Habilitation Thesis Summary:

Hybrid Design and Innovation in Industrial Engineering: Advanced Studies in Additive Manufacturing, Structural Optimization and Personalized Biomechanics

The present habilitation thesis synthesizes a series of original scientific contributions and research directions developed after the completion of doctoral studies, positioning industrial engineering at the convergence of advanced digitalization, functional additive manufacturing, and personalized biomechanics. The work establishes an integrated methodological framework aligned with the Industry 5.0 paradigm, with the overarching objective of validating innovative hybrid design solutions that optimize the Structure–Property–Performance (SPP) relationship in the development of sustainable products and personalized medical devices. The methodological approach is fundamentally interdisciplinary, combining advanced numerical modeling and simulation techniques, such as finite element analysis and generative design, with rigorous experimental protocols focused on tribological characterization, profilometric analysis, and hardness evaluation of polymers processed through Material Extrusion (MEX).

The research systematically investigates the synergy between internal structure, defined by gyroidal infill patterns, and external surface texture on mechanical performance, demonstrating that an optimized infill density maximizes hardness while minimizing friction coefficients for both standard polymers and specialized tribofilaments such as Iglidur. In parallel, the studies elucidate distinct mechanisms of deformation and volumetric failure in flexible thermoplastic polyurethanes, highlighting the influence of induced porosity on structural integrity. In the biomechanical domain, the thesis validates a complete workflow for the design of personalized implants and assistive devices, employing reverse engineering and medical imaging segmentation algorithms to generate anatomically accurate models, thereby contributing to the reduction of intra-prosthetic dislocation risk through geometry optimization based on patient-specific morphology.

From a sustainability perspective, the research confirms the effectiveness of generative design and lattice structures in reducing material footprint for industrial components, while also validating the potential of the circular economy through the conversion of PET waste into functional filament. The scientific relevance of this work is further underscored by the emergence of new research directions, such as the integration of triboelectric nanogenerators into self-powered biomedical devices through controlled surface texturing, thereby strengthening the foundations for the development of a competitive doctoral school focused on translational engineering and industrial sustainability.