ENERGETICS

PNRR FAIR/Eurac Research/DENERG - AI-assisted digital twin framework for enhancing energy management in grid-interactive buildings

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Context of the research activity	This research focuses on developing a framework for the automatic development of digital twins based on standardized ontologies and knowledge graphs (KGs) for buildings and HVAC systems, assisted by Large Language Models (LLMs). It aims to enhance interoperability and optimize the energy use of grid-interactive buildings, leveraging AI-driven insights for improving energy management and regulatory compliance. Progetto finanziato nell'ambito del PNRR M4C2, Investimento 1.3 - Avviso n. 341 del 15/03/2022 - PE00000013 Future Artificial Intelligence Research (FAIR) - CUP E13C22001800001.

	This doctoral research aims to develop an innovative framework that integrates Generative Artificial Intelligence (GenAI) in the development and continuous commissioning of digital twins applied to buildings and HVAC systems to improve operation through real-time optimization. Currently, there is a significant gap in best practices for digital twin development, particularly in addressing interoperability challenges that arise when dynamically integrating multiple building systems and considering interactions of buildings within their context (e.g. indoor environment, users, and grid). Recent advancements, such as the use of knowledge graphs based on standardized ontologies (e.g., ASHRAE223P, Brick), are beginning to address this need. However, developing the necessary digital infrastructure remains a complex, time-consuming process requiring domain expertise. Enhanced by AI assistants built on Large Language Model (LLM), this framework will assist building professionals in multiple key areas, including digital twin generation, real-time optimization, and building's performance assessment, drastically reducing the amount of time required to build the digital infrastructure. The framework will offer real-time recommendations to enhance energy management, focusing on minimizing energy consumption while maintaining comfort.

Objectives	Eventually, the proposed framework will align with established industry standards, such as ISO 52120, Building Automation and Control Systems (BACS) levels, and the Smart Readiness Indicator (SRI). By adhering to these standards, it ensures that the system not only meets regulatory requirements but also effectively integrates with existing technologies and leverages available incentives. Central to this approach is the use of knowledge graphs to standardize data from diverse sources, streamlining the analysis of building systems and facilitating integration with current management platforms. The main objectives of this PhD position are as follows: • Efficient Definition of Knowledge Graphs for Real-Time Interoperability: The first objective is to develop an adaptable and comprehensive ontology-based knowledge graph that accurately represents the structural and functional relationships within building subsystems, with an emphasis on HVAC components and energy management frameworks. This approach will integrate industry standards to ensure regulatory compliance while supporting a scalable data structure compatible with Building Information Modeling (BIM) systems. A key aspect of this objective is to explore the dynamic features of knowledge graphs that can link and integrate building systems with external data sources, such as real-time feedback of the electrical grid and real-time climate data, to provide context-aware recommendations. The challenge lies in designing a flexible yet standardized knowledge graph capable of capturing evolving building data without becoming rigid or overly prescriptive. Success will depend on the knowledge graph's adaptability to new standards, technologies, and variations in building configurations. • Automated Generation of Digital Twin Models for Advanced Applications: The second objective is to leverage the knowledge graph to enable automatic or semi-automatic generation of digital twin models of building and HVAC systems employing both engineering-based models and data-driven models. These digital twins will serve as testbeds for simulations, diagnostics, and optimization, enhancing operational resilience and optimizing energy efficiency without impacting the physical system. This area remains underexplored, particularly regarding real-time dynamic interactions between building energy systems and external environments. • Real-Time Recommendations for Enhanced Energy Management Using Hybrid LLM and Knowledge Graph-Based Assistants: The third objective is to provide adaptive, real-time recommendations for optimizing energy management in grid-interactive buildings by combining dynamic knowledge graphs with digital twin models. These recommendations will include HVAC adjustments and targeted control strategies based on current operational and environmental conditions. Leveraging data on energy usage, occupant behavior, and weather forecasts, the AI assistant will identify high-demand intervals and suggest ways to improve efficiency in line with ISO 52120 and SRI standards. Integrating grid-interactive capabilities, the assistant will also support load shifting and demand response strategies, contributing to grid stability. A key challenge involves balancing the interpretability of LLM-generated recommendations with their accuracy, ensuring transparency in AI-driven decision-making to build trust and drive the adoption of advanced energy management strategies among professionals.

Skills and competencies for the	• Data-driven building energy management; • Energy data analytics technologies; • Building physics and HVAC systems; • Physics-based and data-driven based modeling of digital twins for the built environment and building energy systems;

development of the activity	• Programming skills (Python and R environment are considered preferential); • Knowledge of state of the art of machine learning algorithms; • Knowledge of simulation environment for the assessment of predictive building energy management strategies.