Special Section: Nonprobabilistic and Hybrid Approaches for Uncertainty Quantification and Reliability Analysis

Computational models have played a crucial role in the transition of a traditional experiment-centered engineering practice toward a virtual design context where the performance of designed components is assessed long before the first prototype is built. Recent advances in numerical approaches enable in this context the application of hyper-resolution, high-fidelity and first principle-based computer simulations which provide an analyst with a plethora of information on the design at hand. However, in most realistic engineering cases, the designer is faced with a multitude of sources of uncertainty on both the actual model form (i.e., the equations that have to be solved) as on the physical quantities that are used to parametrize these models. Such uncertainty stems either from the apparently pure random nature of some physical quantities (e.g., earthquake or wind loadings on a structure or the mechanical behavior of complex materials such as soil or parts produced with Additive Manufacturing), incomplete knowledge on the actual value of these quantities (e.g., stemming from incomplete or too scarce data or future design decisions that yet have to be made), or a combination of both. When uncertainty stemming from incomplete knowledge is involved in the design process, nonprobabilistic and hybrid (also referred to as polymorphic) approaches are gaining momentum for the assessment of the (bounds on the) reliability of designed structures and components, and the quantification of the underlying model response uncertainty. In this context, powerful techniques based on, e.g., the framework of interval or fuzzy calculus, *p*-box formulations, information theory, Dempster–Shafer belief functions or game theoretical foundations have been introduced in the last two decades. However, their application toward realistic engineering applications requires further developments both on a theoretical as well as a numerical/algorithmic level.

Many of the pertinent challenges that have yet to be addressed are related to computational expenses of the methods to propagate these hybrid uncertainties, as well as their quantification based on (indirect) measurement data. As highlighted in a recent overview paper that compares approaches for propagating *p*-boxes [1] (active learning-based) surrogate modeling schemes can have a significant contribution to achieving this goal. Contribution by (Peng et al.) made a step in this direction by introducing an adaptive Kriging model approach.

This special section issue further collects a series of papers that deal with nonprobabilistic and hybrid approaches to deal with these uncertainties. Themes that are touched upon in this issue range from the development of pure interval (Sofi et al.) or fuzzy (Valdebenito et al.) analysis and set-theoretical approaches (Ludwig et al.) over Evidence-theory-based approaches (Boumezerane, D., Hou, Y., and Helton, J.C.) to p-boxes (Rohmer, J., Krymsky and Akhmedzhanov, Fina et al., Auer and Ahrens, and Schietzold et al.) and application domains to which these highly advanced methods include footbridge analysis (Sofi et al.), shell buckling (Fina et al.), system analysis (Helton J.C.) information transport (Auer and Ahrens), material data modeling (Romero et al.), human reliability analysis (Krymsky and Akhmedzhanov), inverse approaches (Bi et al.) and even the design of wooden structures (Schietzold et al.).

With this special section issue, we hope to illustrate in which direction the research of nonprobabilistic research is moving. From the included papers, it is clear that nonprobabilistic and hybrid methods are highly suitable to account for combinations of epistemic and aleatory uncertainty in the definition of (the parameters of) a numerical model. Further, more and more approaches are being developed to effectively deal with subproblems in the definition, modeling and propagation of those models. In this context, the biggest challenge might just as well be selecting the most appropriate modeling technique from the plethora of available methods, given the constraints on the available data. Further, translating these methods toward practical engineering cases, including the incorporation of realistic data sources, remains in many cases an open issue, be it that the data are scarce, missing, corrupted, vague, ambiguous, subjective, diffuse or consist , for instance, of measurements or (potentially conflicting) expert opinions. These data-related challenges are often coined under the mnemonic "MUSIC-3X": multivariate, uncertain, unique, sparse, incomplete, corrupted and 3D-spatially variable. This term was originally introduced to denote geotechnical data [2], but is applicable to almost all fields of modern-day engineering that are faced with real data sources, be it offshore, wind, mechanical, infrastructural or energy engineering, as , for instance, also evidenced by multidisciplinary UQ challenges such as the 2019 NASA Langley UQ Challenge on optimization under uncertainty.

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[2] Ching, J., and Phoon, K.-K., 2020, "Constructing a Site-Specific Multivariate Probability Distribution Using Sparse, Incomplete, and Spatially Variable (MUSIC-X) Data," J. Eng. Mech., **146**(7), p. 04020061.