POLITECNICO DI MILANO

PhD in INGEGNERIA GESTIONALE / MANAGEMENT ENGINEERING - 39th cycle

THEMATIC Research Field: COGNITIVE DIGITAL TWIN FOR SUSTAINABLE PRODUCTION SYSTEMS

Monthly net income of PhDscholarship (max 36 months)
€ 1450.0 In case of a change of the welfare rates during the three-year period, the amount could be modified.

Context of the research activity	
Motivation and objectives of the research in this field	The research aims to develop a Cognitive Digital Twin for Sustainable Production Systems (CDT for SPS). This addresses the challenges towards the next generation of sustainable and smart production systems, consisting of proactive and socially intelligent products and assets that (i) meet the requirements of sustainability options and circular lifecycle management and (ii) use collaborative, cyber-physical, operations management approaches. Despite the growing interest in digital twins, research into intelligent and cognitive digital twins has been limited so far. This research takes the position that incorporating intelligence and cognition in a digital twin is a prerequisite to unlock the full potential of this disruptive technology, and to provide seamless integration and collaboration between the physical world and its virtual replica. Therefore, the CDT is expected to promote self-adaptive analysis and proactive/intelligent decision-making enabling to operate on richer knowledge base, and fostering decisional practices ultimately contributing to the overarching goal of sustainability. Digital technologies, such as Internet of Things (IoT) and big data analytics, will enable real-time monitoring and data-driven decision support. Circular technologies will facilitate the implementation of circular economy principles, such as product remanufacturing, recycling, and reuse, reducing waste and minimizing the environmental impact of the production system, ultimately promoting sustainable objectives.

	A fundamental aspect of the CDT for SPS is its ability to enable services throughout the entire production system lifecycle. Through the services it enables, the CDT empowers decision-makers with valuable recommendations. A system-level impact is addressed by considering the performance of assets, products, and processes, at the system level, aligning them with sustainability objectives. In conclusion, the research aims to transform current manufacturing practices by proactively optimizing resources and processes at the system level, thanks to self-aware and socially intelligent assets and products. By achieving these objectives, the CDT for SPS contributes to a more sustainable future, fostering resource efficiency, reducing environmental impact, and promoting socially responsible production systems.
Methods and techniques that will be developed and used to carry out the research	To achieve the objectives of developing a CDT for SPS, the research will employ a range of cutting-edge methods and techniques. In particular, the following main steps and methods are expected to be developed: •Conceptual Architecture of Digital Twin: The development of a high-level meta model for the CDT lays the foundation for its capabilities. This architecture defines the data flow, information exchange, and interactions between the physical production system and its digital twin. By having a well-defined architecture, the CDT can effectively be used for decision-making. •Knowledge Formalization and Conceptual Modeling: To provide decision support, the CDT must possess domain-specific knowledge related to sustainable manufacturing practices. This involves formalizing knowledge in the form of conceptual models specific to the manufacturing domain, with particular emphasis over sustainable manufacturing and circular economy principles. •Data-Driven Algorithms and Solutions: The CDT's ability to analyze vast amounts of real-time data from production processes is essential for decision support. By leveraging data-driven algorithms, the CDT can identify

	patterns, detect anomalies, and predict future trends. The insights enable decision-making aimed at optimizing production parameters, resource utilization, and energy consumption in alignment with sustainability goals. •Test-Bed in Laboratories: Validating the CDT's decision support capabilities in controlled laboratory environments is an expected experimental step. By implementing the CDT as a test-bed in both continuous production and discrete manufacturing scenarios, researchers can assess its performance and effectiveness across different objectives. This validation process ensures that the CDT delivers accurate and reliable decision support services. •Concept Validation through Empirical Investigation: In addition to laboratory tests, real-world validation is necessary to demonstrate the practical value of the CDT. By conducting empirical investigation with industry professionals, the CDT's decision support capabilities can be conceptually validated. This feedback loop allows for fine-tuning the CDT to meet the specific needs and challenges faced by manufacturers in their pursuit of sustainability.
Educational objectives	The doctoral program offers advanced training in the hot topics explored by the scientific community and the industry. The educational objectives of this research encompass fostering research skills, interdisciplinary collaboration at international level, development of domain-specific knowledge, cognitive technology expertise, and decision support abilities, empirical investigation, social impact awareness, and effective communication. Therefore, engaging in this research provides valuable educational opportunities that contribute to the professional and personal growth of the PhD candidate while advancing the field of sustainable and smart production systems. More specifically, the research aims to contribute to a high-skill profile that is able to: •develop critical thinking capabilities regarding the

	opportunities and challenges opened by the green and digital transition to competitiveness, sustainability and circularity of the manufacturing business; •analyze, integrate and contribute to the development of the body of research on Digital Twins, Sustainability and Circularity for industrial engineering; •analyze and evaluate the Digital Twin innovation and the required maturity to support the proficient deployment of proactive intelligence to support decision-making; •develop advanced capabilities to support decision-making in order to enable sustainable production systems by means of Digital Twins.
Job opportunities	High quality research and innovation jobs can be obtained thanks to the professional skills developed during the PhD research. Careers in research organizations, industrial companies, consultancy firms, universities are possible. Specifically, the following jobs could be addressed by the PhD graduate: •research and development in the fields of industrial operations, with specific interest for challenges of the twin transitions (digital and green transition); •industrial engineering for manufacturing innovation and improvement: the PhD graduate will be the right person to lead transition projects in manufacturing companies, assuming a leading role in the transition towards manufacturing practices that embed sustainability and circularity principles and leverage digital capabilities; •advisory and consultancy for those companies that want to invest on the next steps of sustainable, circular and smart manufacturing: the PhD graduate may be hired by consultancy companies which accompany manufacturing companies in their twin transitions; •academic development is also a potential outcome (in Italy and abroad), considering the cutting-edge research and the different knowledge domains related to it.

Composition of the research group	4 Full Professors 1 Associated Professors 11 Assistant Professors 12 PhD Students
Name of the research directors	Irene Roda

Contacts
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Additional support - Financial aid per PhD student per year (gross amount)	
Housing - Foreign Students	--
Housing - Out-of-town residents (more than 80Km out of Milano)	--

Scholarship Increase for a period abroad	
Amount monthly	725.0 €
By number of months	6

Additional information: educational activity, teaching assistantship, computer availability, desk availability, any other information
Funding for educational activities: 5.900,00 Euros for three years. Teaching assistantship: There are various forms of financial aid for activities of support to the teaching practice. The PhD student is encouraged to take part in these activities, within the limits allowed by the regulations. Desk availability: shared use Computer availability: individual use.