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"PROGRAMMABLE MATERIALS & STRUCTURES"

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ABSTRACT

Programmable materials and structures hold great potential for various applications, such as robotics, biomedical devices, and civil structures. The rational design and realization of programmed behaviors in these systems play important roles in enabling functional devices. To encode desired mechanical functionality into structures, we propose a multi-material multi-objective topology optimization approach to inverse design soft composite structures that achieve complex target mechanical responses under large deformations. The multi-material framework simultaneously optimizes both the geometry and material heterogeneity to achieve target behaviors and functionalities. A library of diverse designs is created, showcasing a wide range of precisely programmed nonlinear responses, such as multi-bulking and multi-plateau. In general, the properties of materials and structures typically remain fixed after being constructed. To enable reprogrammable behaviors, we develop a multi-physics topology optimization approach to discover magneto-active and temperature-active materials that achieve tunable buckling and switchable shape morphing, controlled by magnetic fields and temperature fields, respectively. The obtained systems exhibit one response under one stimulus and switch to a distinct response by applying another stimulus. We explore multi-material manufacturing techniques to fabricate a suite of mechanical, magnetic, and thermal metamaterials and metastructures and experimentally validate their programmed behaviors. These complex yet programmable responses are enabled by the interactions among unique geometry, material nonlinearity, large deformations, and external stimuli actuation. The excellent agreement among target, simulation, and experiment demonstrates that the proposed optimization-driven framework, when integrated with hybrid manufacturing techniques, has the potential to systematically design, inform, and create innovative multi-functional materials and structures for various engineering applications.

BIOGRAPHY

Dr. Xiaojia Shelly Zhang is a David C. Crawford Faculty Scholar and Assistant Professor at the Department of Civil and Environmental Engineering and the Department of Mechanical Science and Engineering at the University of Illinois at Urbana Champaign (UIUC). She directs the MISSION (Multi-functional Structures and Systems design Optimization) Laboratory. Dr. Zhang holds B.S. and M.S. degrees from UIUC and a Ph.D. degree from Georgia Tech. Her research explores multi-physics topology optimization, stochastic learning algorithms, and additive manufacturing to develop multi-functional, sustainable, and resilient materials, structures, and robots for applications at different scales. She is the recipient of the National Science Foundation CAREER Award, the ASME Journal of Applied Mechanics Award, the DARPA Young Faculty Award, the AFOSR Young Investigator Award, the Leonardo da Vinci Award from ASCE, the DARPA Director's Fellowship, and the Thomas J.R. Hughes Young Investigator Award from ASME. Dr. Zhang serves on the Executive Committee of the International Society of Structural and Multidisciplinary Optimization (ISSMO) and is a Review Editor for the Journal of Structural and Multidisciplinary Optimization and an Associate Editor for the Journal of Applied Mechanics.