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A Systematic Review of the Principles Used in Industry 5.0

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Abstract
The aim of this paper is to highlight the development capacity and impact of the specific characteristics and technologies of Industry 5.0 in the field of industrial engineering and other sectors. Simultaneously, their impact and implications in these industrial sectors will have an impact on the manufacturing process, which will lead to the development of new manufacturing strategies through the prism of the three principles proposed by I5.0: human-centricity, sustainability and resilience. The Industry 4.0 concept puts smart technologies at the heart of manufacturing and supply chains. In the meantime, the amplification of this digital transformation and the more meaningful and efficient collaboration between people, machines and systems in their digital ecosystem are described in the specific I5.0 concept principles and technologies identified in this paper. It is therefore important to note that, regardless of how the I5.0 concept is presented, these I5.0 characteristics and underlying technologies will define a new structure of organisation and control over future product lifecycle specific activities.

Keywords
industry 5.0, principles, technologies

1. Introduction

In order to evaluate the paper in question, it is necessary to ascertain the following information: an accurate description of the problem being addressed, a detailed analysis of the existing solutions proposed by other researchers in the field, a comprehensive account of the methodology employed by the authors, the novel contributions made by the paper, and the specific manner in which this paper adds to the existing knowledge base.

The concept of Industry 4.0 has facilitated the advancement of industry and manufacturing through the integration of 'smart' technologies, including artificial intelligence (AI), augmented reality (AR), autonomous robots, cloud connectivity and real-time data analytics. In contrast, the concept of Industry 5.0 is intended to enhance the integration of these technologies through the promotion of enhanced collaboration between humans and machines. The primary objective of this collaboration is to enhance sustainability continuously.

This entails the realisation of activities aimed at satisfying the needs of both the company and its partners, concurrently encouraging product reuse or recycling and enhancing the resilience of new products and systems. Furthermore, the techniques used to improve production processes, such Additive Manufacturing, Artificial Intelligence, and so on, will contribute to enhanced resource management and the resolution of unique challenges related to manufacturing technology, human resource availability, and engineering issues. This includes monitoring of activities and equipment that impact production and addressing security and privacy concerns.

2. Aspects of knowledge and research on Industry 5.0

History. The necessity for unceasing growth in the provision of services and products to satisfy consumer requirements has resulted in the implementation of continuous process improvement, accompanied by the development of well-defined strategies and innovative tools.

The concept of "Industry 5.0" has been developed to describe the latest phase of industrial development. As is widely acknowledged, the industry has undergone significant transformations over time [1, 2], collectively termed 'industrial revolutions', as illustrated in Figure 1. Thus, a period of 100 years elapsed between the initial three revolutions [1]. The fourth occurred within approximately 40 years, and it is conceivable that the fifth will occur in less than 40 years [1]. The time between revolutions is therefore becoming shorter, which may be attributed to the aforementioned continuous increase in demand for services and products [1].

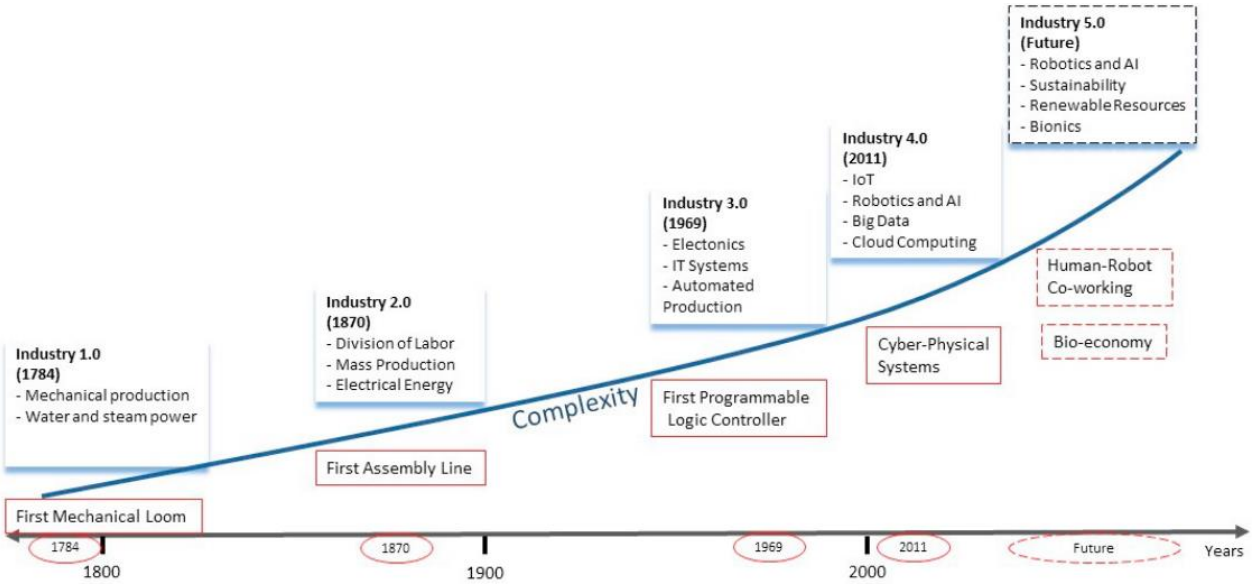

Fig. 1. From Industry 1.0 to Industry 5.0 [1]

The concept of INDUSTRY 5.0 was first proposed in 2015 by Czech researcher Michael Rada [4, 5]. The idea was presented as an evolution based on the principles of industrial upcycling, which is the methodology of systematic waste prevention [3]. Subsequently, in 2021, the European Commission formally introduced the term 'Industry 5.0' in two virtual workshops held on 2 and 9 July 2020 by the Directorate-General for Research and Innovation's Prosperity Directorate. The document entitled 'Industry 5.0' was subsequently published. On 4 January 2021, the European Commission published a document entitled "Towards a Sustainable, Human-centric, and Resilient European Industry" [6, 7].

It may safely be asserted that the advent of Industry 4.0 is still largely a matter of vision, insofar as the evolutionary process that will bring it into being will not become genuinely tangible until the latter half of the next decade. This long-term process also inherently contains a significant degree of uncertainty [8]. For instance, it has been demonstrated that, classified according to size and sector, a surprisingly limited number of enterprises are currently highly familiar with the concept of Industry 4.0. For instance, 35% of large manufacturers (500 to 999 employees) are able to provide a concrete definition of Industry 4.0, whereas only 21% of small manufacturers (20 to 99 employees) and 47% of high-tech companies, and 22% of process manufacturers are able to do so [8].

The advent of the new Industry 5.0 concept can be attributed to a profound transformation in the interplay between humans and intelligent systems [9]. In order to gain an understanding of the concept, its definition and principles, and the general technologies corresponding to this new concept of Industry 5.0, as well as their application in different stages of the industrial engineering field, a comprehensive literature review is required. To this end, databases such as Google Scholar, Scopus and Web of Science were used to find relevant articles using combinations of terms corresponding to the concept "Industry 4."

The literature review encompasses terms up to and including those referring to the new concept of Industry 5.0. It should be noted that the study has not included all articles published on this topic; rather, it has summarised the most recent ones. The information presented is significant and demonstrates progress concerning the new Industry 5.0 concept in the field of industrial engineering, thus providing an overview of the current situation and future directions.

The question of how to define 'Industry 5.0' and the discussions surrounding what is commonly referred to as the 'fifth industrial revolution' present serious limitations to the development of theoretical frameworks [10]. Additionally, the lack of consensus regarding categorisation within the existing literature makes it challenging to conduct meaningful comparative analyses of research studies [11]. A review of the literature on Industry 5.0 reveals significant uncertainty about its potential impact and how it will disrupt business operations. Additionally, there is a question about its capacity to transcend the boundaries between the physical and virtual realms [7].

In an effort to provide a comprehensive definition, some specialists view Industry 5.0 as an opportunity to reclaim and expand beyond the production of goods and services for profit, emphasising three core principles: human-centricity, sustainability and resilience [7].

Industry 5.0 technologies facilitate the optimal utilisation of both virtual and real environments by fostering human creativity and mechanised efficiency.

It is therefore important to understand and define the concept of Industry 5.0 in the context of achieving societal goals that extend beyond the creation or maintenance of jobs, such as becoming a significant contributor to economic prosperity. Furthermore, it is essential to ensure that production respects the limits imposed on the protection and preservation of the environment, while also prioritising the well-being of workers in the industry.

This is a notable shift from the principles underlying Industry 4. This places greater emphasis on digitisation and artificial intelligence-based technologies to improve production efficiency and flexibility, rather than the original principles of social justice and sustainability [1, 12-14].

3. Principles and characteristics of the Industry 5.0 concept used in Industrial Engineering

In general, a principle can be defined as the fundamental element, idea, or basic law on which a theory, system, or rule of conduct is based. Alternatively, it can be understood as the totality of the laws and basic notions that constitute a discipline, its root cause or starting point. With regard to both Industry 5.0 and its predecessor, Industry 4.0, the aforementioned principles and their characteristics describe, as the definition recommends, the smart factory indirectly and propose the inclusion and use of minimum functional requirements.

The implementation of a complete system based on these principles and centred on the needs of the industrial engineering domain represents one of the most important steps towards the realisation and configuration of one's own smart factory, which meets the needs of customers, provides prosperity and sets limits on environmental protection.

In the context of Industry 4.0, the transition from the conventional factory to the smart factory for digitisation, automation, informatisation and mobility is based on three main key processes: vertical integration, horizontal integration and the integrated product lifecycle. These requirements, in conjunction with existing technology, are founded on six fundamental principles [15, 16] (see Figure 2):

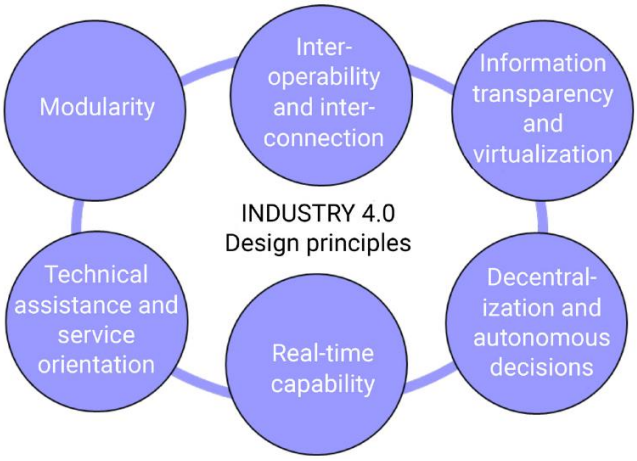

Fig. 2. Six main principles of Industry 4.0 [15]

1. The term "Flexibility (Modularity)" is used to describe the ability of a system to adapt quickly and smoothly to changes and trends in manufacturing practices in industry;
2. Interconnection, or interoperability, refers to the ability of machines, devices, sensors, and individuals to connect and communicate with one another;
3. Virtualisation is a process that combines physical production systems, their digital equivalents and process data to create a virtual factory environment. This environment is capable of monitoring, controlling, simulating physical systems and processes, sending data to update the virtual model in real time, diagnosing and anticipating faults and guiding employees to perform maintenance;
4. The service-orientation design principle entails a shift in focus from product-oriented selling to a more comprehensive approach that encompasses both products and services;
5. The real-time capability of the smart factory is based on the ability to collect and analyse up-to-date data and the use of modularity. This allows the factory to be configured/self-configured to respond in real time to changes from both inside and outside;
6. Decentralized decision-making refers to the capacity of cyber-physical systems to autonomously determine the optimal course of action and execute the requisite tasks.

The requirements set forth by the tenets of the Industry 4.0 concept, as previously outlined, provide a sequential roadmap, emphasizing the integration of autonomous and semi-autonomous procedures, hyper-automation, advanced robotics, self-optimizing systems and data exchange.

The new concept of Industry 5.0 represents the next level of industrialisation. It is characterised by several key features, including the return of the human workforce to factories, distributed manufacturing, smart supply chains and hyper-personalisation.

The objective of these developments is to deliver a personalised customer experience on each occasion. It is evident that the new Industry 5.0 concept serves to complement the existing Industry 4.0 paradigm, with research and innovation driving the transition to a sustainable, human-centric and resilient European industry [17].

Therefore, based on the aforementioned values, fundamentals, ideas, criteria, application rules, and principles (Figure 3), the Industry 5.0 concept can be distilled to three foundational elements that collectively serve as the cornerstone of an industrial system that is:

- human-centred,
- sustainability,
- resilience.

Fig. 3. Core values of Industry 5.0 [6]

3.1. Human-centred

In the current industrial context, scope remains for further progress on the human-centred approach [7]. In order to guarantee that businesses and workers alike benefit from the digital transition, it is imperative that business models are conceptualised and redesigned a new one [7]. It is imperative that workers be included at every stage of this transition process [7].

The human-centred approach prioritises fundamental human needs and interests at the core of the production process, shifting the focus from technology-driven progress to a human and society-centred approach [6]. This approach places emphasis on the importance of empathy, collaboration and a profound comprehension of the user, thereby facilitating the creation of solutions that are more likely to be adopted and genuinely address user needs (Figure 4).

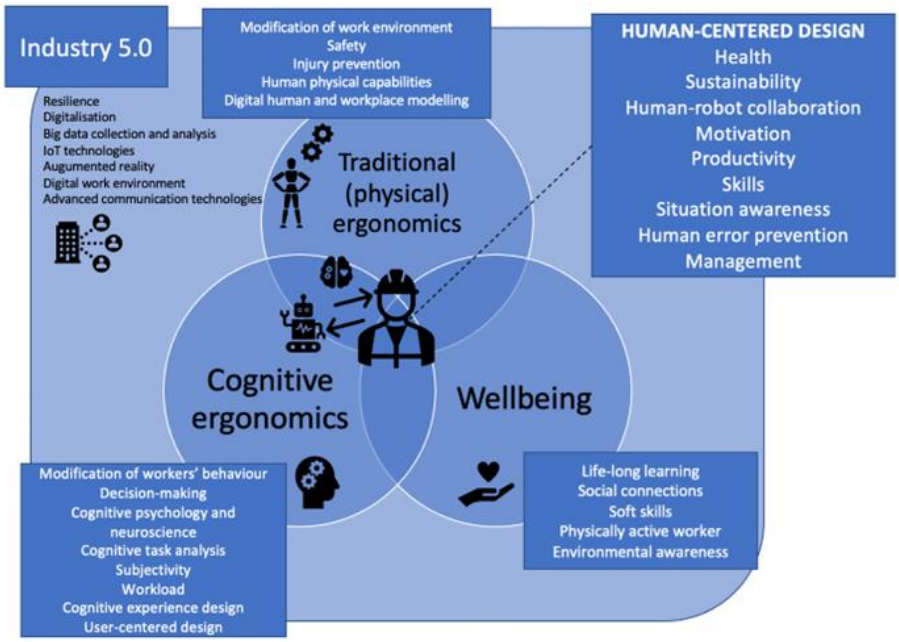

Fig. 4. Cognitive ergonomics in Industry 5.0 framework [18]

The objective of Industry 5.0 is to establish a symbiotic relationship between human capabilities and those of machines, equipment, digital systems and cybernetic systems. This is intended to enhance the efficiency, personalisation and sustainability of production, while safeguarding human value and preventing the creation of divisions between people and technology. Such a transformation could be accompanied by substantial reforms of social policies, including those pertaining to social welfare and health protection systems [7].

The interrelationship between remunerated labour and social security may necessitate reconsideration, accompanied by a review of extant tax systems [7]. In light of the fact that not all workers will be able to secure alternative employment in the context of transformed industries, it is incumbent upon society as a whole to ensure their continued relevance and protection within the social order [7]. Moreover, it can be posited that the digital technologies of Industry 4.0 will be deployed and exploited as Industry 5.0 technologies, albeit with a human-centric focus [19].

The advent of Industry 5.0 in smart manufacturing systems will necessitate a corresponding evolution in the role of the operator. In order to ensure the continued efficacy of these systems, it will be essential to develop a resilient and digitally adept operator base, with due consideration for the human capital that exists within the context of today's industrial reality, particularly the ageing workforce [19]. In light of these observations, it seems reasonable to posit that as long as robots, characterised by relentless precision and artificial intelligence, and other main pillars of the smart factory, despite their advanced capabilities, remain devoid of the critical and creative thinking capacity that is inherent to their human counterparts, they will be capable of fulfilling their designated purpose of assisting and improving our lives through collaborative endeavours.

3.2. Sustainability

The World Conference on the Environment in Rio de Janeiro in 1992 accorded particular attention to this concept, which involves striking a balance between economic growth and environmental protection and identifying alternative resources [20].

The term "sustainability" denotes the capacity to satisfy the requirements of the present without compromising the needs of future generations [21]. The concept of sustainability or sustainable development is fundamental to the endeavour to combine economic progress, social equity and environmental protection in a way that ensures a viable future for both the present and future generations.

The concept of sustainable development has been a central tenet of European policy for some time and is firmly enshrined in the European treaties [7]. Regarding to the protection of the environment through digitisation efforts in the field of recycling, it is now more effective than ever to monitor the flow of materials, assess their environmental impact and so forth.

The Industry 5.0 concept facilitates the attainment of product sustainability through the exploration of diverse avenues, including the comprehension of a company's sustainability accomplishments, the inauguration of a perpetual enhancement procedure, and the resolution of discrepancies between objectives (Figure 5) [22].

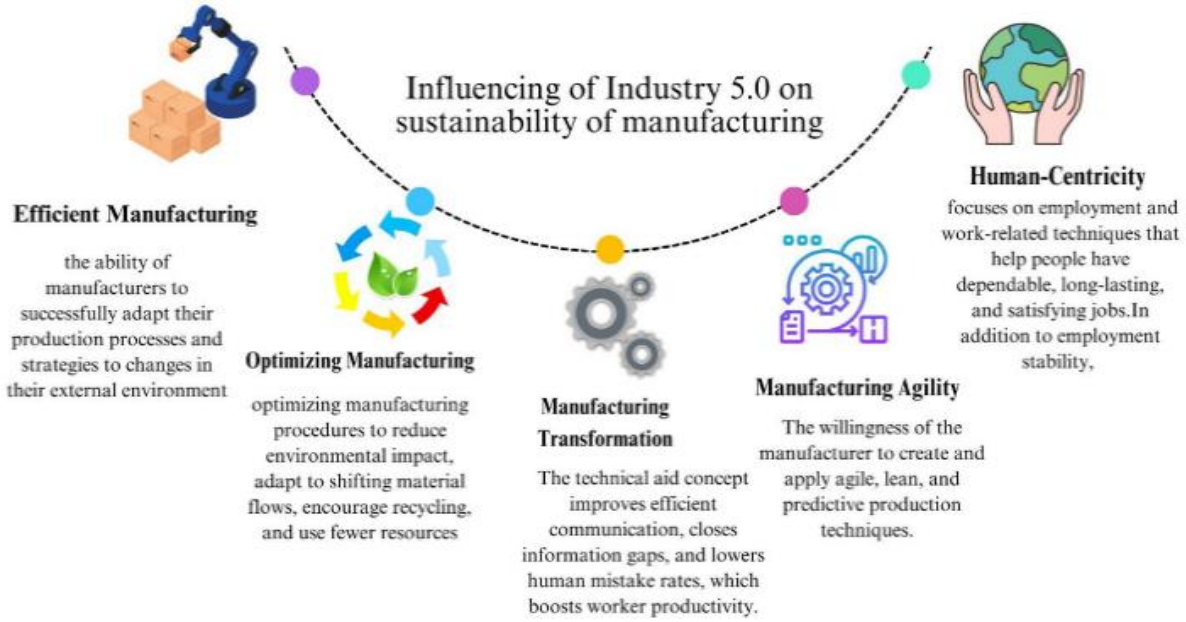

Fig. 5. Role of Industry 5.0 on sustainability of manufacturing [22]

It is therefore evident that the promotion of innovation and the adoption of sustainable technologies represent fundamental aspects of a genuine economic sustainability. Concurrently, the advancement and deployment of technological solutions that diminish the environmental impact will bolster the viability of renewable energies in the long term, thereby enhancing economic efficiency.

Moreover, this economic efficiency ensures the provision of employment opportunities for all members of society. This implies the promotion of inclusiveness and the creation of a business environment that will support the personal and professional development of employees

Consequently, in accordance with the principle of sustainability, which is based on these important values and fundamental elements for industry, there is a need for the development of circular processes that re-use, re-purpose and recycle natural resources, minimise waste and environmental impact, and ultimately lead to a circular economy with improved resource efficiency and effectiveness [6, 7].

A considerable number of European businesses have already acknowledged the advantages of green industry, particularly industrial symbiosis (the sharing and reuse of secondary resources and by-products), not only for the environment but also for enabling industries to compete in global markets and maintain their long-term competitiveness [7].

3.3. Resilience

The term 'resilience' is used to describe the necessity for the industrial production sector to develop a higher degree of robustness, thereby ensuring that it is better equipped to withstand disruptions and to deliver and support critical infrastructure in times of crisis [6]. The future industry must possess the resilience to navigate the complexities of geopolitical shifts and natural disasters [6, 7].

The ability to withstand disruptions and catastrophic events, which relies on people, has not been represented significantly in the context of Industry 4.0 by the research community [23, 24]. At present, the existing literature is predominantly focused on resilience within the context of contemporary technology and the emerging concept of Industry 5.0 [6, 23].

There is a paucity of literature exploring the role of people in resilience. In the developed resilience model, people are identified as one of the most important components, given their role as the first line of detection for anomalies. Their training, education, awareness, leadership, skills and talent are identified as essential factors [23, 25].

In consideration of the third principle of the newly proposed Industry 5 concept, namely resilience, several authors have identified a number of pivotal factors that should be taken into account when striving to enhance industry resilience (Figure 6) [26]:

- Diversification: It would be prudent for businesses to consider diversifying their operations, products, and services. This can assist in the mitigation of the impact of demand shocks in a specific market or product line;
- Technology: The investment in technology can assist businesses in the streamlining of their operations, the reduction of costs and the increase of efficiency. Furthermore, it can assist in reducing reliance on manual labour and enhancing flexibility in responding to demand shocks;
- Risk management: It is recommended that businesses implement a comprehensive risk management strategy to identify and mitigate potential risks [26].

Fig. 6. Understanding Industry Resilience [26]

It can be concluded that an understanding of this principle, which refers to resilience, is essential for those smart factories that wish to become more robust and prosperous in a rapidly changing global economy. This can be achieved by identifying potential risks and implementing strategies to mitigate them. In other words, businesses must be able to meet customer demands even in the face of economic shocks [26].

4. Conclusions

The objective of this paper is to present a topic of general interest within the context of a rigorously researched field such as industrial engineering. The topic addressed is therefore of considerable utility in view of the digital transformation that is transforming the way manufacturing processes are conducted.

We are currently witnessing the advent of an era of digitisation in this field and beyond. The information presented in this paper adheres to the standards of a research paper that outlines the principles and characteristics that have led to the development of the new concept of Industry 5.0. It

also addresses the novelties, challenges, opportunities, restrictions, threats, and implementation concerns that this concept is facing.

It is therefore evident that the Industry 5.0 concept holds considerable importance, as it offers the potential to facilitate the development of a more sustainable and humane manufacturing industry. By placing the human element at the core of the manufacturing process, the Industry 5.0 concept paves the way for the creation of new and more fulfilling employment opportunities for workers, while simultaneously enhancing overall working conditions.

Furthermore, it presents the possibility of developing more efficient and flexible production processes that are better equipped to adapt to changing market demands and supply chain disruptions. It can therefore be concluded that the new Industry 5.0 concept is not a mere passing fad, but rather represents a novel approach to production that will have significant economic and commercial consequences.

Consequently, the industrial sector must modify its production in accordance with the tenets of Industry 5.0 in order to capitalise on its competitive edge, given that the accelerating pace of technological innovation is driving the emergence of new models and the alignment of optimal processes for individual industrial engineering firms. It will be crucial for these entities to embrace the tenets of smart manufacturing to maintain their competitive standing.

References

1. Demir K.A., Döven G., Sezen B. (2019): *Industry 5.0 and Human-Robot Co-working*. Procedia Computer Science, eISSN 1877-0509, Vol. 158, pp. 688-695, https://doi.org/10.1016/j.procs.2019.09.104
2. Pilevari N., Yavari F. (2020): *Industry Revolutions Development from Industry 1.0 to Industry 5.0 in Manufacturing*. Journal of Industrial Strategic Management, eISSN 2588-2732, Vol. 5, is. 5, pp. 44-63, https://sanad.iau.ir/fa/Journal/mgmt/Article/980338
3. Rada, M., Schaller, A. (2024). *The Future of Industry 5.0: A Comprehensive Reflection on Sustainable Industrial Evolution*. In: Gondlach, K., Brinkmann, B., Brinkmann, M., Plath, J. (eds.): *Regenerative Zukünfte und künstliche Intelligenz. SDG - Forschung, Konzepte, Lösungsansätze zur Nachhaltigkeit*. Springer VS, Wiesbaden. https://doi.org/10.1007/978-3-658-43586-8_27
4. Yevsieiev V., Gurin D. (2023): *Comparative analysis of the basic methods used in industry 4.0 and industry 5.0*. Collection of Scientific Papers «ΛΌГОΣ», (September 29, 2023; Bologna, Italy), pp. 113-115, https://doi.org/10.36074/logos-29.09.2023.31
5. Rada M. (2015): https://www.linkedin.com/pulse/industry-50-from-virtual-physical-michael-rada/
6. Xu X., Lu Y., Vogel-Heuser B., Wang L. (2021): *Industry 4.0 and Industry 5.0 – Inception, conception and perception*. Journal of Manufacturing Systems, eISSN 1878-6642, Vol. 61, pp. 530-535, https://doi.org/10.1016/j.jmsy.2021.10.006
7. Breque M., De Nul L., Petridis A. (2021): *Industry 5.0 – Towards a sustainable, human-centric and resilient European industry*. European Commission: Directorate-General for Research and Innovation, Publications Office of the European Union, 2021, https://data.europa.eu/doi/10.2777/308407
8. Heng S. (2014): *Industry 4.0 Upgrading of Germany's industrial capabilities on the horizon*. Current issues, eISSN 1612-3158, Deutsche Bank Research
9. Leng J., Sha W., Wang B., et al. (2022): *Industry 5.0: Prospect and retrospect*. Journal of Manufacturing Systems, eISSN 1878-6642, Vol. 65, pp. 279-295, https://doi.org/10.1016/j.jmsy.2022.09.017
10. Rajab S., Afy-Shararah M., Salonitis K. (2022): *Using Industry 4.0 Capabilities for Identifying and Eliminating Lean Wastes*. Procedia CIRP, eISSN 2212-8271, Vol. 107, is. 11, pp. 21-27, https://doi.org/10.1016/j.procir.2022.04.004
11. Culot G., Nassimbeni G., Orzes G., Sartor M. (2020): *Behind the definition of Industry 4.0: Analysis and open questions*. International Journal of Production Economics, eISSN 1873-7579, Vol. 226, art. 107617, https://doi.org/10.1016/j.ijpe.2020.107617
12. Mao S., Wang B., Tang Y., Qian F. (2019): *Opportunities and Challenges of Artificial Intelligence for Green Manufacturing in the Process Industry*. Engineering, eISSN 2096-0026, Vol. 5, is. 6, pp. 995-1002, https://doi.org/10.1016/j.eng.2019.08.013
13. Mourtzis D. (2021). *Towards the 5th Industrial Revolution: A literature review and a framework for Process Optimization Based on Big Data Analytics and Semantics*. Journal of Machine Engineering, eISSN 2391-8071, Vol. 21, is. 3, pp. 5-39, https://doi.org/10.36897/jme/141834
14. Nahavandi S. (2019). Industry 5.0 – A Human-Centric Solution. Sustainability, eISSN 2071-1050, Vol. 11, is. 16, art. 4371, https://doi.org/10.3390/su11164371

15. Ilanković N., Zelić A., Miklós G., Szabó L. (2020): *Smart factories - The product of Industry 4.0*. Prosperitas, eISSN 2786-4359, Vol. 7, is. 1, pp. 19-30, https://doi.org/10.31570/Prosp_2020_01_2
16. Dikhanbayeva D., Shaikholla S., Suleiman Z., Turkyilmaz A. (2020): *Assessment of Industry 4.0 Maturity Models by Design Principles*. Sustainability, eISSN 2071-1050, Vol. 12, is. 23, https://doi.org/10.3390/su12239927
17. Zhong R.Y., Xu X., Klotz E., Newman S.T. (2017): *Intelligent Manufacturing in the Context of Industry 4.0: A Review*. Engineering, eISSN 2096-0026, Vol. 3, is. 5, pp. 616-630, https://doi.org/10.1016/J.ENG.2017.05.015
18. Trstenjak M., Hegedic M., Cajner H., Tihomir O. (2023). *Cognitive Ergonomics in Industry 5.0*. Chapter, pp. 763-770, DOI:10.1007/978-3-031-38165-2_88, in book: *Flexible Automation and Intelligent Manufacturing: Establishing Bridges for More Sustainable Manufacturing Systems* (Proceedings of FAIM 2023, Vol. 2: Industrial Management), ISBN 9783031381645
19. Alves J., Lima T.M., Gaspar P.D. (2023): *Is Industry 5.0 a Human-Centred Approach? A Systematic Review*. Processes, eISSN 2227-9717, Vol. 11, is. 1, https://doi.org/10.3390/pr11010193
20. United Nations Conference on Environment & Development, Rio de Janerio, 1992. https://www.un.org/en/conferences/environment/rio1992
21. Shohin Aheleroff S., Huang H., Xu X., Zhong R.Y. (2022): *Toward sustainability and resilience with Industry 4.0 and Industry 5.0*. Frontiers in Manufacturing Technology, eISSN 2813-0359, Sec. Sustainable Life Cycle Engineering and Manufacturing, Vol. 2, https://doi.org/10.3389/fmtec.2022.951643
22. Hussein G.S., Zaied A.N.H., Mohamed M. (2023): *ADM: Appraiser Decision Model for Empowering Industry 5.0-Driven Manufacturers toward Sustainability and Optimization: A Case Study*. Neutrosophic Systems with Applications, eISSN 2993-7159, Vol. 11, pp. 22-30, https://doi.org/10.61356/j.nswa.2023.90
23. Crnjac Zizic M., Mladineo M., Gjeldum N., Celent L. (2022): *From Industry 4.0 towards Industry 5.0: A Review and Analysis of Paradigm Shift for the People, Organization and Technology*. Energies, eISSN 1996-1073, Vol. 15, is. 14, art. 5221, https://doi.org/10.3390/en15145221
24. Kemper H.-G., Hoffmann M. (2014): *Application-Pull and Technology-Push as Driving Forces for the Fourth Industrial Revolution*. https://api.semanticscholar.org/CorpusID:196403003
25. Morisse M., Prigge C. (2017): *Design of a Business Resilience Model for Industry 4.0 Manufacturers*. Twenty-third Americas Conference on Information Systems, Boston, https://core.ac.uk/download/pdf/301371962.pdf
26. *** (2024): *Industry Resilience: Building Robustness to Withstand Demand Shocks*. FasterCapital, 2024, June 13. https://fastercapital.com/content/Industry-Resilience--Building-Robustness-to-Withstand-Demand-Shocks.html