, I have been able to carry out on my own the mathematical analysis of some of the models that I have invented, although the most important results have been achieved are with the collaboration of leading experts in the field.

Collaborations

I regard the ability to interact with people with different backgrounds as an invaluable asset and a source of never ending learning. Besides working with engineers, my research involves interaction with people from other applied sciences, mostly applied mathematicians and physicists. The list of my current and past coauthors, to whom I am deeply indebted for what they have taught to me, includes:

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