INNOVATIVE AND SUSTAINABLE ENTREPRENEURSHIP BASED ON INDUSTRY 5.0. EXPECTED BEST PRACTICES, INSIGHTS, AND PATHWAYS

Adrian PETRE

Bucharest University of Economic Studies, Bucharest, Romania
petreadrian10@stud.ase.ro

Abstract
Industry 5.0 highlights the need for synergy between digital technologies and human factors, to meet sustainability objectives and resilience within modern production systems. The general objective of this paper is to generate a representation of the research conducted so far on the topic of Industry 5.0, intending to ultimately understand whether researchers' perspectives indicate the capability of Industry 5.0 to support innovative and sustainable entrepreneurship, as well as to see the most representative application areas and the main boosters. The research methodology used is mainly based on bibliometric analysis. The general results indicate, first of all, that sustainability is one of the main insights in scientific research on the topic of Industry 5.0. On the other hand, advanced digital technologies, such as blockchain, digital twins, and artificial intelligence, are the main enablers of the new industrial revolution, and the areas in which they can be implemented are diverse. Finally, we highlight as limitations of this work the fact that the data were taken from a single database, as well as the reduced number of search criteria. As a follow-up to this work, potential future research is proposed, namely identifying the most representative enablers of Industry 5.0 depending on the implementation sector.
Keywords: Industry 5.0, Sustainability, Enablers, Insights, Entrepreneurship.
DOI: https://doi.org/10.24818/beman/2025.S.I.5-04

1. INTRODUCTION

Industry 5.0 represents the next stage of the evolution of Industry 4.0, a holistic approach that emphasizes the synergistic evolution of technology and people in order to achieve sustainable and resilient goals. Industry 5.0 proposes cooperation between humans and robots to innovate economic processes and their efficiency in organizations while supporting the principles and requirements of sustainable development.

This field of research is still at an early stage, with scientific studies mainly based on conceptual analysis.

Thus, the proposed objective of this paper is to analyze the research trends on this topic, to observe what are considered the perspectives of Industry 5.0, and if sustainability is confirmed as one of them, and on the other hand, what are the potential fields of application and the main enablers, so that we can

understand if, how and for what types of activities there are the most indications that innovative and sustainable entrepreneurship can be developed in the context of the new industrial revolution.

The structure of the paper is as follows. In Section 2 is briefly described the literature regarding Industry 5.0. In Section 3, the research methodology is presented. In Section 4, the results and key findings are highlighted. The paper ends with Section 5, with the conclusions and some limitations.

2. LITERATURE REVIEW

Industry 5.0 is defined in several ways, and according to Breque, De Nul and Petridis (2021) the central elements that characterize this industrial revolution and that underlie its definition are human-centricity, sustainability, and resilience.

Maddikunta et al. (2022) present the new industrial revolution as a concept created to harmonize workspaces and increase the efficiency of both employees and technologies.

Nahavandi (2019) states that employee efficiency can be boosted by the fact that once many of repetitive activities are undertaken by technologies, people can be stimulated to carry out creative activities and collaborate innovatively with integrated robots.

Asif, Searcy and Castka (2023) conceptually highlight the role of Industry 5.0 in achieving ESG objectives, and explain how technologies associated with Industry 5.0 (blockchain, machine learning, AI, digital twins, IoT, cloud computing) contribute to solving ESG challenges, such as authenticity, customizability, efficacy, retrospective reporting and cost. Such technologies are particularly analyzed in many types of research related to the evolution of business models. For example, Csősz (2022) discusses the capabilities of blockchain (using as a case study an insurance company), and Popescu (2023) explains the potential of AI technologies in the development of digital marketing.

Regarding sustainability, Leng et al. (2022) believe that Industry 5.0 does not place a balanced emphasis on all three pillars of sustainability, considering also very important the economic part.

Broo, Kaynak and Sait (2022) emphasize the need to adapt engineering education to the requirements of Industry 5.0 and propose four strategies in this regard: lifelong learning and transdisciplinary education, understanding the implications of new technologies on sustainability and resilience, extending digital fluency to data fluency and developing communication and collaboration between humans and intelligent systems.

The need to develop people's skills following the requirements of the new industrial revolution and to adapt educational programs appears as a fundamental requirement in many scientific research, including Leon (2023), Poláková et al. (2023), Koch et al. (2025) or Lagorio and Cimini (2024).

On the other hand, Lu et al. (2022) identified several social challenges ("technology acceptance and trust", "change of team dynamics," and "lifelong learning") and technical ("human-centric AI and personalized AI," transparency and explainability', 'performance measure' and 'manufacturing system research') in the process of transition to Industry 5.0, while Kour et al. (2024) discuss cybersecurity challenges.

Further, Mukherjee, Raj and Aggarwal (2023) identified one of the most important barriers, namely the cost and funding. Additionally, Ghobakhloo et al. (2024) consider that it is imperative for Industry 5.0 goals that different groups, such as companies, worker unions, governments, regulators, and tech providers, work together efficiently. The role of the government in this transition process is also highlighted by Hsu et al. (2024), who consider government involvement as one of the main enablers of Industry 5.0.

Studies related to the applicability of Industry 5.0 are growing, with its potential implications being researched in areas such as the pharmaceutical sector (Sharma et al., 2022), healthcare (Basulo-Ribeiro and Teixeira, 2024), smart manufacturing (Javaid and Haleem, 2022), agriculture (Haloui et al, 2024), education (Supriya et al., 2024) or circular supply chain (Dwivedi at al., 2023).

3. METHODOLOGY AND DATA

The research methodology in this paper is mainly based on bibliometric analysis.

The data used in the analysis were collected from the Web of Science (WoS) platform by "Industry 5.0" topic (title, abstract, keyword plus, and author keywords), are related to the 2020 - 2025 period, and refer to publications (written in English) classified in the following four categories: article, review article, proceeding paper and early access.

Based on these data, we initially analyzed the evolution over time of the number of scientific research on the mentioned topic, the ten most representative published works according to the number of WoS Core Collection citations, the geographical distribution of works published in the reference period, as well as their distribution according to the field (the ten most relevant fields).

Next, we applied author keywords co-occurrence network analysis using VOSviewer software to observe some of the main current trends regarding the potential areas of applicability of Industry 5.0, the insights, and the pathways. The type of analysis was co-occurrence, and the unit of analysis was author keywords. The threshold regarding the minimum number of occurrences of a keyword was 2. If certain keywords were very similar, only one form was kept.

4. RESULTS

Regarding the number of scientific publications (article, review article, proceeding paper, and early access) on the "Industry 5.0" topic, we observe an upward trend in the 2020 – 2024 period (we believe that this trend will continue in 2025), with an exponential increase in 2024, demonstrating its importance and the growing interest of researchers in discovering characteristic elements like capabilities, enablers, barriers or limitations (Figure 1).
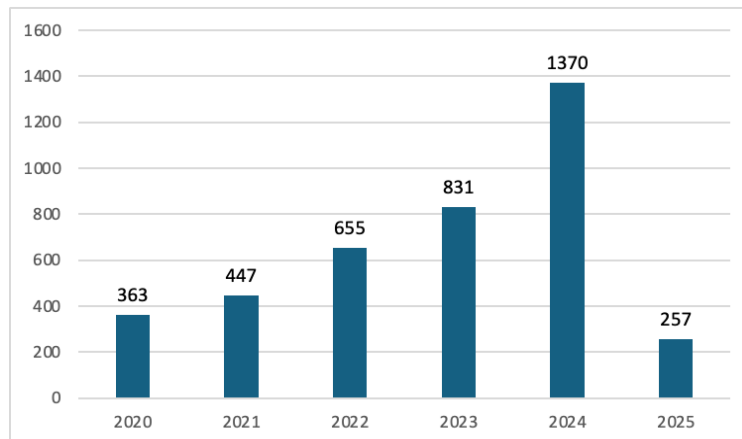
FIGURE 1. THE NUMBER OF SCIENTIFIC PUBLICATIONS ON "INDUSTRY 5.0" TOPIC OVER THE 2020 - 2025 PERIOD
Source: author's computation based on WoS data (March 23, 2025)

Further, regarding the most cited publications on "Industry 5.0" in WoS Core Collection (Table 1), the Top 10 ranking is led by a study conducted by Xu et al. (2021) in which the authors try to answer certain questions with reference, among other things, to how Industry 5.0 differs from Industry 4.0, which are the enabling technologies that can support the objectives of the new industrial revolution, and how companies involved in development based on Industry 4.0 should adjust their objectives, to also integrate the principles of Industry 5.0.

Many of the following studies in the Top 10 include as a common research element the analysis of technologies that support Industry 5.0, but we also find particular elements, such as potential applicability (Maddikunta et al., 2022; Leng et al., 2022; Adel, 2022 and Rehman et al., 2022), the description of measures that could support the human-machine relationship (Choi et al., 2022) or, as we showed earlier, the presentation of technical and social challenges (Lu et al., 2022).

Also related to technologies, Francesco, Padovano and Umbrello (2020) emphasize the imminent "value-oriented and ethical technology engineering", Ivanov (2022) considers six major technological principles of Industry 5.0, while Yin and Yu (2022) discuss about digital green innovation.

TABLE 1. THE MOST 10 CITED PAPERS ON "INDUSTRY 5.0" TOPIC OVER THE 2020 – 2025 PERIOD

Authors	Article title	Source/Year	Citations (In WoS Core Collection)
Xun Xu, Yuqian Lu, Birgit Vogel-Heuser, Lihui Wang	Industry 4.0 and Industry 5.0- Inception, conception and perception	Journal of Manufacturing Systems / 2021	834
Praveen Kumar Reddy Maddikunta, Quoc-Viet Pham, Prabadevi B, N Deepa, Kapal Dev, Thippa Reddy Gadekallu, Rukhsana Ruby, Madhusanka Liyanage	Industry 5.0: A survey on enabling technologies and potential applications	Journal of Industrial Information Integration / 2022	759
Jiewu Leng, Weinan Sha, Baicun Wang, Pai Zheng, Cunbo Zhuang, Qiang Liu, Thorsten Wuest, Dimitris Mourtzis, Lihui Wang	Industry 5.0: Prospect and retrospect	Journal of Manufacturing Systems / 2022	385
Tsan-Ming Choi, Subodha Kumar, Xiaohang Yue, Hau-Ling Chan	Disruptive Technologies and Operations Management in the Industry 4.0 Era and Beyond	Production and Operations Management / 2022	295
Yuqian Lu, Hao Zheng, Saahil Chand, Wanqing Xia, Zengkun Liu, Xun Xu, Lihui Wang, Zhaojun Qin, Jinsong Bao	Outlook on human-centric manufacturing towards Industry 5.0	Journal of Manufacturing Systems / 2022	285
Longo Francesco, Antonio Padovano, Steven Umbrello	Value-Oriented and Ethical Technology Engineering in Industry 5.0: A Human-Centric Perspective for the Design of the Factory of the Future	Applied Sciences-Basel / 2020	253
Dmitry Ivanov	The Industry 5.0 framework: viability-based integration of the resilience, sustainability, and human-centricity perspectives	International Journal of Production Research / 2023	249
Abdul Rehman Javed, Faisal Shahzad, Saif ur Rehman, Yousaf Bin Zikria, Imran Razzak, Zunera Jalil, Guandong Xu	Future smart cities requirements, emerging technologies, applications, challenges, and future aspects	Cities /2022	235
Amr Adel	Future of industry 5.0 in society: human-centric solutions, challenges and prospective research areas	Journal of Cloud Computing-Advances Systems and Applications / 2022	234
Shi Yin, Yuanyuan Yu	An adoption-implementation framework of digital green knowledge to improve the performance of digital green innovation practices for industry 5.0	Journal of Cleaner Production / 2022	221

Source: author's computation based on WoS data (March 23, 2025)

Top 10 countries in terms of the number of scientific publications (based on the same search criteria), is led by China (864), followed by India (448). From Europe, there are five countries in Top 10. The performer was Italy (3rd place worldwide), with 321 documents, followed by England (5th place worldwide), with 227 documents, Spain (6th place worldwide), with 169 papers, Germany (8th place worldwide), with 154 papers and Poland (10th place worldwide), with 135 papers. The other countries in Top 10 were USA (4th place worldwide), with 319 publications, Brazil (7th place worldwide), with 163 papers and Saudi Arabia (9th place worldwide), with 142 papers (Table 2).

TABLE 2. THE NUMBER OF SCIENTIFIC PUBLICATIONS ON "INDUSTRY 5.0" TOPIC OVER THE 2020 – 2025 PERIOD, BY COUNTRY

Country	Documents
Peoples R China	864
India	448
Italy	321
USA	319
England	227
Spain	169
Brazil	163
Germany	154
Saudi Arabia	142
Poland	135

Source: author's computation based on WoS data (March 23, 2025)

Analyzing the distribution of scientific publications by the field of research (based on the same search criteria), we can see that the first ten categories account for approximately 78% of the total number of publications that resulted based on selected criteria (3.923 documents). In Figure 2, we can see that the most popular domain is Engineering Electrical Electronic (9.992%), followed by Engineering Industrial (8.896%) and Computer Science Interdisciplinary Applications (8.820%).
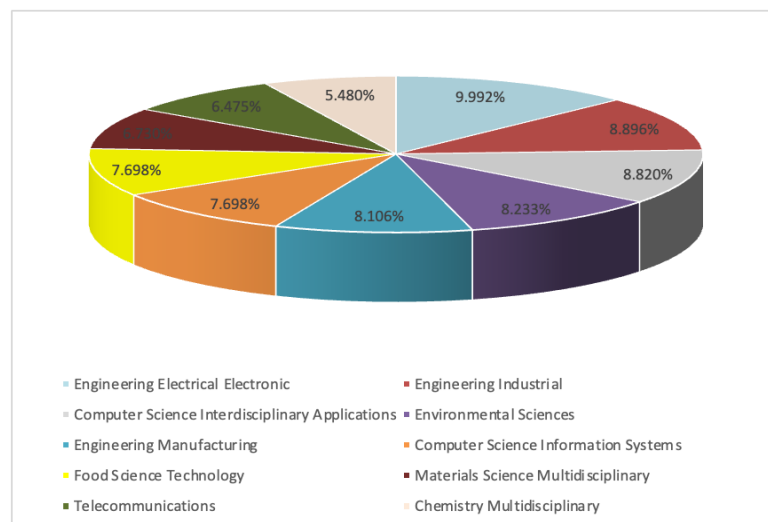

FIGURE 2. TOP 10 RESEARCH AREAS ON "INDUSTRY 5.0" TOPIC OVER THE 2020 – 2025 PERIOD
Source: author's computation based on WoS data (March 23, 2025)

4.1 Insights and expected best practices

The keyword co-occurrence analysis regarding the expected applications and insights of Industry 5.0 was based on two keyword categories: (1) - "Industry 5.0 & practice" and (2) - "Industry 5.0 & insights".

In the case of the first category, 325 results were generated, but after the title and abstract screening, the included documents were 107. In the case of the second category, 380 results were obtained, and after eliminating duplicates and applying title and abstract screening, the number of documents remaining was

78. Finally, after combining the documents selected in the two categories, we obtained a total of 185 studies that we entered into keyword network analysis in VOSviewer. The results obtained in this case are presented in Figure 3.
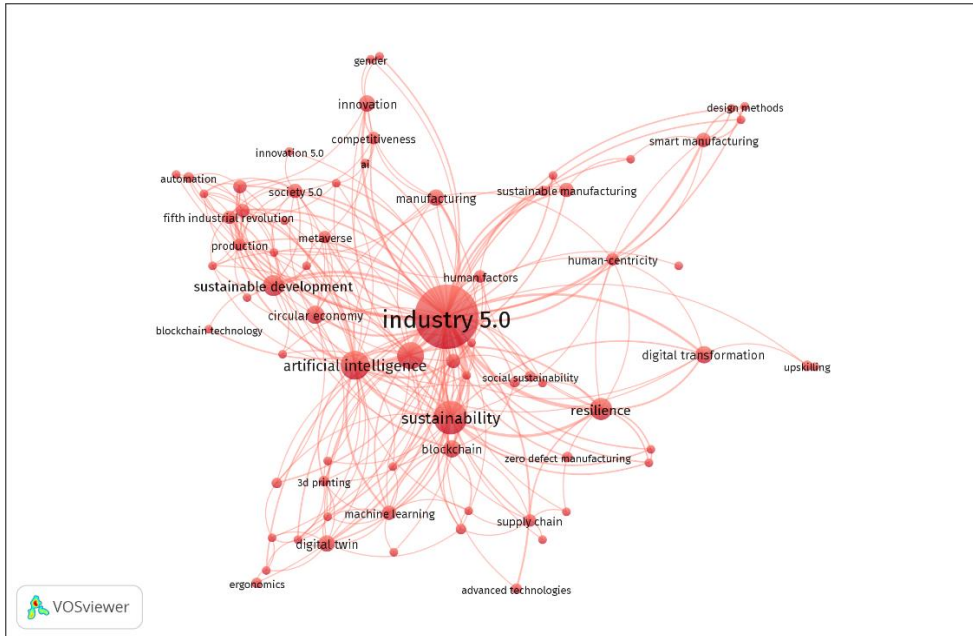
FIGURE 3. CO-OCCURRENCE KEYWORDS NETWORK REGARDING POTENTIAL BEST PRACTICES AND INSIGHTS OF INDUSTRY 5.0
Source: author's computation

Given these results, sustainability development is seen as the main insight of Industry 5.0, followed by the potential to sustain resilience. At the same time, we can see that the development of the circular economy, smart manufacturing, zero-defect manufacturing, or supply chain is among the fields to which Industry 5.0 can contribute.
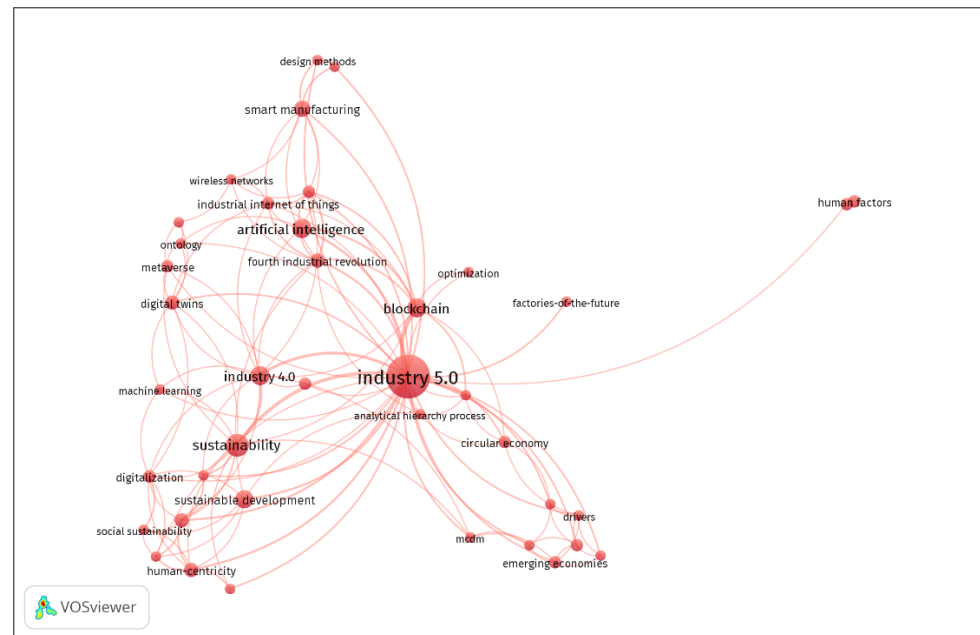
4.2 Pathways

Considering the prospects and some of the potential best practices of Industry 5.0, it is important to analyze what are considered to be some of the main enablers that can support an efficient and sustainable transition to this new industrial revolution.

The keyword co-occurrence analysis in this case was based on two categories of keywords: "Industry 5.0 & enabler" and "Industry 5.0 & driver".

In the case of the first category, 81 results were generated, but after the title and abstract screening, the included documents were 60. In the case of the second category, 71 results were obtained, and after eliminating duplicates and applying title and abstract screening, the number of documents remaining was 17. Finally, after combining the remaining documents in the two categories, we obtained a total of 77 studies that we used in VOSviewer keyword network analysis (Figure 4).

FIGURE 4. CO-OCCURRENCE KEYWORDS NETWORK REGARDING POSSIBLE PATHWAYS FOR INDUSTRY 5.0
Source: author's computation

The results show us that some of the main enablers of Industry 5.0 are considered to be the advanced digital technologies (artificial intelligence, blockchain and digital twins), but also the human factors.

5. CONCLUSIONS

Industry 5.0 is an increasingly important and widely addressed topic in international scientific research, given its objectives and potential. We note that these studies are carried out over an extensive geographical area and have a distribution across multiple domains, which contributes to strengthening the results obtained in terms of perspectives, possible applicabilities and potential enablers.

As a general conclusion, we can state that Industry 5.0 has the characteristics and potential necessary to stimulate innovative and sustainable entrepreneurship, and the progress of scientific research in this field makes its extended applicability and expected results increasingly closer.

The present work of course, has certain limitations, especially in terms of the number of databases used, as well as regarding the diversification of search criteria.

A possible future direction of research is the identification of enablers that have the most important influence depending on the specific field in which Industry 5.0 is implemented.

REFERENCES

Adel, A. (2022). Future of industry 5.0 in society: human-centric solutions, challenges and prospective research areas. J Cloud Comp 11, 40. https://doi.org/10.1186/s13677-022-00314-5.

Asif, M., Searcy, C. & Castka, P. (2023). ESG and Industry 5.0: The role of technologies in enhancing ESG disclosure. Technological Forecasting and Social Change, 195, 122806. https://doi.org/10.1016/j.techfore.2023.122806.

Basulo-Ribeiro, J. & Teixeira, L. (2024). The Future of Healthcare with Industry 5.0: Preliminary Interview-Based Qualitative Analysis. Future Internet, 16(3), 68. https://doi.org/10.3390/fi16030068.

Broo, D. G., Kaynak, O. & Sait, S. M. (2022). Rethinking engineering education at the age of industry 5.0. Journal of Industrial Information Integration, 25, 100311. https://doi.org/10.1016/j.jii.2021.100311.

Choi, T., Kumar, S., Yue, X. & Chan, H. (2022). Disruptive Technologies and Operations Management in the Industry 4.0 Era and Beyond. Production and Operations Management, 31(1), 9-31. https://0411500cm-y-https-doi-org.z.e-nformation.ro/10.1111/poms.13622.

Commission: Directorate-General for Research and Innovation, Breque, M., De Nul, L., & Petridis, A. (2021). Industry 5.0 – Towards a sustainable, human-centric and resilient European industry. Publications Office of the European Union. https://data.europa.eu/doi/10.2777/308407.

Csősz, C. (2024). The economics of innovation: Blockchain technology. Annals of 'Constantin Brancusi' University of Targu-Jiu. Economy Series/Analele Universităţii 'Constantin Brâncuşi' din Târgu-Jiu Seria Economie, (5).

Dwivedi, A., Agrawal, D., Jha, A. & Mathiyazhagan, K. (2023). Studying the interactions among Industry 5.0 and circular supply chain: Towards attaining sustainable development. Computers & Industrial Engineering, 176, 108927. https://doi.org/10.1016/j.cie.2022.108927.

Ghobakhloo, M., Iranmanesh, M., Fathi, M., Rejeb, A., Foroughi, B. & Nikbin, D. (2024). Beyond Industry 4.0: a systematic review of Industry 5.0 technologies and implications for social, environmental and economic sustainability. Asia-Pacific Journal of Business Administration, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/APJBA-08-2023-0384.

Haloui, D., Oufaska, K., Oudani, M. & El Yassini, K. (2024). Bridging Industry 5.0 and Agriculture 5.0: Historical perspectives, opportunities, and future perspectives. Sustainability 16(9), 3507. https://doi.org/10.3390/su16093507.

Hsu, C.-H., Cai, X.-Q., Zhang, T.-Y. & Ji, Y.-L. (2024). Smart logistics facing Industry 5.0: Research on key enablers and strategic roadmap. Sustainability, 16(21), 9183. https://doi.org/10.3390/su16219183.

Ivanov, D. (2022). The Industry 5.0 framework: Viability-based integration of the resilience, sustainability, and human-centricity perspectives. Int. J. Prod. Res., 61, 1683–1695. https://doi.org/10.1080/00207543.2022.2118892.

Javaid, M. & Haleem, A. (2020). Critical components of Industry 5.0 towards a successful adoption in the field of manufacturing. Journal of Industrial Integration and Management, 5(3), 327-348. https://doi.org/10.1142/S2424862220500141.

Javed, A. R, Shahzad, F., Rehman, S., Zikria, Y. B., Razzak, I., Jalil, Z. & Xu., G. (2022). Future smart cities: requirements, emerging technologies, applications, challenges, and future aspects. Cities, 129, 103794. https://doi.org/10.1016/j.cities.2022.103794.

Koch, V., Tomasevic, D., Pacher, C. & Zunk., B. M. (2025). Preparing students for Industry 5.0: Evaluating the industrial engineering and management education. Procedia Computer Science, 253, 2219-2228. https://doi.org/10.1016/j.procs.2025.01.282.

Lagorio, A. & Cimini, C. (2024). Towards 5.0 skills acquisition for students in industrial engineering: the role of learning factories. Procedia Computer Science, 232, 317-326. https://doi.org/10.1016/j.procs.2024.01.031.

Leon, R. D. (2023). Employees' reskilling and upskilling for industry 5.0: Selecting the best professional development programmes. Technology in Society, 75, 102393. https://doi.org/10.1016/j.techsoc.2023.102393.

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.

Longo, F., Padovano, A. & Umbrello, S. (2020). Value-oriented and ethical technology engineering in Industry 5.0: A human-centric perspective for the design of the factory of the future. Applied Sciences, 10(12), 4182. https://doi.org/10.3390/app10124182.

Lu, Y., Zheng, H., Chand, S., Xia, W., Liu, Z., Xu, X., Wang, L., Qin, Z. & Bao, J. (2022). Outlook on human-centric manufacturing towards Industry 5.0. Journal of Manufacturing Systems, 62, 612-627. https://doi.org/10.1016/j.jmsy.2022.02.001.

Maddikunta, P. K. R., Pham, Q.-V., Prabadevi, B., 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.

Mukherjee, A. A., Raj, A. & Aggarwal, S. (2023). Identification of barriers and their mitigation strategies for industry 5.0 implementation in emerging economies. International Journal of Production Economics, 257, 108770. https://doi.org/10.1016/j.ijpe.2023.108770.

Nahavandi, S. (2019). Industry 5.0—A Human-centric solution. Sustainability, 11(16), 4371. https://doi.org/10.3390/su11164371.

Poláková, M., Suleimanová, J. H., Madzík, P., Copuš, L., Molnárová, I. & Polednová. J. (2023). Soft skills and their importance in the labour market under the conditions of Industry 5.0. Heliyon, 9(8), e18670. https://doi.org/10.1016/j.heliyon.2023.e18670.

Popescu, A. (2023). The role of artificial intelligence in digital marketing strategies. Annals of 'Constantin Brancusi' University of Targu-Jiu. Economy Series/Analele Universităţii 'Constantin Brâncuşi' din Târgu-Jiu Seria Economie, (3).

Ravdeep, K., Ramin, K., Pierre, D. & Naveen., V. (2024). Cybersecurity for Industry 5.0: trends and gaps. Frontiers in Computer Science, 6. https://doi.org/10.3389/fcomp.2024.1434436.

Sharma, M., Sehrawat, R., Luthra, S., Daim, R. & Bakry, D. (2024). Moving towards Industry 5.0 in the pharmaceutical manufacturing sector: Challenges and solutions for Germany. in IEEE Transactions on Engineering Management, 71, 13757-13774. Doi: 10.1109/TEM.2022.3143466.

Supriya, Y. et al. (2024). Industry 5.0 in smart education: Concepts, applications, challenges, opportunities, and future directions. in IEEE Access, 12, 81938-81967. Doi: 10.1109/ACCESS.2024.3401473.

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, 61, 530-535. https://doi.org/10.1016/j.jmsy.2021.10.006.

Yin, S. & Yu, Y. (2022). An adoption-implementation framework of digital green knowledge to improve the performance of digital green innovation practices for industry 5.0. Journal of Cleaner Production, 363, 132608. https://doi.org/10.1016/j.jclepro.2022.132608.