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GREEN-BY-DESIGN: USING DIGITAL TWINS FOR LIFECYCLE SUSTAINABILITY IN INDUSTRY 5.0

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Digital twins—virtual replicas of physical assets, systems, or processes—are emerging as critical tools for sustainable industrial transformation. Integrating real-time data, simulation, and predictive analytics, they enable optimized resource use, innovative process design, and environmental impact reduction. In alignment with the European Union’s *Industry 5.0* vision, digital twins foster human-centric, resilient, and sustainable production systems (EIT Manufacturing, 2021).

At the design stage, they simulate the environmental footprint of materials and product lifecycles. During operations, they monitor emissions, water usage, and waste generation, enabling real-time interventions to improve sustainability metrics (He & Bai, 2021). This capability is particularly impactful in sectors such as chemicals, food processing, and discrete manufacturing.

European initiatives like DigiTwin4Green and programs by the European Institute of Innovation & Technology (EIT) are funding pilots that integrate sustainability KPIs into digital twin platforms (EIT Manufacturing, 2023, 2024). These systems also advance predictive maintenance, circular economy strategies, and worker well-being, supporting EU climate targets.

Challenges persist in data standardization, cross-platform integration, and the computational cost of high-fidelity models. However, advances in edge computing and cloud-native architectures are making scalable deployments increasingly viable (IBM Research, 2025).

This paper outlines methodologies for implementing digital twins in green manufacturing and argues for their formal inclusion in sustainability reporting, certification, and regulatory frameworks.

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