The Faculty of Engineering

POPULAR SCIENTIFIC ABSTRACT

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Generic Digital Twin Development Framework for Enhancing Energy Efficiency and Flexibility in Industrial Production Processes

This research addresses the growing need for energy efficiency and flexibility in industrial production processes in the context of the evolving dynamics of the global energy transition. Several challenges are currently hindering the implementation of energy efficiency and flexibility practices in the industry. The challenges are mainly centred around industries unaware of the potential cost savings and efficiency gains possible through implementing energy efficiency and flexibility practices. Furthermore, due to the complexity and interconnection of industrial production processes, predicting the consequences of integrating energy efficiency and flexibility practices is challenging. These practices' ripple effects on the broader production system are often hard to determine.

To address these challenges, a digital twin development framework is proposed. Through digital twin technology, the implementation of energy efficiency and flexibility practices can be investigated without risk to the production process. This research presents a generic digital twin development framework that provides a structured and systematic approach to designing and implementing digital twin models for these processes. The framework facilitates the investigation of energy efficiency and flexibility opportunities, allowing virtual testing, evaluating strategies, and reducing risks associated with real-world implementation.

This research presents a six-layer digital twin development framework that addresses various parts of the digital twin development process. The framework is divided into a physical twin layer, a data collection protocol layer, a data storage and processing layer, a digital twin layer, a communication and integration layer, and an application layer. Various methods and frameworks are presented with each layer. In the data collection protocol layer, the DEVELOP cycle is introduced as a novel data and information source identification approach. The data storage and processing layer presents an approach to data analytics combining logistical and environmental data from the investigated production process. The digital twin layer is realized as a software framework providing an interface hierarchy and utility package for extending into domain-specific variations, which enables capturing process commonalities and variabilities.

The research presented in this thesis employs a multi-method approach that integrates ecosystem modelling for data and information source identification, data analytics, and multi-method modelling and simulation, including agent-based modelling, discrete event simulation, and system dynamics. Furthermore, examples of multi-criteria decision-making, time series K-means clustering, and multi-objective optimization are presented in the application layer of the framework.

The applicability of the proposed framework is verified using several case studies from different Danish industrial production processes, including two ornamental horticulture processes, meat process cooling, a brewery, and a foundry. These case studies provided diverse applications that verify the framework's ability to develop digital twins in various domains and assess energy efficiency and flexibility.

This research reveals the framework's capacity to develop digital twins for various production processes across domains and identify potential implications of energy efficiency and flexibility practices. The framework examines the consequences of integrating such practices into complex production systems. Furthermore, the results verify the ability of the digital twin framework to communicate with external software systems and digital twins.

This research contributes to the field by introducing a generic digital twin framework that enables a structured and systematic approach to designing and developing digital twin models of industrial production processes for energy efficiency and flexibility assessments. Scientifically, it provides a novel methodology that synergizes ecosystem modelling, data analytics, and multi-method simulation. This approach provides an in-depth

understanding of energy efficiency and flexibility in various industrial domains, offering cross-domain insights and validating the framework's generic nature. The research presents opportunities for industries to optimize energy use, reduce costs, mitigate risks associated with real-world implementations, promote environmental sustainability, and support informed decision-making related to energy efficiency and flexibility practices.