## *SECTION 2*
## CONCEPTUAL AND METHODOLOGICAL BASES OF DESIGN OF DIFFERENT CLASSES OF INFORMATION CONTROL SYSTEMS

*Mozgalli O.P., Doctor of Economic Sciences, Professor, Kyiv National Economic University named after Vadym Hetman,*
*Ustenko S.V., Doctor of Economic Sciences, Professor, Kyiv National Economic University named after Vadym Hetman,*
*Tishkov B.O., Candidate of Economic Sciences, Associate Professor, Kyiv National Economic University named after Vadym Hetman*

# CONCEPTS OF INDUSTRY 4.0 AND INDUSTRY 5.0 BASED ON THE USE OF MODERN INFORMATION TECHNOLOGIES IN APPLIED INFORMATION SYSTEMS

### 1. Introduction

The concepts of Industry 4.0 and Industry 5.0 reflect the evolution of approaches to the use of modern information technologies in production and management. Industry 4.0 refers to the transition to digital transformation, where automation, the Internet of Things (IoT), artificial intelligence (AI) and data big data analysis play a key role in improving efficiency and optimizing production processes. In contrast to the Industry 4.0 concept, Industry 5.0 is defined by human-centeredness and emphasizes the importance of cooperation between humans and machines, where AI and robots complement human labor.

In applied information systems, these concepts are realized through the development of intelligent control systems that combine the power of data analytics, advanced artificial intelligence algorithms, and IoT capabilities to optimize production processes. However, the success of these concepts depends on the ability of companies to adapt to new technologies, train staff to use them properly, and ensure effective cooperation between people and information systems.

## 2. Evolution of the industrial revolutions concepts

The history of industrial revolutions has been going on for the past three centuries, but their intensity has been increasing dramatically over time and causing fundamental changes in the socio-economic space of human life [1–3], as shown in Figure 1.

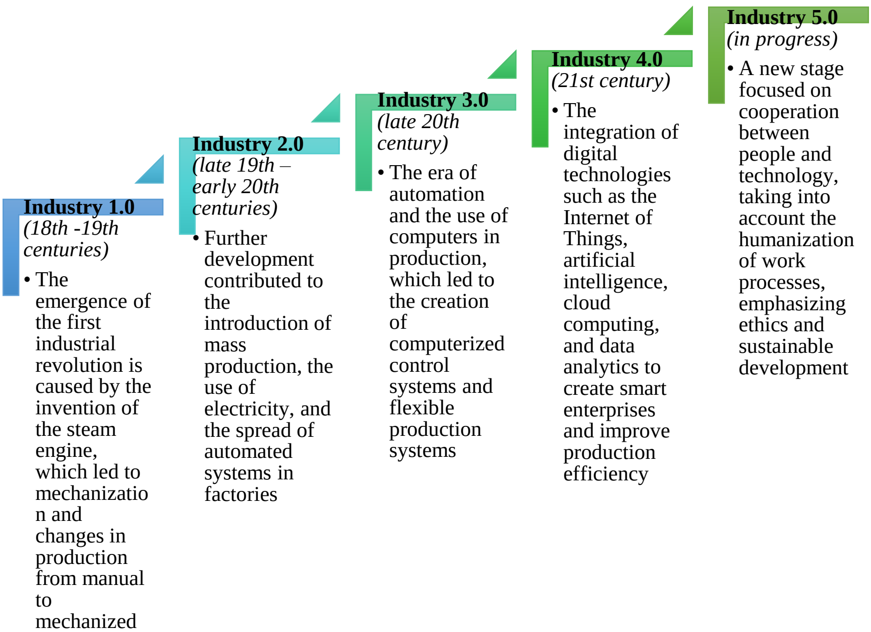


Figure 1. Evolution of industrial revolutions

*Source: compiled by the authors based on [1–3].*

Today, the fourth industrial system is dominated by the main technological achievements of which are additive manufacturing (AM), artificial intelligence (AI), augmented reality, cyber-physical systems, blockchain technologies, cybersecurity, smart manufacturing, smart products, the Internet of Things, cloud services, smart supply chains, and much more. It should be noted that although Industry 4.0 has enormous potential for industrial growth, it poses many challenges, including the potential to negatively affect the sustainability of existing information systems used in various sectors of the economy; requires increased consumption of energy and other resources, which causes climate problems, leads to deterioration of safety standards, etc. The interconnection of machines and resources generates a lot of data, and analyzing this data is one of the new challenges of Industry 4.0, especially in the field of quality management, where this generated data can be used in a variety of ways to track the quality of products resulting from production processes, to optimize the supply chain, etc.

Despite the fact that Industry 4.0 considers sustainable development as one of the most important factors, African countries have little chance of benefiting, as it is believed that the Industrial Revolution 4.0 is unlikely to benefit low- and middle-income countries [1]. There are some examples of Industry 4.0 being more energy efficient [6] but some researchers have found that this concept does not fully meet the goals of sustainable development [7]. But the main problem of Industry 4.0 is not providing the necessary basis to achieve the global goals of Europe and the whole world by 2030, as it creates a technological monopoly in the market and does not consider the needs of individual industries, countries, people, and for effective socio-economic development, it is necessary to take into account future shocks that humanity may face, such as the war in Ukraine, the war in Israel, the Covid-19 pandemic and others, and to increase the focus on the real needs of people in the context of following the principles of sustainable development [7]. Under such conditions, Industry 5.0 can significantly help overcome the challenges faced by Industry 4.0.

## 3. Industry 4.0 concept: technologies and applied information systems

In this part, we will focus on the concept of Industry 4.0 and its inherent technological features.

Industry 4.0 is primarily based on data-driven cyber-physical systems and their use for knowledge integration, so the digitalization of industries is commonly referred to as Industry 4.0 [8]. Industry 4.0 has led to the introduction of many new and advanced technologies, which can be divided into two main classes: basic technologies – technologies that emerged and are inherent in the fourth industrial revolution, and applied technologies – technologies that support functional tasks on the user side (Table 1).

Many different applied information systems have been created and are currently being actively used on the basis of Industry 4.0 technologies, as shown in Fig. 2–6.

*Table 1*

**INDUSTRY 4.0 TECHNOLOGIES**

<table>
<tr><th>Basic technologies</th><th>Applied technologies</th></tr>
<tr><td>1. Internet of Things (IoT). IoT is the interconnection of computing capabilities and network communication with sensors and objects. It uses various communication models, such as device-to-device and device-to-gateway. The maximum potential of IoT can only be utilized if security and privacy issues are addressed [9].</td><td rowspan="2">1. Smart manufacturing. The continuous development of computers and information processing technologies has led to the introduction of smart manufacturing. Automated systems provide information support for material processing. Smart manufacturing promotes the integration of production systems with communication technologies, sensors and modeling [15].</td></tr>
<tr><td>2. Artificial intelligence (AI). AI is the use of computers to simulate intelligent behavior with minimal need for human intervention. It is also often defined as a scientific technique for creating intelligent machines that can make decisions without human intervention [10].</td></tr>
<tr><td>3. Computer Aided Design (CAD). CAD is a technology used to digitally design and manufacture the final product. CAD software is used to create the geometry of an object or product. Parts manufactured using CAD can be produced using subtractive or additive manufacturing [11].</td><td rowspan="3">2. Smart products. A smart product can be defined as a tangible service or software created and capable of self-organize into different intelligent environments throughout its life cycle. This is achieved by improving the interaction between the product and the user and between products through contextual awareness, self-description, proactivity, artificial intelligence-based planning, and machine learning concepts [16].</td></tr>
<tr><td>4. Additive manufacturing (AM). The need for mass customization of products in Industry 4.0 has led to the introduction of additive manufacturing. AB can produce more complex products with advanced features. It can also help in the production of product prototypes [12].</td></tr>
<tr><td>5. Augmented Reality. It is a technology that focuses on enhancing the real-world experience of using a display by making the display environment more interactive and reality-based. It also focuses on improving sound quality and helps to combine virtual and real objects [3].</td></tr>
<tr><td>6. Cloud services are a new technology that can eliminate the need for industry to maintain computer hardware. Thanks to virtualization and time-sharing between resources, clouds meet the needs of a large number of users with diverse needs using a single set of physical resources. Thus, clouds have the potential to provide their owners with economies of scale and become an alternative to in-house clusters and parallel production environments for both industry and academia [13].</td><td>3. Smart supply chain. The overall efficiency of an organization can be improved by better supply chain management. Integrating IoT with the supply chain can help significantly as it allows for real-time tracking of the supply chain. Location tracking can be greatly improved by integrating the supply chain with the Internet of Things, known as the smart supply chain [17].</td></tr>
</table>

*The end of the table 1*

| Basic technologies | Applied technologies |
|---|---|
| **7. Cyber-physical systems (CPS)** are a new generation of systems integrated with computational and physical capabilities that can interact with humans in various new ways. Thanks to computing capabilities, the ability to interact with the physical world extends the capabilities of the physical world through the use of computing and communication. Communication and control are crucial for future technological progress [14]. | |
| **8. Global positioning systems (GPS).** They help GPS receivers to make accurate location calculations and display them. For this purpose, satellites are used to transmit signals [5]. This has significantly improved the ability to determine time and perform complex calculations related to navigation. | **4. Smart buildings.** This technology uses a variety of sensors, communication devices, and other smart devices to automate and control various aspects of the building's interior environment to improve comfort, safety, energy efficiency, and convenience for people, allowing them to manage various aspects of their home or building from anywhere using modern technology [18]. |
| **9. Nanotechnology**. The control over individual atoms or molecules involved in the formation of a macroscale object has improved significantly thanks to nanotechnology, often known as molecular nanotechnology [6]. They have helped improve medical equipment, such as drug delivery systems. They have also helped improve shelf life as well as manufacturing processes. | |
| **10. Sensors and accelerators.** These are devices capable of responding to external stimuli in the form of light, sound, heat, magnetism, and many others and, in turn, producing a response [12]. Sensors perceive physical gestures from the environment and convert them into electrical signals. In contrast, accelerators receive electrical signals and facilitate the transformation of this signal into a specific physical gesture. | **5. Smart work.** Smart work is the flexibility of the work environment and adaptation to various changes that may occur in the work environment. Flexibility of work is the central point of smart work [19]. |

*Compiled by the authors based on [3, 5, 6, 9–19].*

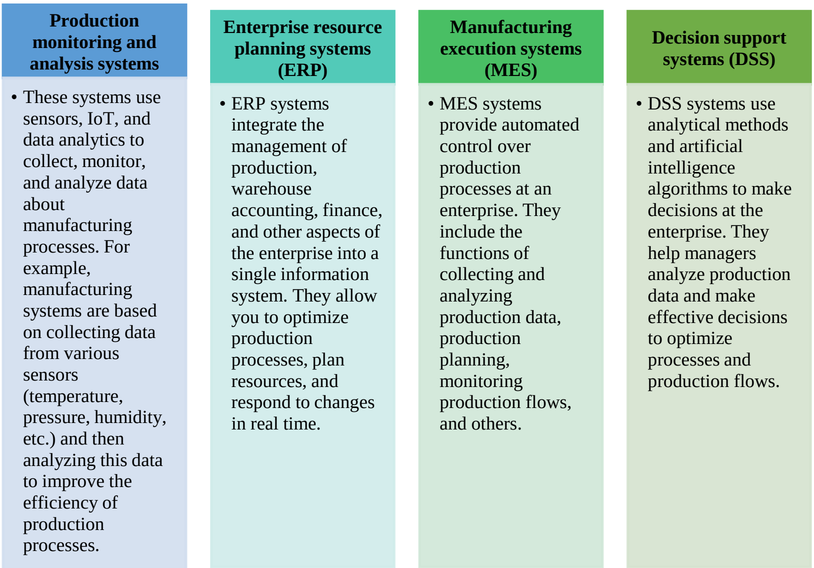


Figure 2. Applied information systems related to smart manufacturing technology

*Source: systematized and compiled by the authors based on [20, 21].*

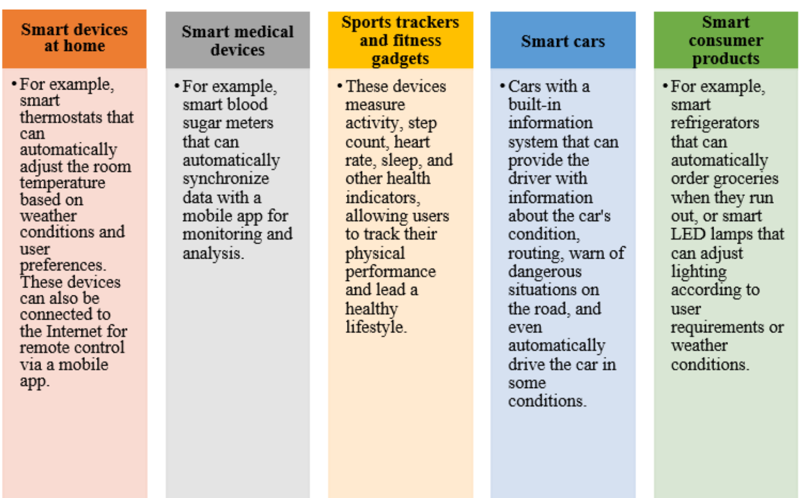


Figure 3. Applied information systems related to smart product technology

*Source: systematized and compiled by the authors based on [22–24].*

| RFID tracking systems | Demand forecasting systems | Inventory management systems | Systems for monitoring and analyzing supplier data | Transportation and logistics management systems |
|---|---|---|---|---|
| • These systems use RFID tags to track the movement of goods from suppliers to end users. They allow you to accurately track the location of goods at each stage of the supply chain and ensure on-time delivery. | • These systems use data on sales, weather, consumption trends, and other factors to predict the demand for goods. They help businesses optimize inventory and plan production based on expected demand. | • These systems are used to optimize the inventory of goods in warehouses and stores. They automate the processes of ordering, receiving goods, inventory, and stock allocation, allowing businesses to manage inventory efficiently and reduce costs. | • These systems allow you to track and analyze supplier data, including their reliability, product quality, delivery times, and other parameters. They help businesses select the best suppliers and optimize their supply chain. | • These systems help plan and track transportation routes, track cargo, and monitor its delivery. They ensure efficient management of transportation resources and reduce logistics costs. |

Figure 4. Applied information systems related to smart supply chain technology

*Source: systematized and compiled by the authors based on [25–26].*

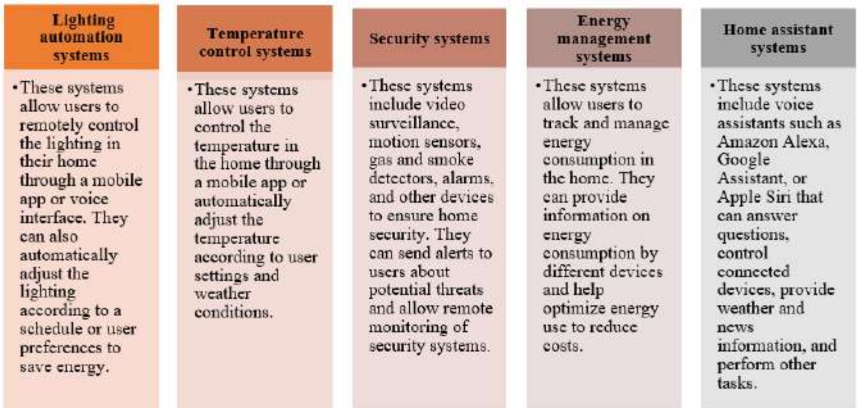


Figure 5. Applied information systems related
to smart building technology

*Source: systematized and compiled by the authors based on [17, 27].*

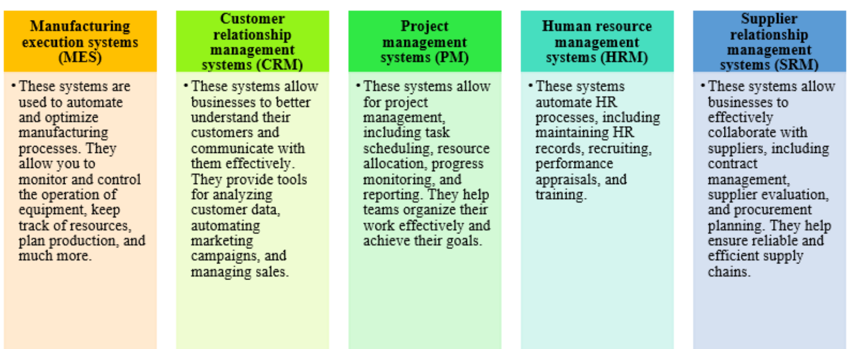


Figure 6. Applied information systems related
to smart work technology

*Source: systematized and compiled by the authors based on [28].*

Along with its high potential for development and positive impact on the organization of global socio-economic processes, Industry 4.0 faces serious challenges, including the problem of technical integration, data and information security, human resources, supply chain management, and threats to product safety and quality (Fig. 7).

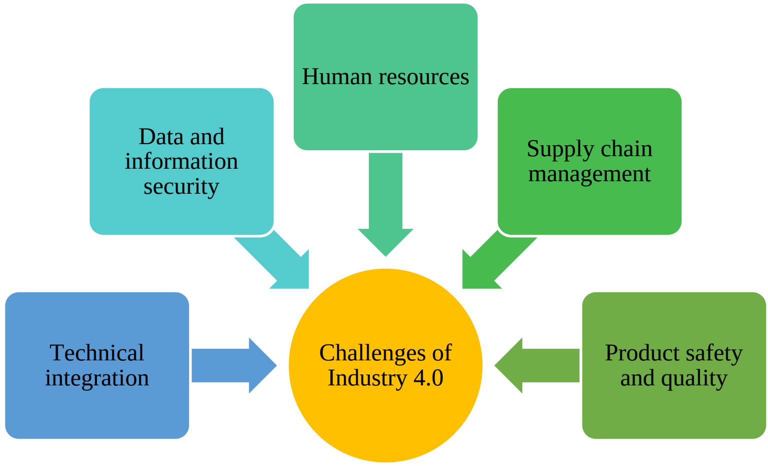


Figure 7. Challenges of Industry 4.0

*Source: developed by the authors*

Thus, one of the important challenges faced by Industry 4.0 is the technical integration. The use of technologies that do not have a potential to cope with digitalization can lead to the manufacturing of low-quality products. Moreover, the introduction of new IT solutions requires additional costs. In addition, standard protocols need to be developed to ensure efficient communication between machines [29].

Data and information security is another major challenge that organizations are facing. IoT can make industries vulnerable to industrial espionage and unauthorized access [29]. In 2016, about 75 % of companies involved in the oil, gas, and energy sectors faced at least one cyberattack, and the continuous monitoring of patients in the healthcare sector also increases the risk of data breaches [30]. The cargo transportation and storage sector also faces threats to data privacy. As shown by B.C. Ervural, B. Ervural (2018), data privacy is one of the most important issues in the freight transportation industry [31]. Consequently, it can be argued that Internet-connected systems, especially IoT-based systems, are more susceptible to cyberattacks [31].

Another challenge faced by Industry 4.0 is the problem of human resources. Employees need to be properly trained to work in rapidly changing environment [29]. It requires good management practices for workers to have the appropriate competencies and professional skills to cope with smart manufacturing. Effective policies can enhance dynamic capabilities, leading to more innovation [32].

Industry 4.0 has also led to specific challenges in supply chains. Supply chains are becoming increasingly digitalized and automated. The accuracy of market forecasting has increased significantly as well as the ability to track products [33]. This has led to shorter planning cycles. However, the results of the study by A.I. Aljumah, H. Shahroor, M.T. Nuseir and G. A. El Refae (2022) show that managing data privacy and integration remains the biggest challenge in supply chain management [26].

The increasing complexity of systems and the use of new technologies sometimes demand on using more capacity and poses a threat to **product safety and quality,** which is another challenge faced by organizations [29].

## 4. Transition from Industry 4.0 to Industry 5.0

The recent changes known as the fifth industrial revolution are intended to address the existing challenges and problems posed by the Industry 4.0 concept and improve its useful technologies and approaches. Some Industry 4.0 technologies remain unchanged, some are being improved, and fundamentally new ones, known as Industry 5.0 technologies, are emerging (Fig. 8).

Thus, the Industry 4.0 supply chain considers strategies as disruptive technologies and various implications for supply chain efficiency and is generally technology-oriented while the Industry 5.0 supply chain considers the balance between people and technology. The Industry 4.0 supply chain is based on mass customization and improvement of the supply chain efficiency through greater transparency, flexibility, reduced waste, and responsiveness. Industry 5.0 aims to maintain these benefits while adding more value through hyper-customization. The supply chain in Industry 4.0 mostly uses the Internet of Things, artificial intelligence, and blockchain technologies while Industry 5.0 uses these technologies with more advanced technological capabilities, especially in the field of AI and the use of cobots [1]. Industry 5.0 also focuses on sustainability in supply chain management [34].

IoT in Industry 4.0 has caused many problems, such as data piracy, hacking, and information leakage. These problems are conceptually solved in Industry 5.0. For example, blockchain technologies are used for the decentralized industrial Internet of Things (IIoT), which integrates data from various resources and services used in smart manufacturing. These individual resources are then used to support the targeted value chain. Thus, it helps to somewhat reduce the intensity of problems associated with network failures and error resolution. Proper use of blockchain in smart contracts can help eliminate the need for third-party registrations or documentation [35]. Smart contracts implemented with blockchain technology can increase the autonomy of Industry 5.0 systems and make them more resilient, as these contracts can reduce dependence on third parties and the requirement for different documentation. Resilient manufacturing strategies can help improve data security, as IIoT contains a lot of critical and sensitive data that needs to be protected [36].

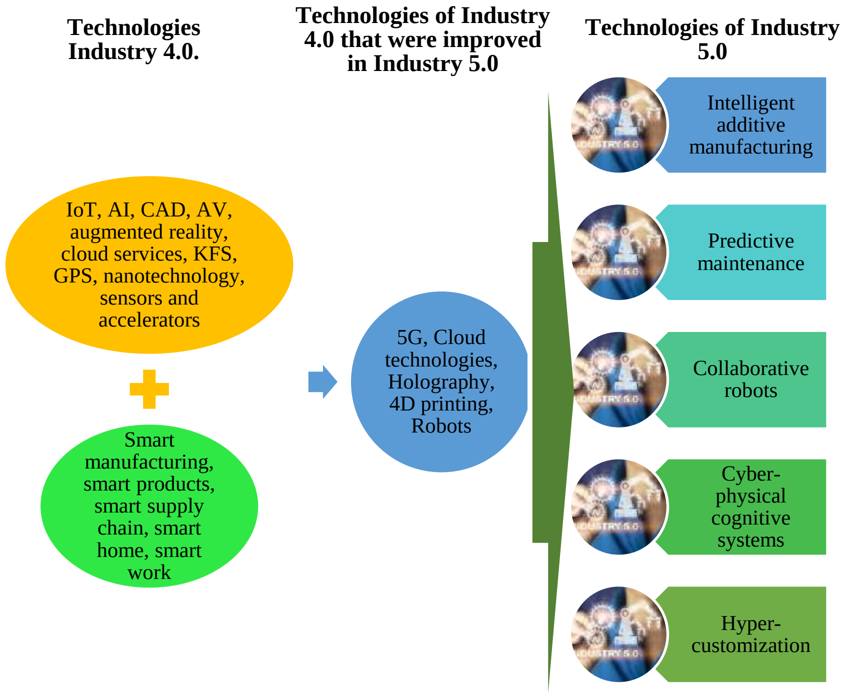


Figure 8. Transition from Industry 4.0 to Industry 5.0 technologies

*Source: generalized and compiled by the authors based on [33–38].*

One of the important challenges of Industry 4.0 is also the issue of technical integration, as technologies will have to cope with the increasing level of digitalization. Nevertheless, Industry 5.0 is human-centered and combines human creativity with machine precision to improve productivity and efficiency. It can also help improve product quality by using robots to perform repetitive tasks [37].

An equally significant challenge of the fourth industrial revolution is the issue of human resources. Industry 4.0 has led to the automation of existing production technologies. Thus, employees need to be trained accordingly. At the same time, Industry 5.0 focuses on human-centeredness and is based on proper communication between humans and robots to achieve the best results in accordance with the given tasks. In this way, they help to increase employee productivity. In addition, workers can be involved in higher value-added tasks without having to perform monotonous work or be involved in dangerous jobs. However, preventive maintenance is a necessary to protect these machines from potential malfunctions [38].

## 5. Development of Society 5.0

The development of industry and technology driven by the fourth and fifth industrial revolutions is actively influencing the social aspects of human development, which are centered on the concept of Society 5.0.

Society 5.0 is a concept that describes the future stage of development of society that actively uses technology to ensure sustainable development and solve social problems; it is aimed at balanced development of people and technology, creation of a favorable environment for living and working, and improvement of the quality of life. The main principles of the Society 5.0 concept are shown in Fig. 9.

Along with the positive changes that the concept of Society 5.0 brings to our lives, there are also challenges that we must properly address, including the following:

– ethical issues, as the development of new technologies such as artificial intelligence, genetic editing, and automation, raise~~s~~ complex ethical questions for society about their use [39];

– inequality due to the uneven distribution of benefits from technological development, which is extremely important to eliminate in order not to deepen the level of inequality in society;

– data privacy and security issues due to the emergence of new threats with the growing level of digitalization, which requires the development and application of effective protection methods;

– environmental challenges caused by the destruction of natural resources and environmental pollution to achieve the goals of technological development [40];

– inaccessibility of digital technologies for less affluent and remote groups of people.

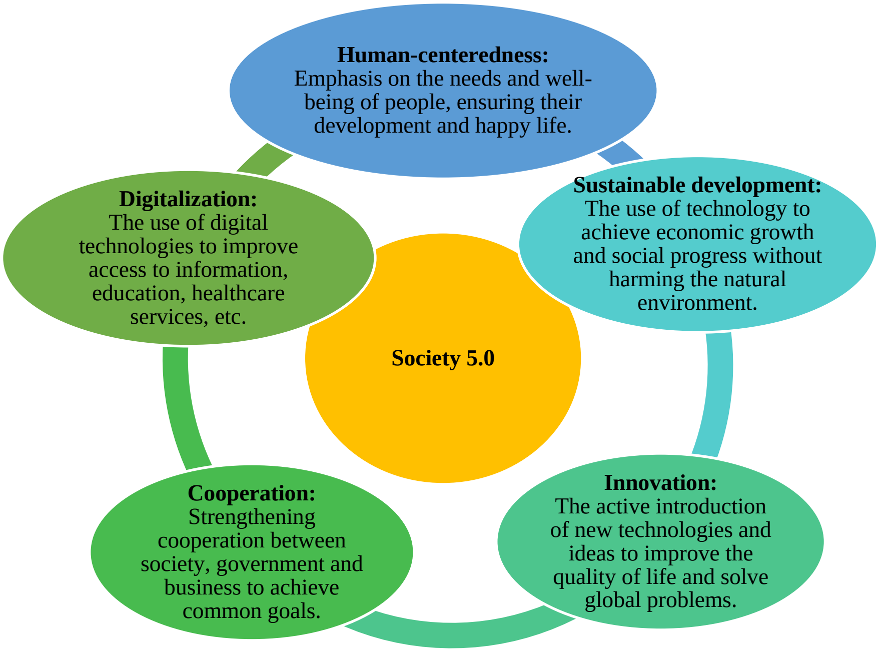


Figure 9. Basic principles of the Society 5.0 concept

*Source: compiled by the authors based on [39, 40].*

## 6. Industry 5.0 concept: advanced information technologies and systems

Industry 5.0 is an attempt to revive the presence of human labor in factories, where humans and machines will work together to increase process efficiency by fully utilizing human intelligence and creativity through their integration with modern intelligent systems [40]. One of the main goals of Industry 5.0 is waste management through recycling. Industry 5.0 includes the interoperability of networked sensor data, an improved version of Industry 4.0 with new additional features. Some of these are intelligent additive manufacturing (AM), predictive maintenance, hyper-customization in industry, cyber-physical cognitive systems, and the introduction of collaborative robots [41]. Let us consider these technologies in more detail.

**Smart additive manufacturing (AM).** Thanks to the potential of artificial intelligence, its use has spread to additive manufacturing. The implementation of AM is a complex process that includes design, parameter selection, planning and control. Information and communication technologies have greatly contributed to the development of additive manufacturing. As noted by Y. Wang, P. Zheng, T. Peng, H. Yang, J. Zou (2020), smart AM can be considered at three levels: market, system, and technological [42].

At the market level, AM can be combined with cloud technologies, and several companies have started selling 3D printing services online. Customers can access resources using AI technologies directly via the Internet. However, this requires the customer to have enough knowledge to make the right decisions and, accordingly, print the right parts needed [43].

At the system level, cyber-physical systems (CPSs) are presented, which have enormous potential. CPSs have been developed for various 3D printers. Data can be processed and optimized in real time to improve the printing process. 3D printers can use previous data to adjust to the task and automatically generate different solutions [44].

At the technological level, the key parameters are the development of information and communication technologies, including cloud computing, 5G, the Internet of Things, and edge computing, which facilitate the collection of large amounts of data and its processing. Humans cannot process such a huge amount of data, so it is necessary to study and research learning agents. These self-learning agents include data collection and efficient computing [42].

Predictable maintenance. Maintenance accounts for 15 to 60 % of the costs associated with operating a production facility [45]. Data collected from various sensors can be used to predict the life of an asset. Predictive maintenance can create a schedule of actions according to the performance of the equipment. Thus, it can help reduce maintenance costs and improve productivity and quality [36]. Industry 5.0 also takes into account human factors. People demand that decisions made in the framework of predictive maintenance are based on forecasting. Predictive maintenance focuses on operational decision-making and should also focus on implementation issues through the Work System model. Predictive maintenance has five stages: signal processing, diagnostics, prognosis, maintenance, decision-making, and actions [38].

Collaborative robots, or cobots, can work with humans and help perform repetitive or dangerous work while humans can do more creative and challenging work. Instead of replacing humans, cobots take over monotonous tasks and help manufacturers increase production. In this way, cobots help to increase productivity and worker safety. In 2014, out of 422,000 robots installed in industry, about

14,000 were cobots. They can be used to automate parts of a production line with minimal changes [46].

The introduction of robots can also face specific challenges, while the acceptance of cobots by workers can only be achieved if they are introduced at the initial stage of the production system [47]. Another challenge faced by cobots is their design. Different aspects that need to be considered when designing cobots are actions, type of robot, interaction technologies, and sensors. The third challenge faced by cobots is the development of an appropriate software architecture. The fourth challenge is to create a user-friendly interface between humans and cobots. In addition, cobots need to be able to detect collisions and be easy enough to control according to the user's needs. There are many infrastructure challenges, as described in detail by V.G. Ivancevic, D.J. Reid, M.J. Pilling (2018), and cobots need to know their workspace well [48].

**Cyber-physical cognitive systems.** Cyber-physical cognitive systems are a subset of trusted autonomy. Furthermore, they fall into three broad categories: physical autonomy, cybernetic autonomy, and cognitive autonomy. It offers many benefits to humans, such as better decision-making, product classification, and various defense applications [49].

Autonomous systems that are trusted can have a significant positive impact on society, including providing assistance to the elderly and helping robots increase the level of trust in them by people. Trust between humans and machines can help increase productivity in various challenging situations [50]. Cognitive-cybernetic symbiosis can help improve the manufacturability of production. They achieve this either by enabling human abilities and skills to interact with machines in the cyber-physical world through an intelligent human-machine interface, meeting the physical and cognitive needs of the operator, or by enhancing the physical senses of the human and their cognitive abilities [51].

**Hyper-customization.** Industry 4.0 has proven to be able to meet the ever-growing demand for customization. Hypercustomization is a concept that uses real-time data to prepare more specific products according to user needs using artificial intelligence and big data. This customization of robot-human integration makes it easier to produce products in large quantities. Hyper-customization and personalization require a shift to flexible manufacturing. Yoram Koren and his team suggest that we are witnessing the emergence of a new manufacturing paradigm, which they call «mass individualization» [41]. This is a concept in which large numbers of individualized products can be manufactured, and each of these products will meet the needs of individuals. This involves developing an open platform for products with defined interfaces for each module [52]. Individualization of production improves the flexibility of both hardware and software components by decoupling physical systems from logical ones [41, 53].

The growing demand for individualization is driving the need for flexible production systems. Introducing modularization into the production line can help meet these requirements. To improve modularity, an open architecture model is used, for example, a relatively new class of machine tools based on fixed standard platforms and customized modules that also follow open architecture models. Also, to achieve the best results, as shown by M. Khan, A. Haleem, M. Javaid (2023), it is necessary to transform the Industry 4.0 manufacturing paradigm into a more decentralized and socialized version of Industry 5.0 to improve the idea of crowdsourcing [1].

## Conclusions

The study analyzes the features of the concepts of Industry 4.0 and Industry 5.0, identifies the challenges facing the fourth industrial revolution, and outlines approaches to addressing them within the next industrial order. It is shown how Industry 5.0 uses new technological advances, such as predictive maintenance, hyper-customization in industry, cyber-physical cognitive systems, and collaborative robots to overcome the challenges of Industry 4.0. Furthermore, Industry 5.0 provides enormous opportunities for research, especially in the areas of security and data integration, which is considered the most significant challenge in IoT.

The main results of this paper are as follows: having considered the evolutionary paths of different industrial revolutions, we can observe the movement of humanity towards total digitalization and human-centeredness, which is confirmed by the modern modes of Industry 4.0 and Industry 5.0. While the Industry 4.0 concept is at the stage of implementing and overcoming the existing problems of this way of life, the Industry 5.0 concept is currently a more theoretical development that only determines the direction of movement in the development of industry, economy and humanity as a whole.

This paper demonstrates how these issues are being addressed in the concept of Industry 5.0, which has introduced more advanced technologies such as predictive maintenance, hyper-customization in industry, cyber-physical cognitive systems, and collaborative robots.

The study categorizes Industry 4.0 technologies and characterizes the challenges associated with them; demonstrates that Industry 4.0 is technology-oriented, while Industry 5.0 implements these technologies through human-centeredness. For example, in the supply chain, where Industry 5.0 retains the benefits of Industry 4.0 and at the same time adds the benefits of robots and cobots, while people remain an integral part of the supply chain.

Another important aspect of this paper is the consideration of the concept of Society 5.0, which is driven by the development of industry and technology based on the fourth and fifth industrial modes and allows combining human creativity and intelligence with the precision and accuracy of machines and technologies.

The study also systematizes and summarizes the applied information systems based on technologies that characterize the achievements of Industry 4.0, as well as shows their limitations and approaches to address them in the context of Industry 5.0 development. Industry 5.0 actually puts the Industry 4.0 approach into a broader context, providing a restorative purpose and focus for the technological transformation of industrial production for the prosperity of people and humanity as a whole, rather than just the growth of economic indicators such as GNP or a company's financial capitalization.

The findings are intended to help researchers and practitioners in various sectors of the economy learn about the various challenges faced by Industry 4.0 and how these challenges can be overcome with the help of Industry 5.0.

Prospects for further research may be focused on work aimed at addressing the existing challenges of Industry 4.0 related to human-centeredness, data security, improvement of technologies for human-robot interaction, and 4D printing technologies. Thus, ensuring the prominent role of human-centeredness will help to increase human productivity and provide meaningful work for employees. If data security issues are overcome, organizations will be able to implement Industry 5.0 principles and technologies more quickly and efficiently, and this will also provide increasing trust in digitalization, which will help employees do their jobs with cobots. As human-machine interaction increases, future work could also focus on developing intelligent control by improving existing pattern recognition algorithms. 4D printing technologies can be improved to provide better print quality, given their huge potential in the prosthetics industry and other industries.

## *References*

1. Khan, M., Haleem, A., & Javaid, M. (2023). Changes and improvements in Industry 5.0: A strategic approach to overcome the challenges of Industry

4.0. *Green Technologies and Sustainability*, *1*(2), 100020. https://doi.org/10.1016/j.grets.2023.100020

2. Vinitha, K., Prabhu, R. A., Bhaskar, R., & Hariharan, R. (2020). Review on industrial mathematics and materials at Industry 1.0 to Industry 4.0. *Materials Today: Proceedings*, *33*, 3956–3960. https://doi.org/10.1016/j.matpr.2020.06.331

3. Leng, J., Sha, W., Wang, B., Zheng, P., Zhuang, C., Liu, Q., Wuest, T., Mourtzis, D., & Wang, L. (2022). Industry 5.0: Prospect and retrospect. *Journal of Manufacturing Systems*, *65*, 279–295. https://doi.org/10.1016/j.jmsy.2022.09.017

4. Mangla, S.K., Kusi-Sarpong, S., Luthra, S., Bai, C., Jakhar, S.K., & Khan, S.A. (2020). Operational excellence for improving sustainable supply chain performance. *Resources, Conservation and Recycling*, *162*, 105025. https://doi.org/10.1016/j.resconrec.2020.105025

5. Jamwal, A., Agrawal, R., Sharma, M., & Giallanza, A. (2021). Industry 4.0 Technologies for Manufacturing Sustainability: A Systematic Review and Future Research Directions. *Applied Sciences*, *11*(12), 5725. https://doi.org/10.3390/app11125725

6. Machado, C.G., Winroth, M.P., & Da Silva, E. H. D. R. (2019). Sustainable manufacturing in Industry 4.0: an emerging research agenda. *International Journal of Production Research*, *58*(5), 1462–1484. https://doi.org/10.1080/00207543.2019.1652777

7. Górny, A. (2023). Developing Industry 5.0 To Effectively Harness Production Capacities. *Management Systems in Production Engineering*, *31*(4), 456–463. https://doi.org/10.2478/mspe-2023-0052

8. Oeij, P. R.A. (2024). Workforce Ecosystems: Reaching Strategic Goals, Partners and Technologies. Elizabeth J. Altman, David Kiron, JeffSchwartz, and Robin Jones. The MIT Press: Cambridge, MA, London, UK, 2023, ISBN 9780262047777, hardcover, pp. 244, e-pub available. *R & D Management*. https://doi.org/10.1111/radm.12683

9. La Diega, G.N. (2022). *Internet of Things and the Law*. https://doi.org/10.4324/9780429468377.

10. Stibbs, P., Woo, J., & Brody, T. (2023). *Utilization of AI-Based Tools like ChatGPTin the Training of Medical Students and Interventional Radiology Residents:* https://doi.org/10.14293/p2199-8442.1.sop-.pftabj.v1

11. Bidra, A.S., Taylor, T.D., & Agar, J.R. (2023). Computer-aided technology for fabricating complete dentures: Systematic review of historical background, current status, and future perspectives. *The Journal of Prosthetic Dentistry*, *109*(6), 361–366. https://doi.org/10.1016/s0022-3913(13)60318-2

12. Prashar, G., Vasudev, H., & Bhuddhi, D. (2022). Additive manufacturing: expanding 3D printing horizon in industry 4.0. *IJIDEM*, *17*(5), 2221–2235. https://doi.org/10.1007/s12008-022-00956-4

13. Iosup, A., Yigitbasi, N., & Epema, D. (2011). *On the Performance Variability of Production Cloud Services*. https://doi.org/10.1109/ccgrid.2011.22

14. Lee, J., Bagheri, B., & Kao, H.A. (2015). A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems. *Manufacturing Letters, 3*, 18–23. https://doi.org/10.1016/j.mfglet.2014.12.001

15. Kusiak, A. (2017). Smart manufacturing. *International Journal of Production Research, 56*(1–2), 508–517. https://doi.org/10.1080/00207543.2017.1351644

16. Fogaça, D.R., Grijalvo, M., Iglesias, A.O., & Neto, M.S. (2024). Institutionalization and framing of Industry 4.0: a framework for understanding stakeholders and comparing countries. https://doi.org/10.1108/bl-01-2023-0026

17. Zhang, A., Venkatesh, V.G., Wang, J. X., Mani, V., Wan, M., & Qu, T. (2021). Drivers of industry 4.0-enabled smart waste management in supply chain operations: a circular economy perspective in china. *Production Planning & Control, 34*(10), 870–886. https://doi.org/10.1080/09537287.2021.1980909

18. Mondejar, M.E., Avtar, R., Diaz, H.L.B., Dubey, R.K., Esteban, J., Gómez-Morales, A., Hallam, B., Mbungu, N.T., Okolo, C.C., Prasad, K.A., She, Q., & Garcia-Segura, S. (2021). Digitalization to achieve sustainable development goals: Steps towards a Smart Green Planet. *Science of the Total Environment*, *794*, 148539. https://doi.org/10.1016/j.scitotenv.2021.148539

19. Kraus, S., Durst, S., Ferreira, J.J., Veiga, P., Kailer, N., & Weinmann, A. (2022). Digital transformation in business and management research: An overview of the current status quo. *International Journal of Information Management*, *63*, 102466. https://doi.org/10.1016/j.ijinfomgt.2021.102466

20. Lu, Y., Liu, C., Wang, K.I.K., Huang, H., & Xu, X. (2020). Digital Twin-driven smart manufacturing: Connotation, reference model, applications and research issues. *Robotics and Computer-integrated Manufacturing*, *61*, 101837. https://doi.org/10.1016/j.rcim.2019.101837

21. Galindo-Salcedo, M., Pertúz-Moreno, A., Guzmán-Castillo, S., Gómez-Charris, Y., & Romero-Conrado, A.R. (2022). Smart manufacturing applications for inspection and quality assurance processes. *Procedia Computer Science*, *198*, 536–541. https://doi.org/10.1016/j.procs.2021.12.282

22. Meneghello, F., Calore, M., Zucchetto, D., Polese, M., & Zanella, A. (2019). IoT: Internet of Threats? A Survey of Practical Security Vulnerabilities in Real IoT Devices. *IEEE Internet of Things Journal*, *6*(5), 8182–8201. https://doi.org/10.1109/jiot.2019.2935189

23. *Smart Home Market Size To Reach $537.01 Billion By 2030*. (n.d.). https://www.grandviewresearch.com/press-release/global-smart-homes-market

24. Almaazmi, J., Alshurideh, M., Kurdi, B.A., & Salloum, S.A. (2020). The Effect of Digital Transformation on Product Innovation: A Critical Review. In *Advances in intelligent systems and computing* (pp. 731–741). https://doi.org/10.1007/978-3-030-58669-0_65

25. Kassab, E.A., Nordin, N., Amlus, M.H., & Ahmad, B. (2022). After Clouds Sunshine: A Theoretical Framework for SMEs Survival amidst

COVID-19 Pandemic. *International Journal of Business & Management*, *10*(8). https://doi.org/10.24940/theijbm/2022/v10/i8/bm2208-027

26. Aljumah, A.I., Shahroor, H., Nuseir, M.T., & Refae, G. a. E. (2022). The effects of employee commitment and environment uncertainty on product quality: The mediating role of supply chain integration. *Uncertain Supply Chain Management*, *10*(4), 1379–1386. https://doi.org/10.5267/j.uscm.2022.7.001

27. *Smart Building Market Size, Share, Competitive Landscape and Trend Analysis Report by Component, Solution type Building Infrastructure Management, Security & Emergency Management, Energy Management, Network Management, Workforce Management, and Waste Management), and Building Type : Global Opportunity Analysis and Industry Forecast, 2023–2032*. (n.d.). Allied Market Research. https://www.alliedmarketresearch.com/smart-building-market

28. Marikyan, D., Papagiannidis, S., Rana, O.F., & Ranjan, R. (2023). Working in a smart home environment: examining the impact on productivity, well-being and future use intention. *Internet Research*. https://doi.org/10.1108/intr-12-2021-0931

29. Kiel, D., Müller, J.M., Arnold, C., & Voigt, K.I. (2017). SUSTAINABLE INDUSTRIAL VALUE CREATION: BENEFITS AND CHALLENGES OF INDUSTRY 4.0. *International Journal of Innovation Management*, *21*(08), 1740015. https://doi.org/10.1142/s1363919617400151

30. Amjad, A., Almusaed, A., & Almssad, A. (2023). Sustainable Smart Cities – A Vision for Tomorrow. In *IntechOpen eBooks*. https://doi.org/10.5772/intechopen.100727

31. Ervural, B.C., & Ervural, B. (2017). Overview of Cyber Security in the Industry 4.0 Era. In *Springer series in advanced manufacturing* (pp. 267–284). https://doi.org/10.1007/978-3-319-57870-5_16

32. Koh, L., Orzes, G., & Jia, F. (2019). The fourth industrial revolution (Industry 4.0): technologies disruption on operations and supply chain management. *International Journal of Operations & Production Management*, *39*(6/7/8), 817–828. https://doi.org/10.1108/ijopm-08-2019-788

33. Ghadge, A., Kara, M.E., Moradlou, H., & Goswami, M. (2020). The impact of Industry 4.0 implementation on supply chains. *Journal of Manufacturing Technology Management*, *31*(4), 669–686. https://doi.org/10.1108/jmtm-10-2019-0368

34. Tao, F., Zhang, H., Liu, A., & Nee, A. Y. C. (2019). Digital Twin in Industry: State-of-the-Art. *IEEE Transactions on Industrial Informatics*, *15*(4), 2405–2415. https://doi.org/10.1109/tii.2018.2873186

35. Ahmad, I., Rodriguez, F., Kumar, T., Suomalainen, J., Jagatheesaperumal, S.K., Walter, S., Asghar, M.Z., Li, G., Papakonstantinou, N., Ylianttila, M., Huusko, J., Sauter, T., & Harjula, E. (2024). Communications Security in Industry X: A Survey. *IEEE Open Journal of the Communications Society*, 1. https://doi.org/10.1109/ojcoms.2024.3356076

36. Yan, J., Meng, Y., Lu, L., & Li, L. (2017). Industrial Big Data in an Industry 4.0 Environment: Challenges, Schemes, and Applications for

Predictive Maintenance. *IEEE Access*, *5*, 23484–23491. https://doi.org/10.1109/access.2017.2765544

37. Wu, D., Jennings, C., Terpenny, J., & Kumara, S. (2016). *Cloud-based machine learning for predictive analytics: Tool wear prediction in milling*. https://doi.org/10.1109/bigdata.2016.7840831

38. Pizoń, J., & Gola, A. (2023). Human–Machine Relationship—Perspective and Future Roadmap for Industry 5.0 Solutions. *Machines*, *11*(2), 203. https://doi.org/10.3390/machines11020203

39. Zengin, Y., Naktiyok, S., Kaygın, E., Kavak, O., & Topçuoğlu, E. (2021). An Investigation upon Industry 4.0 and Society 5.0 within the Context of Sustainable Development Goals. *Sustainability*, *13*(5), 2682. https://doi.org/10.3390/su13052682

40. Mourtzis, D., Angelopoulos, J., & Panopoulos, N. (2022). A Literature Review of the Challenges and Opportunities of the Transition from Industry 4.0 to Society 5.0. *Energies*, *15*(17), 6276. https://doi.org/10.3390/en15176276

41. Maddikunta, P. K. R., Pham, Q.V., B, P., Deepa, N., Dev, K., Gadekallu, T.R., Ruby, R., & Liyanage, M. (2022). Industry 5.0: A survey on enabling technologies and potential applications. *Journal of Industrial Information Integration*, *26*, 100257. https://doi.org/10.1016/j.jii.2021.100257

42. Wang, Y., Zheng, P., Peng, T., Yang, H., & Zou, J. (2020). Smart additive manufacturing: Current artificial intelligence-enabled methods and future perspectives. *Science China. Technological Sciences/Science China. Technological Sciences*, *63*(9), 1600–1611. https://doi.org/10.1007/s11431-020-1581-2

43. Luo, X., Zhang, L., Ren, L., & Lali, Y. (2020). A dynamic and static data based matching method for cloud 3D printing. *Robotics and Computer-integrated Manufacturing*, *61*, 101858. https://doi.org/10.1016/j.rcim.2019.101858

44. Da Xu, L., & Duan, L. (2018). Big data for cyber physical systems in industry 4.0: a survey. *Enterprise Information Systems*, *13*(2), 148–169. https://doi.org/10.1080/17517575.2018.1442934

45. Santos, J., Ferraz, M., Pinto, A., & Nomura, T. (2023). *ACCEPTANCE OF INDUSTRIAL COLLABORATIVE ROBOTS: PRELIMINAR RESULTS OF APPLICATION OF PORTUGUESE VERSION OF THE FRANKENSTEIN SYNDROME QUESTIONNAIRE (FSQ)*. https://doi.org/10.24840/978-989-54863-4-2_0339-0346

46. Prassida, G.F., & Asfari, U. (2022). A conceptual model for the acceptance of collaborative robots in industry 5.0. *Procedia Computer Science*, *197*, 61–67. https://doi.org/10.1016/j.procs.2021.12.118

47. Gualtieri, L., Rauch, E., & Vidoni, R. (2021). Emerging research fields in safety and ergonomics in industrial collaborative robotics: A systematic literature review. *Robotics and Computer-integrated Manufacturing*, *67*, 101998. https://doi.org/10.1016/j.rcim.2020.101998

48. Ivancevic, V.G., Reid, D.J., & Pilling, M.J. (2017). *Mathematics Of Autonomy: Mathematical Methods For Cyber-physical-cognitive Systems*. https://openlibrary.org/books/OL30596319M/Mathematics_of_Autonomy

49. Wang, L., Gao, R., Váncza, J., Krüger, J., Wang, X., Makris, S., & Chryssolouris, G. (2019). Symbiotic human-robot collaborative assem

50. Wang, Y., Zheng, P., Peng, T., Yang, H., & Zou, J. (2020). Smart additive manufacturing: Current artificial intelligence-enabled methods and future perspectives. *Science China. Technological Sciences/Science China. Technological Sciences*, *63*(9), 1600–1611. https://doi.org/10.1007/s11431-020-1581-2

51. Dwivedi, Y.K., Hughes, L., Ismagilova, E., Aarts, G., Coombs, C., Crick, T., Duan, Y., Dwivedi, R., Edwards, J., Eirug, A., Galanos, V., Ilavarasan, P.V., Janssen, M., Jones, P., Kar, A.K., Kizgin, H., Kronemann, B., Lal, B., Lucini, B., Williams, M.D. (2021). Artificial Intelligence (AI): Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy. *International Journal of Information Management*, *57*, 101994. https://doi.org/10.1016/j.ijinfomgt.2019.08.002

52. Leng, J., Chen, Z., Sha, W., Ye, S., Liu, Q., & Chen, X. (2022). Cloud-edge orchestration-based bi-level autonomous process control for mass individualization of rapid printed circuit boards prototyping services. *Journal of Manufacturing Systems*, *63*, 143–161. https://doi.org/10.1016/j.jmsy.2022.03.008

53. Leng, J., Chen, Z., Sha, W., Lin, Z., Lin, J., & Liu, Q. (2022). Digital twins-based flexible operating of open architecture production line for individualized manufacturing. *Advanced Engineering Informatics*, *53*, 101676. https://doi.org/10.1016/j.aei.2022.101676