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Unlocking Insights for High-Performance Materials Design: Sensitivity Analysis and Uncertainty Quantification using novel computational methods

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ABSTRACT:

Additive manufacturing has blurred the line between solids and structures, making it possible to design materials with unique properties and functions known as Architected Materials (AMs). Although AMs have attracted interest from various fields, they remain underutilized due to their sensitivity to defects and imperfections. Moreover, current methods of analyzing and designing AMs are based on deterministic numerical models that do not account for unintended imperfections, limiting their full impact in industrial applications. To address this, new computational approaches are needed to quantify the effect of inevitable uncertainties arising from fabrication, assembly, and actuation in the numerical analysis and design of AMs.

This presentation introduces a new computational technique that enables one to accurately quantify the sensitivity of material parameters and their variability in the mechanical response of AMs. This technique relies on the Finite Element Method (FEM) augmented with the Hypercomplex Automatic Differentiation Method (HYPAD). HYPAD-FEM allows computing highly accurate estimates of arbitrary-order shape, material property, or loading sensitivities with respect to any input parameter in the model without the issues associated with traditional differentiation techniques. This provides new insights into the effects of material parameters in the material response and enables a new moment-based fast Uncertainty Quantification (UQ) technique. The fast-UQ method approximates the probabilistic moments of the simulation outputs using a single simulation run, and it provides the probabilistic importance of the input parameters and their interactions as Sobol indices. Using this approach, one can obtain previously unattainable sensitivity and UQ information in a single simulation run, utilizing all the fidelity of a finite element model. Preliminary results show that our UQ method can reproduce probability density functions with the same accuracy as Monte Carlo modeling and polynomial chaos but at a fraction of the computational cost. Applications of HYPAD-FEM and the fast UQ method in the areas of programmable architected materials, and elastic wave propagation will also be discussed.

Biography:

Dr. Restrepo is an Assistant Professor and Endowed Faculty Fellow in Mechanical Engineering at the Klesse College of Engineering & Integrated Design (KCEID) at the University of Texas at San Antonio. Before his current role, he was a Postdoctoral Fellow at Northwestern University in the Department of Mechanical Engineering. He received his Ph.D. in Engineering from Purdue University in 2015.

Dr. Restrepo's research focuses on advancing the development of new materials with exceptional properties and functionalities. To achieve this goal, his research thrust areas encompass architected materials, additive manufacturing, and bioinspired design. Moreover, his research approach combines computational simulations, theoretical analysis, fabrication, and experimental testing to bridge the gap between theoretical concepts and practical applications. Dr. Restrepo has received several awards for his research, including the prestigious CAREER award from the National Science Foundation. His sponsored research activities include grants from the National Science Foundation, the Navy Research Office, the Army Research Office, and the Air Force.