MANAGEMENT AND PRODUCTION ENGINEERING

CRT/DIGEP - AI-Enhanced Digital Twin for Virtual Product Development and Lifecycle Optimization in the Healthcare Industry

Funded By	Dipartimento DIGEP FONDAZIONE CRT CASSA DI RISPARMIO DI TORINO [P.iva/CF:06655250014]

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Context of the research activity	The digital transformation of manufacturing and engineering leverages AI, Digital Twins (DTs), and PLM to create intelligent, adaptive environments. AI enables automation, prediction, and optimization, reducing time and improving quality and sustainability. Applied to medical devices, this approach supports personalized, safe, and traceable solutions through simulation, generative design, and XR-based collaboration, enhancing decision-making, validation, and patient-centered innovation.

	The digital transformation of manufacturing systems and engineering processes is driving a paradigm shift in the way products are designed, simulated, and managed throughout their lifecycle. Virtual product development environments, in combination with Product Lifecycle Management (PLM) systems, are increasingly being integrated with Digital Twins (DTs), enabling continuous synchronization between the physical product and its digital counterpart. However, these systems are often limited by static or simulation-based logic and lack dynamic intelligence. In this context, the integration of Artificial Intelligence (AI) models into the virtual product development phase can significantly enhance the capabilities of Digital Twins. By incorporating AI-based functionalities, such as automation, prediction, and optimization, into the DT architecture, the system becomes capable of supporting engineers in decision-making, geometry management, functional validation, and performance prediction. This leads to a drastic reduction in development time, improved product quality, and the promotion of sustainable design strategies. The proposed approach enables the creation of intelligent and adaptive engineering environments that can optimize configurations, suggest design alternatives, and learn from historical data, thereby improving the efficiency and resilience of development processes. These capabilities are especially relevant in fields where products must be highly customized, safe, and regulated, such as in the case of medical devices, where collaboration between engineering and clinical

Objectives	teams is essential. In particular, the application of this paradigm to the surgical and diagnostic domains opens new opportunities for the development of advanced medical tools, surgical planning systems, and diagnostic platforms. Here, the combined use of Digital Twins, high-fidelity virtual simulations, and complex clinical data enables the design of patient-specific solutions, improving accuracy, safety, and traceability throughout the product lifecycle. Unlike traditional design approaches based on iterative physical prototyping and empirical testing, the proposed research adopts a data-driven and model-based engineering paradigm. At its core is the use of Digital Twins as high-fidelity, continuously updated virtual replicas of medical devices or patient-specific anatomical regions. These DTs will serve as platforms for simulation, risk assessment, and design space exploration, supporting the development of adaptive, safe, and regulatory-compliant solutions. Finally, the integration with PLM systems, immersive Extended Reality (XR) environments, and collaborative design platforms will enhance the usability, traceability, and clinical applicability of the proposed methods. These integrated systems will support engineers, designers, and clinicians throughout the entire development lifecycle, from the initial concept to virtual testing and clinical validation, facilitating effective collaboration among all stakeholders and accelerating the adoption of innovative, patient-centered solutions. The goal of the research is to design and implement an AI-powered framework for virtual product development, integrated with Digital Twin and PLM systems. The framework will enable automatic feature recognition, simulation surrogation, design space exploration, and performance prediction in a digital environment. In particular, the PhD candidate will: Develop AI-based systems for the automatic recognition and classification of features in medical CAD models and patient-specific anatomical data. Leverage deep learning techniques to simulate the behavior and performance of surgical and diagnostic tools within virtual environments. Apply generative design methodologies to create solutions that are both functionally optimized and ergonomically efficient. Integrate the framework with Virtual and Augmented Reality (VR/AR) tools and PLM platforms to enable collaborative validation, improved usability, and full design traceability.

Skills and competencies for the development of the activity	The ideal candidate should hold a master's degree in engineering (mechanical, biomedical, industrial, or computer science), with proven knowledge or interest in the following areas: • 3D modeling and CAD • Artificial Intelligence (machine/deep learning, computer vision) • Python, MATLAB, and modern AI frameworks (e.g., TensorFlow, PyTorch) • Digital health technologies and product design processes