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Multiscale and microstructure-inspired constitutive models for soft materials. On the occasion of Giuseppe Saccomandi's 60th birthday

The elucidation of the intricate **thermomechanical behavior of soft matter** has been a significant challenge for decades, both from theoretical and technological aspects. Recent advancements in experimental techniques have facilitated a better understanding of the underlying phenomena governing the response of soft matter to various external stimuli, down to the molecular scale. In turn, this progress has enabled the modeling of macroscopic responses by accounting for the complex mechanisms of energy exchanges across different scales.

A comprehensive understanding of these processes is within reach, particularly for high-performance biological materials, which often outpace the capabilities of artificial materials. This knowledge has led to the development of **novel materials** with sophisticated, potentially hierarchical designs. Notably, high thermomechanical performance has been achieved, especially in the realm of bioinspired materials, and even when the base materials exhibit standard mechanical responses.

From a theoretical standpoint, the demand for **new theories** that elucidate how microscopic material and topological properties translate into homogenized macroscopic behavior has driven the reformulation of classical continuum mechanics theories, with a focus on microstructure and multiscale approaches. The macroscopic behavior of these materials, characterized by intricate effects such as history and rate-dependence, natural configurational changes, growth, instability effects, and hysteresis, emerges from complex molecular-scale phenomena. These include scission and re-crosslinking events, continuous network configuration variations, domain unfolding and refolding, and intricate energy interchanges among different scales.

Building on this understanding and classical multiscale approaches to rubber-like elasticity, a successful synergy has emerged between equilibrium and non-equilibrium statistical mechanics, kinetic theories at lower scales, and the mathematical theory of nonlinear elasticity. This interdisciplinary collaboration has paved the way for a new generation of **multiscale models**, wherein the macroscopic behavior of biological and rubberlike materials is derived from their properties at the micro- and meso-scopic scales. The theoretical and technological interest in these novel approaches is further amplified by the recognition that the resulting problems are inherently **multi-field physics** problems.

In this vibrant research field, **Professor Giuseppe Saccomandi** stands as a leading figure, having achieved outstanding scientific results in a wide range of research areas. These include mechanical modeling of soft materials, methodical fitting of hyperelastic models to experimental data, biomechanics of biological tissues and systems, nonlinear elasticity and viscoelasticity, and nonlinear wave propagation in solids, among others. Professor Saccomandi has greatly contributed to the development of novel mechanical theories that demonstrate how low-scale material and topological properties influence macroscopic material response. His focus in these fields has led him to reformulate classical theories of continuum mechanics, to include microstructure and multi-scale effects in a way that is both straightforward and relevant to the engineering field. His research has significantly contributed to the development of exciting multiscale mechanical models of biological and rubberlike materials, where the macroscopic behavior is deduced from material properties at the micro- and mesoscopic scales, making use of multi-field approaches. Two outstanding pillars of his progress in soft tissue biomechanics consist in the mechanical modeling of brain tissue and in elastographic investigations of localized damage of tissues and organs (due, for example, to benign and malignant lesions).

This special issue is dedicated to him in celebration of his 60th birthday, and in recognition of his extensive cooperation and esteemed position within the international scientific community.

Michel Destrade*
School of Mathematics and Statistical Sciences, University of Galway, Galway, H91 TK33, Republic of Ireland

Giuseppe Puglisi
Department of Civil, Environmental, Land Building, Engineering and Chemistry, Polytechnic University of Bari, via Orabona 4, 70125 Bari, Italy

Ivonne Sgura
Department of Mathematics and Physics "E. De Giorgi", University of Salento, Via per Arnesano, Lecce, 73100, Italy

* Corresponding author.
E-mail address: michel.destrade@universityofgalway.ie (M. Destrade).

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