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Guest Editorial

Special Issue: Design of Engineered Materials and Structures

The design of engineered materials and structures is a growing and increasingly impactful field of research that intersects materials science, engineering design, engineering mechanics, manufacturing, and data science. The overarching goal is to accelerate the discovery of new materials for engineering applications. The approach compliments a traditionally empirical, trial-and-error approach to materials discovery with an inverse, requirements-driven approach that strategically leverages material databases, simulations, and engineering design algorithms and methods to synthesize new materials and structures.

The inherently interdisciplinary nature of materials design makes it not only challenging but also intriguing to growing cadres of design engineers and materials scientists who are driven by the opportunity to explore new material systems that meet increasingly ambitious performance goals. This type of design exploration requires new design frameworks and tools that can search high-dimensional, multiscale design spaces from a practical perspective, such that the resulting materials can be fabricated with existing and emerging manufacturing processes. Ongoing work in materials discovery and computational materials engineering is essential for enabling materials design research, but this work must be accompanied by design frameworks for solving the inverse problems that are inherent to the field. *Arroyave, Shields, Chang, Fowler, Malak*, and *Allaire* highlight many of these challenges as articulated by participants in a workshop on interdisciplinary research on designing engineering material systems. They describe not only some of the conceptual barriers between the materials and engineering design research communities but also the open research questions motivated by challenges in the field.

One of the challenges facing the materials design research community is representing and reconstructing microstructures in a way that is conducive to design exploration and optimization. *Yang, Li, Brinson, Choudhary, Chen*, and *Agrawal* apply deep adversarial learning approaches for representing microstructure with low-dimensional latent variables that form the basis for more efficient and more accurate design exploration than competing approaches. *Ghumman, Iyer, Dulal, Munshi, Wang, Chien, Balasubramanian*, and *Chen* utilize a spectral density function methodology for representing and reconstructing microstructures for simulation-based design of organic photovoltaic cells. *Yang, Xu, Chuang*, and *Zhan* introduce a structural equation modeling-based strategy for reducing the dimensionality of the design space for optimizing multilayer composites. Finally, *Acar* merges microstructural design with reliability-based design optimization to consider the impact of microstructural uncertainties on material properties.

A related challenge is the optimization of material topology with research efforts now spanning macrostructural and microstructural scales. Many of these research efforts also address the challenge of designing the topology of structures and their constituent micro- or mesostructures concurrently. *Du, Zhou, Picelli*, and *Kim* address the challenge of topology optimization of architected materials with spatial variations in structure by introducing a connectivity index that leads to well-connected spatial variations in unit cells throughout a component. *Smyl* also focuses on spatial variations by introducing an inverse method for optimizing spatially varying elastic material properties in structural domains subject to multiple target displacements and loading conditions. *Liu, Detwiler*, and *Tovar* describe clustering techniques for improving the efficiency of cellular materials design for crashworthiness, which is an inherently nonlinear problem. *Kazemi, Vaziri*, and *Norato* introduce a topology optimization approach, based on an extension of the geometric projection method, for structures composed of discrete components and multiple materials. *Zhang, Liu, Du, Zhu*, and *Guo* introduce a moving morphable component approach for the topology optimization of rib-stiffened structures.

A rapidly growing subfield of materials design is the design of metamaterials, which gain their unique properties from the *arrangement* of material rather than the composition of the underlying material itself. *Delissen, Radaelli, Shaw, Hopkins*, and *Herder* design isotropic metamaterials with constant stiffness and zero Poisson's ratio over large deformations and demonstrate their properties with an additively manufactured prototype. *Park* and *Rosen* focus on designing and modeling the behavior of additively manufactured lattice structures more accurately by incorporating geometric approximation errors and joint stiffening into homogenized models of their mechanical properties. *Wang, Arabnejad, Tanzer*, and *Pasini* utilize homogenized lattice properties and topology optimization for the design of a microarchitected hip implant, mitigating peri-implant bone resorption resulting from stress shielding. *Petrovic, Nomura, Yamada, Izui*, and *Nishiwaki* introduce an optimization strategy for tailoring orthotropic material orientation for enhanced heat dissipation. *Hau, York, Rizzello*, and *Seelecke* establish a model-based strategy for scaling the geometry of dielectric elastomer membrane actuators for mechatronics applications. *Ortiz, Zhang*, and *McAdams* introduce a new topology for aluminum foams inspired by the architecture of the pomelo peel and demonstrate its superior impact resistance and damping behavior. In an application very similar to metamaterials, functionally graded materials are designed by spatially arranging multiple material phases to achieve unique combinations of properties; those arrangements are typically enabled by additive manufacturing. *Kirk, Galvan, Malak*, and *Arroyave* introduce a methodology for planning the path of a functionally graded material from one material phase to another while avoiding undesirable intermediate phases.

Finally, several researchers are establishing multiscale, multidisciplinary design exploration and optimization approaches that are particularly appropriate for materials design applications. *Morris, Bekker, Haberman*, and *Seepersad* leverage Bayesian network classifiers for efficient multilevel design exploration of metamaterials and utilize the classifiers for rapid evaluation of manufacturability. *Ghoreishi, Mokeri, Srivastava, Arroyave*, and *Allaire* establish a framework for the fusion of information from multiple computational and experimental sources by exploiting correlations among them and by sequentially querying them via a value-gradient policy. Finally, *Nellippallil, Rangaraj, Gautham, Singh, Allen*, and *Mistree* establish an inverse method for design exploration of process–structure–property–performance spaces that are encountered frequently in materials design.

The papers in this special issue range from microstructural design to metamaterials design to topology optimization to multilevel design exploration. As such, they are representative of the wide variety of emerging research at the intersection of materials and engineering design. It is our hope that the contents of this special issue will continue to stimulate new advances in the design of engineering materials.

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