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"INTEGRATING FINITE ELEMENTS WITH MACHINE LEARNING: GEOENERGY AND STRUCTURAL DIGITAL TWINS APPLICATIONS"

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ABSTRACT

Understanding the mechanics of materials is crucial across geoenergy systems and civil infrastructure, where predictive modeling directly informs risk mitigation, design, and optimization. Despite decades of computational mechanics research, challenges persist in balancing model fidelity with computational efficiency. This talk presents two interconnected directions that leverage machine learning, and advanced numerical methods to address these challenges.

The first part highlights the development of I-FENN, a hybrid framework embedding machine learning directly within the finite element method (FEM). The approach is designed to reduce the elevated computational cost of nonlinear and multiphysics models commonly encountered in subsurface energy applications such as carbon sequestration, and geothermal systems. Within I-FENN, neural networks are pre-trained to approximate selected coupled processes and then deployed inside the FEM loop to accelerate the prediction of state variables. This enables efficient yet accurate simulation of processes such as non-local damage, phase-field fracture, thermoelasticity, and poroelasticity. By combining the efficiency of ML surrogates with the versatility of FEM solvers, I-FENN advances the modeling of fracture–fluid–thermal interactions critical to energy applications. The second part of the talk focuses on structural digital twins, where real-time monitoring and predictive modeling are fused to create dynamic computational counterparts of physical structures. On the digital-to-physical path, a deep operator neural network based on structural mechanics principles enables rapid, accurate prediction of structural response while rigorously enforcing equilibrium and energy conservation through stiffness relationships. On the physical-to-digital path, damage detection is carried out through a multistage pipeline combining signal processing, system identification, and machine learning to localize and quantify deterioration. These ideas are demonstrated on the KW51 bridge in Leuven, Belgium, and ongoing work is extending the framework to infrastructure in Abu Dhabi, UAE.

BIOGRAPHY

Mostafa Mobasher is an Assistant Professor of Civil and Urban Engineering at New York University Abu Dhabi (NYUAD). Dr. Mobasher holds Associated Affiliations with the Civil and Mechanical Engineering departments at New York University, Tandon School of Engineering. Dr. Mobasher is also a Co-PI and the leader of the Energy Research Theme for Sand Hazards and Opportunities for Resilience, Energy, and Sustainability (SHORES) at NYUAD. Dr. Mobasher received his PhD and MPhil Degrees from Columbia University in Engineering Mechanics. Prior to joining NYUAD, Dr. Mobasher was an Associate at the Applied Science Practice of the multidisciplinary consultancy firm Thornton Tomasetti based in New York.

Dr. Mobasher's research is focused on modeling fracture and multi-physical response of manmade and natural materials across spatial and temporal scales. The research contributes to the development of a wide-range of numerical models to address the needs for non-linear modeling of materials subjected to mechanical and multi-physical loading scenarios. Dr. Mobasher's research scope was expanded to explore the integration between the Machine Learning (ML) and Artificial Intelligence (AI) approaches along with well-established computational methods such as Finite Element Method (FEM).