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Design Engineering in the Age of Industry 4.0

Industry 4.0 is based on the digitization of manufacturing industries and has raised the prospect for substantial improvements in productivity, quality, and customer satisfaction. This digital transformation not only affects the way products are manufactured but also creates new opportunities for the design of products, processes, services, and systems. Unlike traditional design practices based on system-centric concepts, design for these new opportunities requires a holistic view of the human (stakeholder), artefact (product), and process (realization) dimensions of the design problem. In this paper we envision a "human-cyber-physical view of the systems realization ecosystem," termed "Design Engineering 4.0 (DE4.0)," to reconceptualize how cyber and physical technologies can be seamlessly integrated to identify and fulfil customer needs and garner the benefits of Industry 4.0. In this paper, we review the evolution of Engineering Design in response to advances in several strategic areas including smart and connected products, end-to-end digital integration, customization and personalization, data-driven design, digital twins and intelligent design automation, extended supply chains and agile collaboration networks, open innovation, co-creation and crowdsourcing, product servitization and anything-as-a-service, and platformization for the sharing economy. We postulate that DE 4.0 will account for drivers such as Internet of Things, Internet of People, Internet of Services, and Internet of Commerce to deliver on the promise of Industry 4.0 effectively and efficiently. Further, we identify key issues to be addressed in DE 4.0 and engage the design research community on the challenges that the future holds. [DOI: 10.1115/1.4051041]

Keywords: Industry 4.0, industrial IoT, human-cyber-physical systems, smart manufacturing, operations and services, smart and connected products, design engineering 4.0, design automation, design for manufacturing, design integration, design methodology

1 Frame of Reference[2]

Integration of smart sensors and networked manufacturing systems has given rise to human-cyber-physical manufacturing systems that can address the requirements of individual customers on a global scale [1–8]. The ability to bring together technologies such as Internet of Things (IoT), Big Data Analysis, Machine Intelligence with traditional technologies such as Smart Automation, Supply Chain, Logistics, and Cloud Computing has resulted in a new wave of advances in manufacturing technologies for product realization [9], which are collectively envisioned as Industry 4.0 [10]. Factories conforming to Industry 4.0 will integrate services across the entire manufacturing and operations processes and will be able to adapt to disruptions in real-time, thereby improving the quality of products and services [11]. The vertical integration of IoT and data analytics will enable these factories to optimize supply and logistic networks, implement policies based on predictive instead of reactive behaviors, improve end-to-end throughputs, and provide services and products at a lower cost [12].

Industry 4.0 represents the Fourth Industrial Revolution and provides a framework to address the challenges arising in the integration of cyber systems and physical resources and covers all aspects of manufacturing systems [13], including robust and flexible automation; data collection, analysis, learning and decision-making; distributed production systems; industrial IoT; and supply chain integration. Industry 4.0 is characterized by a digital model of end-to-end supply chain enabled by smart manufacturing processes, and thus provides a mechanism to transfer autonomy from the physical realm to the cyber-physical realm. Cyber representation of physical processes is much more involved than just networking the associated components of the manufacturing system and involves human interaction with the automation, leading to a human-cyber-physical system [14]. Systems realization in the age of Industry 4.0 requires a new paradigm that considers the distributed and networked aspect of the manufacturing processes [15]. The design process must be able to satisfy the structural

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[2]Definitions of the terms used are in the Appendix–Glossary.

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