Abstract

Buildings are undergoing rapid digitalization with the adoption of IoT sensors, smart meters, and advanced control systems. This digital transformation has introduced the concept of digital twins, which can monitor, adapt, and optimize building operation. However, while the concept of digital twins has been successfully adopted in other industries such as manufacturing and aerospace engineering, it has still not reached a mature stage for the building domain.

This thesis introduces an innovative modeling framework as a key component in the construction of digital twin solutions for buildings. The framework is designed for the development of scalable and adaptable energy simulation models with a focus on two major topics: 1) data-driven simulation models and 2) ontology-based semantic models.

To implement this concept, the framework incorporates the SAREF ontology and its extensions, providing a standardized semantic structure for representing building components, systems, and their interactions. A modular, data-driven approach is proposed where individual building components are modeled using either physics-based grey-box models or machine-learning black-box models. A novel method is presented, for the automated assembly of these component models into a complete building energy model, based on the system topology and equipment properties defined in the semantic model. A method for automated model calibration based on actual operational data is also presented.

The added value and potential services unlocked using the framework is demonstrated in several case studies of different types and scales ranging from a single university classroom, and a ventilation system with its central equipment, to a large-scale case of a hospital building. The results demonstrate that the framework can effectively integrate in real-time, detect anomalies, evaluate energy-saving and comfort-improving strategies, and provide actionable insights to building managers. The focus on data-driven models and ontologies ensures interoperability and scalability to potentially expand to large-scale buildings, building clusters, or urban-scale digital twins in the future. Looking ahead, this framework opens the door to more sophisticated applications, such as predictive maintenance and automated control adjustments. As digital twins become more prevalent, this research provides a foundational step toward smarter and more efficient buildings.