# ROAD TO INDUSTRY 5.0: CHALLENGES AND OPPORTUNITIES

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# ROAD TO INDUSTRY 5.0: CHALLENGES AND OPPORTUNITIES

***Abstract:*** *The application of advanced digital technologies has the greatest potential for innovation in the industry, as demonstrated by Industry 4.0. However, Industry 4.0's technology–centered approach neglects the importance of human impact in its implementation, since this transformation requires new knowledge and skills for engineers and workers alike. The European Commission has introduced the concept of Industry 5.0, which emphasizes the sustainability and resilience of smart manufacturing systems through human–centric production. Thus, Industry 5.0 represents a shift from Industry 4.0, focusing on bringing humans back to the forefront while maintaining the digital agenda to develop human–cyber–physical systems. However, as a new strategy, Industry 5.0 faces a great challenge, where the lack of human resources represents the largest gap. Thus, the present research provides a methodology that supports this strategy shift. In addition, this research addresses the main challenges of Industry 5.0 and provides opportunities for overcoming them based on the developed methodology.*

***Keywords:*** *Smart Manufacturing, Industry 5.0, Human–Cyber-Physical Systems (HCPS), Upskilling*

## 1. Introduction

In the last decade, the global hype around digital transformation in the industry was focused on creating smart, connected manufacturing systems based on Industry 4.0 concept, emphasizing the role of Cyber-Physical Systems (CPS) (Qiao, Liu, Ma, & Liu, 2021). However, the CPS environments, in which physical objects and software are closely integrated via the Industrial Internet of Things (IIoT) empowered by Artificial Intelligence (AI), constrict the human impact on manufacturing (Pacaux-Lemoine, Berdal, Enjalbert, & Trentesaux, 2018). Moreover, recently the European Commission (EC) pointed out that humans are still the most valuable asset of every company: they are dexterous, intelligent, flexible, and creative, and outperform most machines or robots (European Commission, 2019). Thus, it seems that the technology–centered approach of Industry 4.0 has proved improper since the lack of a human impact in the application of Industry 4.0 has been reported (Bajic, Rikalovic, Suzic, & Piuri, 2021; Rikalovic, Suzic, Bajic, & Piuri, 2022). Therefore, it becomes evident that the overall change in the industry has effects that go far beyond technological transformation.

In reply to the paradigm shift, the EC adopted an official document introducing the concept of Industry 5.0 which emphasizes the main role of the research and innovation sector in support of the industry through three core pillars, namely: human–centricity, sustainability, and resilience (European Commission, 2021, 2022). Thus, Industry

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5.0 puts the human aspect back in the center of manufacturing processes proposing the development of Human Cyber-Physical Systems (HCPS) (Bajic et al., 2023).

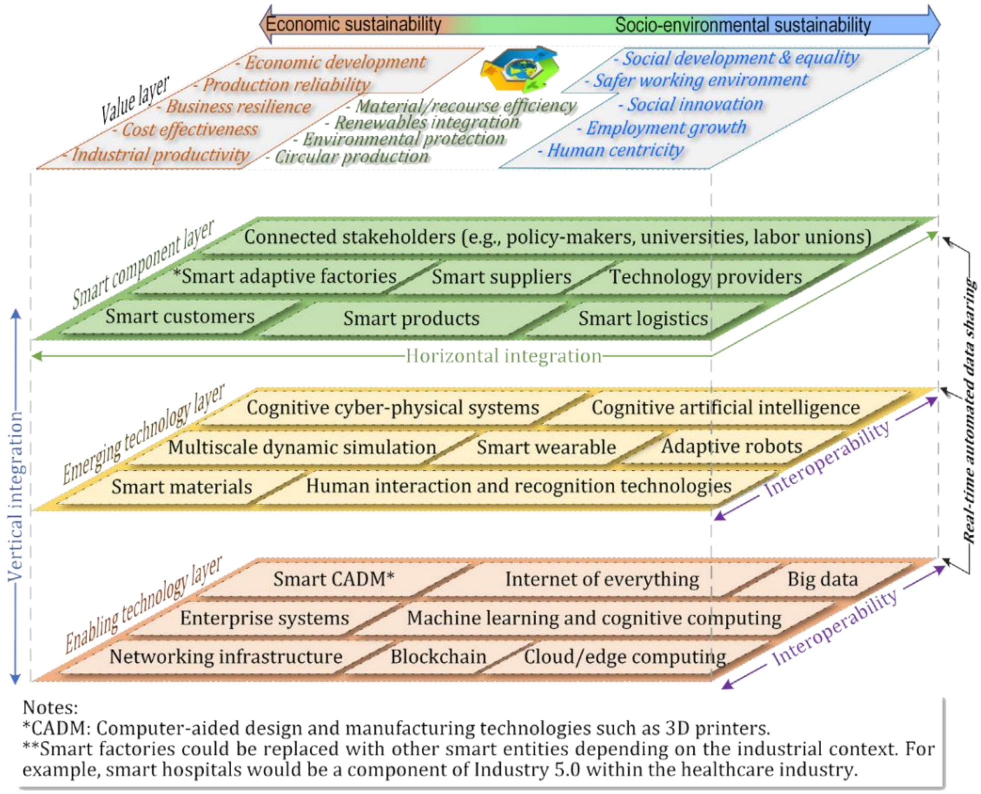


**Figure 1.** The reference model of Industry 5.0 was developed by Ghobakhloo et al., 2022

As a part of the Industry 5.0 concept, the HCPS represents an advanced intelligent system composed of humans— experienced engineers, skilled shop floor workers, and data researchers — implementing the expert domain knowledge in the CPS to achieve a smart manufacturing system by assessing manufacturing data based on AI applications(Bajic et al., 2023; Jabrane & Bousmah, 2021; Maddikunta et al., 2021; Nahavandi, 2019; Zhou, Zhou, Wang, & Zang, 2019).However, this future form of the industry requires new knowledge and skills from both engineers and workers.

Thus, the present research tries to fill the gap and contributes to the existing literature in two ways:1) addresses the main challenges that Industry 5.0 faces and, 2) provides opportunities for overcoming them through the proposed academia–industry collaboration methodology.

The rest of the article is organized as follows. Section 2 provides a theoretical background of Industry 5.0 and HCPS. Section 3 presents the addressed challenges in Industry 5.0, while Section 4proposes the opportunities through developed academia–industry collaboration methodology for overcomingaddressed challenges. Finally, Section 5 derives some conclusions.

## 2. Industry 5.0 and HCPS

The first academic research on the concept of Industry 5.0 dates back to 2016 (Sachsenmeier, 2016) when discussions about the essence of humanity's existence, physical integrity, and relationship with nature were initiated through the emerging field of bionics. After that, many human–oriented initiatives were launched (Demir, Döven, & Sezen, 2019; Nahavandi, 2019; Scanilon, 2018). However, in 2021, the EC adopted an official document presenting Industry 5.0 and emphasizing the main role of the research and innovation sector in supporting industry in its long–term service to humanity(European Commission, 2021).

However, Industry 5.0 is not a new paradigm, but the natural continuation of Industry 4.0. Thus, the transition from Industry 4.0 concept to Industry 5.0 represents a combination of the advantages of a CPS, intelligent machines, and human knowledge, which have a focus on increased productivity, manufacturing resilience, and sustainability(Pizon & Gola, 2023).

Additionally, authors (Ghobakhloo et al., 2022) developed the reference model of Industry 5.0, presented in Figure 1. The reference model describes this phenomenon, explaining its underlying technologies, techno-functional principles, smart components, and values.

Moreover, the official definitions of Industry 5.0 are still abstract ideas generalized from the practices and shortcomings of Industry 4.0, focusing primarily on human aspects(Bajic et al., 2021; Nahavandi, 2019; Rikalovic et al., 2022; Sachsenmeier, 2016), and sustainable and resilient manufacturing processes (European Commission, 2021; Humayun, 2021). Thus,definitions of Industry 5.0 depend on the field of research. In particular, the definition of Industry 5.0, accepted in this research is adapted from(Bajic et al., 2023), and reads as follows:

"Industry 5.0 represents the concept of transition to sustainable and resilient manufacturing systemsfocused on human resources(European Commission, 2021, 2022)and driven by advanced technologies, grouped into categories (adapted from(European Commission, 2020)) for:

- individualized human–machine interaction (including robotics with AI and augmented and virtual reality);
- simulation of the production system (including CPS, digital–twins of products, processes, and entire systems); and
- data transmission, storage, and analysis technologies (including IIoT, cybersecurity, big data analytics (BDA), and Egdecomputing),

to enable the development of HCPS". The Industry 5.0 ecosystem is presented in Figure 2.

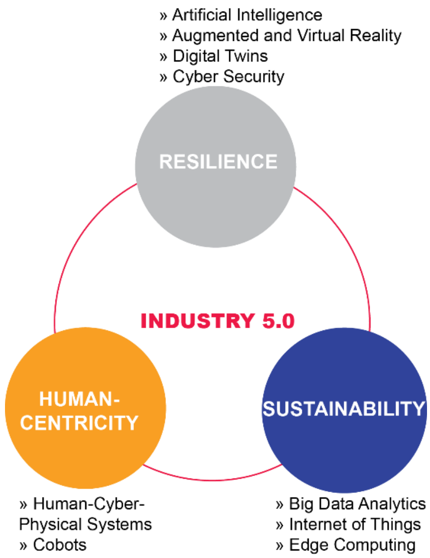


Figure 2. Industry 5.0 ecosystem with three main pillars: human–centricity, resilience, and sustainability (adapted from European Commission, 2020)

Human Cyber-Physical Systems are composed of human experts, cyber systems, and physical components to achieve specific manufacturing goals, i.e.flexibility, resilience, and sustainability (Ji et al., 2018; Kim et al., 2022). Noticeably, we were unable to locate a precise definition for HCPS in the relevant literature, nor did we encounter accurate information concerning the term "human". According to some authors (Coronado et al., 2022; Garrido-Hidalgo et al., 2018), “human” in HCPS denotes a shop floor worker who collaborates with machines, i.e., collaborative robots (cobots)(Jabrane & Bousmah, 2021), whereas other authors (Ji et al., 2018; Pathak, Pal, Shrivastava, & Ora, 2019; Zhou et al., 2019) believe that it refers to human knowledge that is implemented within CPS. Nevertheless, no research was found that highlighted the significance of data researchers as a vital connection between CPS and human domain expert knowledge, empowered by AI. To address this inadequacy in the current definitions, we define HCPS as an advanced intelligent system that encompasses humans, such as experienced engineers, skilled shop floor workers, and data researchers, who implement expert knowledge in CPS to achieve intelligent manufacturing systems based on AI and manufacturing big data(Jabrane & Bousmah, 2021; Maddikunta et al., 2021; Nahavandi, 2019; Zhou et al., 2019) presented in Figure 3.

## 3. Industry 5.0 Challenges

As Industry 4.0 failed to fulfill the industry expectation due to managerial and technological challenges (Bajic et al., 2021; Rikalovic et al., 2022), it is considered that Industry 5.0 will overcome those gaps. However, the majority of unsurpassed challenges from Industry 4.0 present issues in Industry 5.0 as well. Thus, the main challenges can be grouped into three categories referring to the Industry 5.0 pillars, namely:human–centricity, resilience, and sustainability.

Human–Centricity. To achieve human–centric manufacturing, it is essential for every participant in the factory, including both humans and machines, to consistently learn and acquire new knowledge. (Adel, 2022; Gürdür Broo, Kaynak, & Sait, 2022; Lu et al., 2022). Thus, the fundamental prerequisites to Industry 5.0 implementation are related to reskilling and upskilling of experienced engineers and workers. However, the reluctance of workers to embrace change and improve their skills can impede a company's progress in commencing or advancing with the Industry 5.0 implementation (Bajic et al., 2021; Kumar, Bhamu, & Sangwan, 2021).

Resilience.To achieve the relisience of manufacturing systems, the most important is to establish trust within HCPSwhere security presents a challenge in this regard(Adel, 2022; Bajic et al., 2021). The HCPS incorporates a diverse range of cyber technologies (e.g., AI,IIoT, Cloud, Fog and Edge computing, BDA, etc.)that generate, transmit, and handle significant amounts of security and privacy–sensitive data in manufacturing systems, making it susceptible to numerous potential cyber-attacks in the realm of cybersecurity(Wang, Zheng, Yin, Shih, & Wang, 2022). Thus, the integration of AI, IIoT, and automation into HCPS creates security threats, necessitating trusted security measures to protect businesses. The focus of Industry 5.0 applications on information and communication systems leads to stringent security requirements to address security challenges.

**Sustainability**. On the one hand, sustainable development of manufacturing systems seeks the protection of the environment through sustainable products andlogistics to approach the zero–waste objective(European Commission, 2022). In addition to waste prevention, the manufacturing processes mustbe environmentally friendly(Bajic et al., 2021)—for example, by using renewable resources and digital technologies (Bajic et al., 2023).On the other hand, considering human capital sustainability is essential in the realm of smart manufacturing because humans possess a considerable amount of knowledge. Moreover, how stakeholders choose to leverage this knowledge can have a profound effect on transitioning the companyfrom CPS into HCPS (Wang et al., 2022).

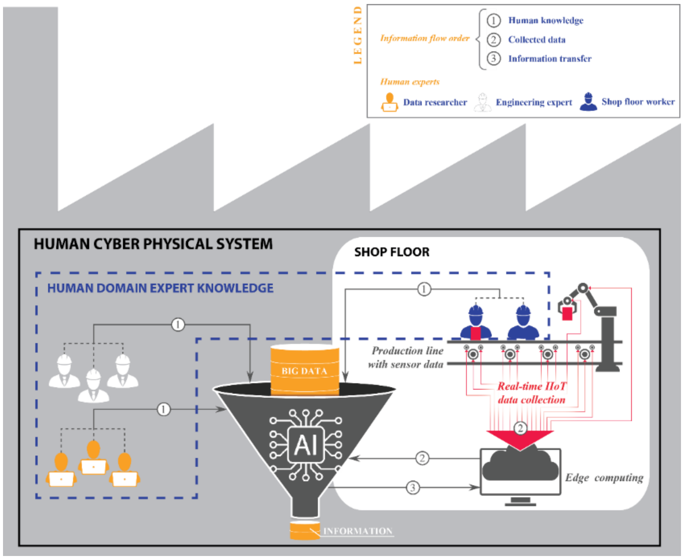


**Figure 3.** HCPS inIndustry 5.0 ecosystem empowered by human domain expert knowledge, AI, and advanced technologies (adapted from Bajic et al., 2023)

## 4. Industry 5.0 Opportunities

In the present section, upon the Industry 5.0 challenges, we derived the opportunities to overcome them. These opportunities are obtained based on the approach of connecting academia and industry to respond to the real needs of manufacturing companies. In addition to the need for digitization to technologically improve companies, a major challenge is also the lack of human resources with adequate skills(Adel, 2022; Bajic et al., 2021; Gürdür Broo et al., 2022; Lu et al., 2022; Wang et al., 2022).Based on these state–of–the–art research papers, the Industry 5.0 opportunities are presented via developed academia-industry collaboration methodology (Figure 3) consisting of the following phases:

***Phase 1: Industry needs analysis*** – represents the collection of relevant information related to Industry 5.0 challenges according to the following steps:

- the industry must determine its specific needs regarding the implementation challenges of the Industry 5.0 concept;
- academia has to do research in the field of implementation challenges of Industry 5.0 that companies have in practice.

The output of this phase will be the aggregate results of all the challenges noted by the industry during the implementation of Industry 5.0. These results are the starting point for addressing the challenges related to the lack of human resources.

***Phase 2: University/LLL course definition***– represents a response to defined needs based on industry needs. Thus, the response to industry needs will be developed in a two–way direction:

- academia has todevelop and improve university courses in accordance to industry needs to teach the next generation of young engineers who will have the skills necessary to develop and implement AI in an HCPS environment of Industry 5.0.
- academia has to develop lifelong learning (LLL) training course for upskilling and reskilling of existing engineers and shop floor workers with AI digital skills and AI-based knowledge to improve:
- lack of Industry 5.0 skilled engineerswith a clear vision of digital skills benefits to industry(Bajic et al., 2021),
- engineers' resistance to knowledge upgrades(Kumar et al., 2021),
- engineeracceptance of AI in manufacturing processes(Angulo, Chacón, & Ponsa, 2023; Nahavandi, 2019).

The results of this phase will be developed courses for students/engineers based on theoretical and practical AI knowledge for implementation of HCPS in Industry 5.0.

***Phase 3: Industry 5.0 engineers***–represents the implementation of developed University/LLL courses and attendance of students/engineers/shop floor workers in relevant courses for the practical application of AI HCPS. Thus, the upskilling should be done based on academia and industry collaboration to design the Industry 5.0 labs for practical education and simulation of AI-based manufacturing for both students and engineers.

The results of this phase will be trained students and engineers with AI knowledge for practical application of Industry 5.0. The first goal of this phase will be training students in the development and use of AI to improve the industry in the direction of HCPSin Industry 5.0. The second goal will be the training of engineers and shop floor workers employed in the industry in the direction of Industry 5.0 so that they can practically and independently apply AI tools to solve manufacturing problems.

The proposed methodology represents a resilient, human-oriented, and sustainable concept for overcoming Industry 5.0 challenges, whereby:

- human–centricity is reflected in the cooperation between academia and industry to transfer and implementstate–of–the–art knowledge in the field of AI with a focus on Industry 5.0, where AI will enable increased levels of automation and human interaction in HCPS environments,
- resilience is reflected in the generation of knowledge within the industry itself, where a new generation of engineers would be able to independently apply and develop AI models,
- sustainability is reflected in the circular process of continuousimprovement of the industry by applying AI skills.

The developed methodology provides opportunities for future academia and industry collaborations. This collaboration will ensure the adaptation of existing needs, both in the industry and academia, for providing knowledge and skills to existing engineers working or students that can work in the future in the companies, able to sustain industry to obtain and apply AI–based to the HCPS solutions.

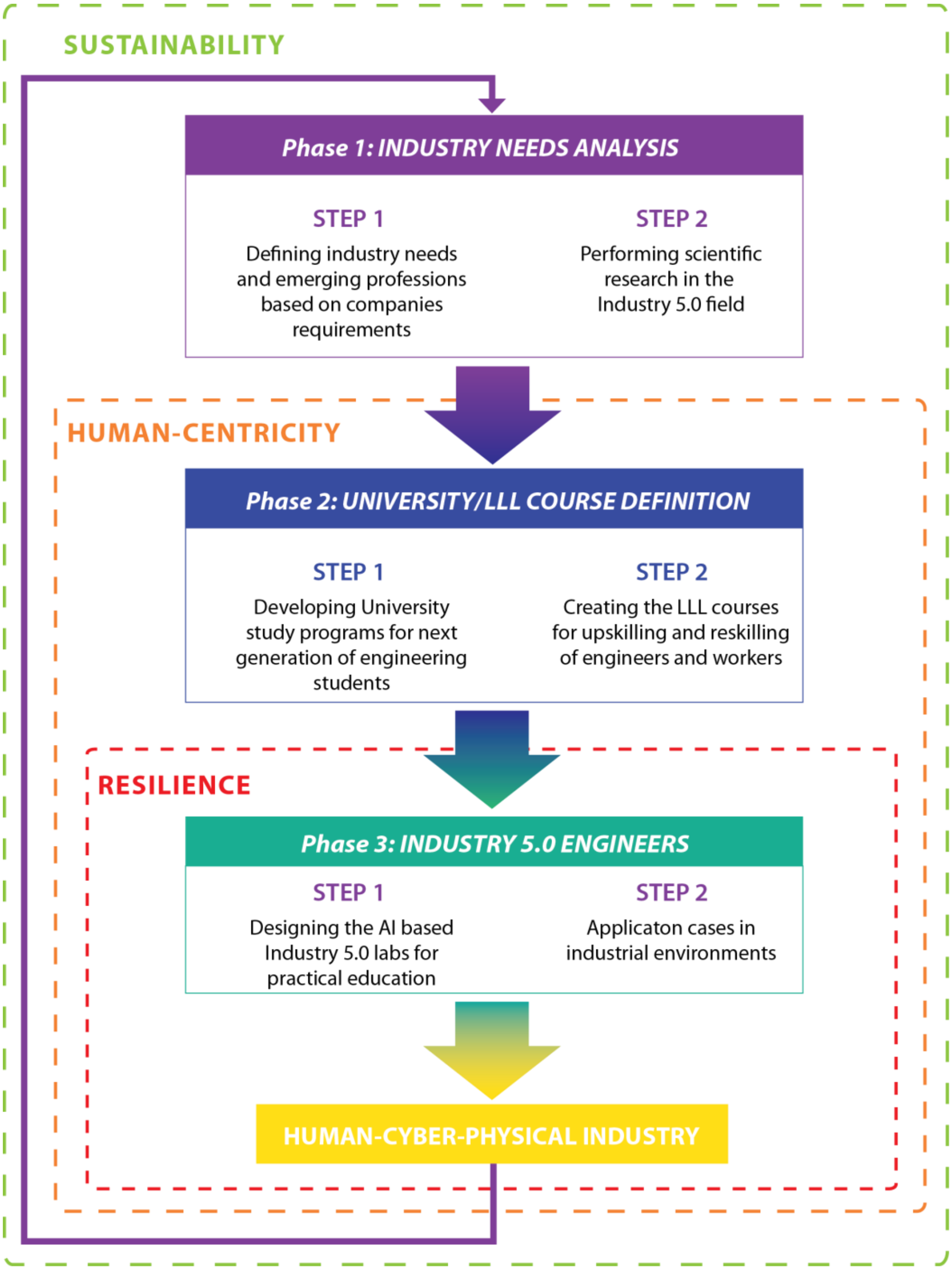


**Figure 3.** HCPS inIndustry 5.0 ecosystem empowered by human domain expert knowledge, AI, and advanced technologies (adapted from Bajic et al., 2023)

## 5. Conclusion

Industry 5.0 represents a shift towards a more human–centric, sustainable, and resilient approach to achieving HCPS production. However, achieving these goals presents several challenges that must be overcome. One major challenge is the need to ensure that human engineers and workers remain at the center of the manufacturing process, with advanced technologies, such as AI, IIoT, BDA, and automation, being used to augment rather than replace workers. This will require a focus on upskilling and reskilling workers, with an accent on designing workplaces that prioritize workers' safety and well–being.

Another challenge is the need to design a resilient manufacturing system in Industry 5.0 with a focus on cybersecurity. Cybersecurity refers to a company's ability to anticipate, withstand, and recover from cyberattacks. It requires a comprehensive strategy of continuous improvement that includes proactive measures, and incident response plans. The goal of minimizing the impact of security incidents on a company can be achieved by using advanced technology (e.g., Edge computing) to ensure that knowledge and data flow will stay within the manufacturing company limiting external intrusions into the system.

Finally, achieving sustainability in the manufacturing industry, with a focus on reducing environmental impacts such as greenhouse gas emissions, waste, and resource depletion. This will require the use of new green technologies, e.g., AI and BDA, that are more efficient. The use of AI and BDA can minimize waste and maximize productivity.

Thus, to solve all of these Industry 5.0 challenges in HPS environments, this research provides the methodology for establishing the collaboration between academia and industry, to develop strategies (i.e., focusing on knowledge upgrading) that can ensure the long–term viability of industrial manufacturing in an uncertain and rapidly changing world.

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