

Abstract The Industrial Revolution can be termed as the transformation of traditional industrial practices into new techniques dominated by the technologies available at that time. The definition of "sustainability trilemma" a new term coined by the authors, and the reasoning for calling the next industrial revolution "Industry 4.0S" (another new term) rather than Industry 5.0 are also presented. Keywords Industrial revolution . Sustainability . Artificial Intelligence . Internet of things . Collaborative robots . Digital twins . Edge computing . Block chain . Cyber-Physical Systems Received: 18 February 2022 / Accepted: 20 January 2023 / Published online: 5 February 2023 (C) The Author(s), under exclusive licence to Springer-Verlag France SAS, part of Springer Nature 2023 Industry 5.0 or industry 4.0S? Introduction to industry 4.0 and a peek into the prospective industry 5.0 technologies Abirami Raja Santhi^{1,2} . Padmakumar Muthuswamy^{1,2} 1 3 International Journal on Interactive Design and Manufacturing (IJIDeM) (2023) 17:947–979 by various electronic devices. Digital sensors and computers became a part of the shop floor. Although the working conditions improved tremendously during this period, exploitation of labor continued, cities became overcrowded, and widespread pollution and environmental degradation became common across the world. The ongoing fourth industrial revolution which is commonly referred to as Industry 4.0 or 4IR is built upon the third industrial revolution which relied on transistors, sensors, and micro-electronics to generate data. The term Industry 4.0 was coined by German Professor Wolfgang Wahlster, in the year 2011 at the Hannover Fair. It is the digital transformation of manufacturing industries that focuses on automation, interconnectivity, and real-time process optimization using enabling digital technologies such as Internet of Things (IoT), Machine Learning (ML), Artificial Intelligence (AI), Cyber-Physical Systems (CPS), Cloud computing, Additive Manufacturing (AM), Digital twins, Cybersecurity and so on to communicate and control each other [4, 5]. In other words, it can be called the computerization of manufacturing in which advanced digital technologies are married to industrial machines and processes. The interconnection of these technologies into the manufacturing setup is to achieve operational efficiency, productivity, and automation to the highest possible extent [6]. This in turn creates a manufacturing ecosystem that is smart, connected, and driven by data. The fundamental model of Industry 4.0 can be divided into digital or computing technologies that are married with the systems of the physical world. While AI, ML, Big Data, Cloud Computing, and cyber security form a part of the core computing technologies, other technologies such as Automation and Robotics, IoT, CPS, and AM form the physical part. These technologies together realize the benefits of Industry 4.0 systems to enable agile, flexible, and on-demand manufacturing which is an essential part of smart manufacturing or smart factories. While there are tremendous advantages for the industries in implementing these technologies to achieve competitive advantage and higher operational efficiency, there is widespread apprehension about the potential job loss for low-skilled laborers due to the high level of automation which can cause economic imbalance and greater inequality in the society [7]. The various stages of the Industrial Revolution with their timeline, driving force, and technologies are shown in Fig. 1. While the world is still trying to adapt and realize the potential of Industry 4.0, some industrialists and scholars have started envisioning and discussing the next Industrial Revolution, Industry 5.0. If Industry 4.0 is about digitally connecting machines to enable a seamless flow of data and the highest possible optimization, Industry 5.0 is believed to bring humans back into the game for

collaboration and introduce the human touch to manufactured products while simultaneously focusing on sustainable manufacturing [8, 9]. Elon Musk, a visionary entrepreneur and CEO of one of the most highly automated factories in the world, Tesla Inc., has acknowledged the downside of excessive automation through his tweet in April 2018, "Yes, excessive automation at Tesla was a mistake. Humans are underrated". He went on to admit that robots have slowed down production, and humans, not machines, were the solution. This is in line with the predictions that the next big thing would be the collaboration between humans, robots, and digital technologies.

1.1 Need for the study Despite the ongoing adaptation of Industry 4.0 in various sectors and growing discussions on Industry 5.0, this paper aims to provide a brief background on the enabling technologies of Industry 4.0 and their application in various functions of manufacturing industries, the prospective Industry 5.0 technologies and their potential applications Fig. 1 The various stages of the Industrial Revolution 1 3 948 International Journal on Interactive Design and Manufacturing (IJIDeM) (2023) 17:947–979 and attempts to answer the following five research questions (RQ), RQ1. What are the enabling technologies of Industry 4.0 and their application in manufacturing industries? RQ2. What are the socio-economic challenges of Industry 4.0 technologies? Why must the industries overlook these technologies and upgrade to the prospective Industry 5.0 technologies? RQ3. What are the prospective technologies of Industry 5.0 and their application in manufacturing industries? RQ4. What is "sustainability trilemma" and how does Industry 5.0 technologies help to overcome it? Why "Industry 5.0" must be called "Industry 4.0S"? The above questions are answered through various sections of this article. The Sect. 2 introduces the various enabling technologies of Industry 4.0 and their application in manufacturing industries which aims to answer RQ1. The socio-economic challenges of Industry 4.0 technologies and the reason to overlook these technologies and upgrade to the prospective Industry 5.0 technologies are explained in Sect. 3 which answers RQ2. The Sect. 4 of the article discusses the predictions from industry leaders and provides the definitions of Industry 5.0 as quoted by industries and scholars. The scholarly articles related to the prospective Industry 5.0 technologies and their application in manufacturing industries are discussed in Sect. 5 which answers RQ3. The definition of "sustainability trilemma" a new term coined by the authors, the sustainability dimension of Industry 5.0 technologies, and how the industries can embrace sustainable development using the technologies are discussed in Sect. 1.2 Methodology and structure To understand the enabling technologies of Industry 4.0, prospective Industry 5.0 technologies, and their respective application in various functions of manufacturing industries, a comprehensive literature review was performed. The first three industrial revolutions were driven respectively by mechanization, electrification, and automation which had gradually transformed the agrarian economy .into a manufacturing-based economy. To be precise, my mistake. RQ5.6 which answers RQ4