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DIGITAL TWINS FOR INFRASTRUCTURES – FROM MODELS TO DECISION SUPPORT

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ABSTRACT

Digital twins are dynamic digital counterparts of physical assets that enable simulation-driven decision-making by bidirectionally coupling physics-based models (physical twin) with real-world data [1]. Originally emerging from the manufacturing sector within the framework of Industry 4.0, digital twins are now being applied across diverse fields such as healthcare, education, meteorology, and construction [2], as well as critical infrastructures, such as road networks, bridges, wastewater treatment plants, and energy systems – systems that are costly, long-lived, and safety-critical. The digital twins' predictive power and value in operational settings hinge on advanced computational mechanics, real-time simulation capabilities, and robust data-model integration.

Developing reliable digital twins for infrastructures requires extensive interdisciplinary collaboration – bridging domain-specific modeling, numerical simulation, data assimilation, and machine learning to effectively develop and connect sub-models, datasets, and interfaces. Unlike traditional simulation pipelines, digital twins must address real-time performance constraints, online data integration, and dynamic model updating – particularly challenging in high-dimensional, multi-physics, or nonlinear systems. Ensuring robustness and interpretability in safety-critical contexts introduces additional demands on numerical stability, uncertainty quantification, and model hierarchy design.

Topics of interest include, but are not limited to:

- Efficient numerical models (e.g., FEM, ROMs) and scientific machine learning approaches (e.g., PINNs, Neural Operators) for simulating the complex physical asset
- Acquisition, preprocessing, and assimilation of sensor data from real objects and experiments as data source for model calibration and real-time updating
- Coupling of heterogenous models and data into a unified digital representation (e.g., model hierarchies, hybrid physics-data models)
- Twinning approaches to keep the real object and its digital representation consistent
- Digital twin system architectures, deployment strategies, and domain-specific use cases
- Quantification and propagation of uncertainties within digital twins.

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