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INDUSTRY 4.0 TO 5.0: A FUTURE PERSPECTIVE

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Abstract

After ten years of providing industry 4.0 to the benefits of industry and it address the inadequacy of the industry, the time has come for industry 5.0. Industry 4.0 is limited as smart factories are raising corporate productivity. This study discusses industry 5.0 opportunities, challenges, and potential directions for further research. Industry 5.0 is bringing about a paradigm shift and resolution by placing less emphasis on technology and assuming that human-machine cooperation is the foundation for success. By using customised products, the industrial revolution is increasing client happiness. Industry 5.0 is necessary in today's company with the paid technical advancements to obtain competitive advantages and spur economic growth for the industrial unit. The purpose of the study is to examine industry 5.0's possible uses. The definitions of industry 5.0 and the cutting-edge technology needed for this industrial revolution are first discussed. The applications enabled by Industry 5.0, such as cloud manufacturing, healthcare, supply chain and manufacturing production, and are also discussed. This article covers the following technologies: block chain, digital twins, Internet of Things, big data analytics, collaborative robotics, and upcoming 6G systems. In order to understand the problems generated by organisations between the people and robots on the assembly line, the research also incorporated the challenges.

Keywords: Industry 5.0, Human Machine Collaboration, Supply Chain, Disaster Recovery, Smart Healthcare, Cognitive Systems, Green Manufacturing.

INTRODUCTION

The eighteenth-century first industrial revolution, or Industry 1.0, brought about a significant change in production methods by allowing machines to make goods using newly devised means and techniques. By the end of the eighteenth century, it had spread from England, where it had begun in 1760, to the United States. Industry 1.0 affected a number of industries, including mining, textile, agricultural, glass, and others, and signalled a change from the handcraft economy to one dominated by machines [1]. The next industrial revolution, known as Industry 2.0, occurred between 1871 and 1914 and was characterised by a quicker flow of people and creative ideas. During this revolution, businesses are becoming more productive, which is leading to a rise in unemployment as robots take the position of manufacturing workers.

The digital revolution, also known as Industry 3.0, began in the 1970s with the automation of computers and memory-programmable controllers. Mass manufacturing and the use of integrated circuit chips, or digital logic, are the focal points of this specific phase; related technologies include computers, digital cell phones, and the internet [2, 3]. Technology advancements are changing not just company processes but also traditional goods. Technology is being transformed into digital format by the digital revolution. Industry 4.0 unites modern technologies like cloud computing, robotics, 3D printing, IoT, and artificial

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intelligence with physical assets. Organisations that have embraced 4.0 are adaptable and ready to make decisions based on facts [4]. The next generation of technology, known as Industry 5.0, was created for intelligent and productive machines. The industry revolution from industry 1.0 to industry 5.0 is depicted in Figure 1. Table 1 lists the surveys that cover the most relevant topics related to industry X.0.

The rationale following the progression of industry 5.0

The industry 5.0 revolution is characterised by the collaboration of humans and machines, which enhances the productivity of industrial output. The industrial sector is becoming more productive thanks to human labour and universal robotics [5]. The manufacturing company's management teams must first establish the production line, then monitor key performance indicators to make sure everything is operating well. The production of industrial and robotic robots is the route that industry 5.0 will take. The manufacturing industry is expanding rapidly, and company efficiency is rising thanks to the development of AI and cognitive computing technologies [20]. Industry 5.0 offers advantages for sustainability as well as the manufacturing sector because it seeks to create a sustainable system based on renewable energy.

Workers must properly communicate with both machines and operators in order for businesses to implement Industry 5.0. It is expertise in disciplines like artificial intelligence and robotics [21, 22]. Making judgements based on sophisticated considerations is the foundation of the corporate organization's function.

While production does not have to halt in order to provide employees with training, firms must teach their staff virtually in order to save costs. It offers safe training that helps shield employees from unnecessary problems during training sessions. Creating interactive knowledge environments improves staff motivation and communication [1, 6, 23, 24]. The employment positions are related to communication with the robotics systems as well as artificial intelligence.

The goal of collaborative robot design is to enable natural human-robot communication. Industry 5.0 requires technology that expands digital twins. Tests and understanding will be improved with the use of visual representations of the generation, products, and processes. The software needed to propel the industrial business's transition in industry 5.0 is the Nexus Integra platform [7].

It is an integrated solution that enables businesses to quickly adopt digital transformation for the large-scale management of industrial assets. Past generations modified their way of life to accommodate machinery [25, 26]. Nevertheless, industry 5.0 is distinct from all other resolutions in that human beings are the primary focus of industrial processes.

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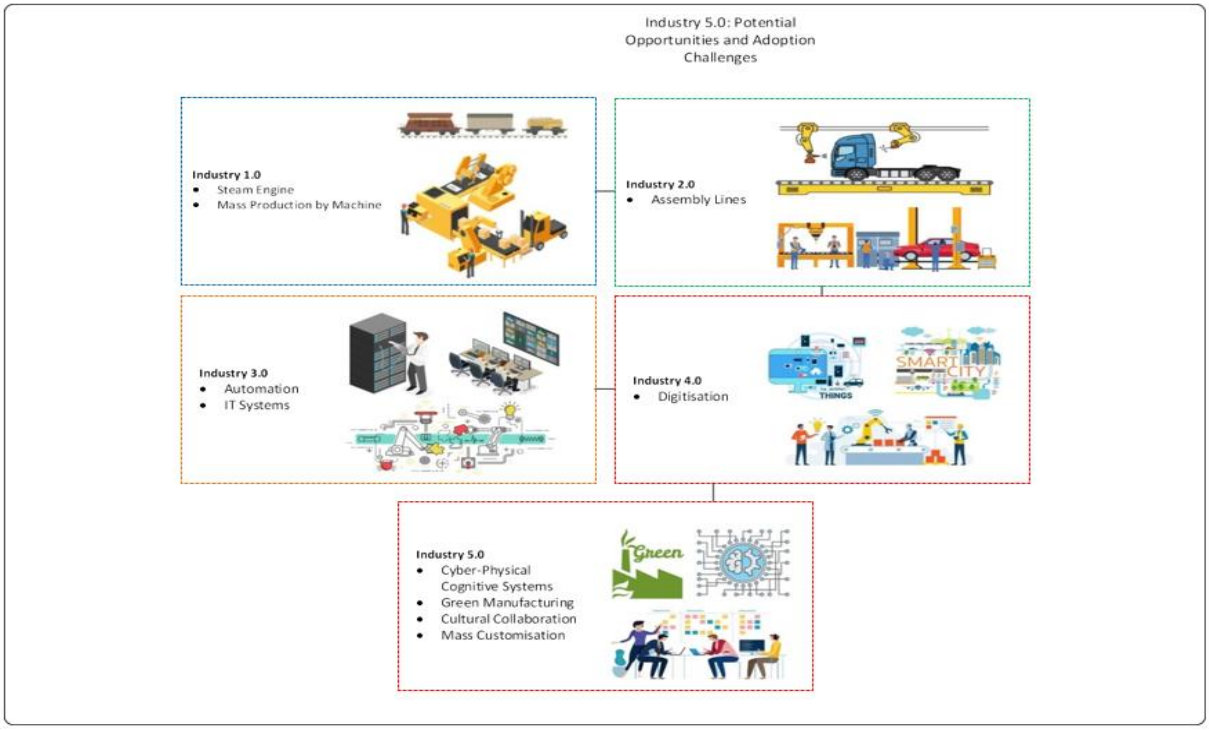

Fig 1: Industrial Evolution from Industry 1.0–5.0

Table 1: Summary table of most relevant surveys

Ref. No.	Industry 5.0 Apps	Prerequisites and Concept	Adopted Technologies	Limitations	Future Research	Research Main Focus
[1]	N/A	M	H	L	L	Main focus is on managing the barriers of Industry 4.0 adoption and implementation in textile and clothing industry
[4]	M	M	M	H	H	Main focus is on Value-oriented and ethical technology engineering in industry 5.0
[6]	N/A	H	H	L	H	Main focus is on blockchain for big data: approaches, opportunities, and future directions
[30]	H	M	H	M	N/A	Main focus is on Industry 5.0—A human-centric solution.
[35]	M	M	H	H	H	Main focus is on Industry 4.0 and Society 5.0: opportunities and threats.

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[61]	N/A	M	H	H	H	Main focus is on Tackling faults in the industry 4.0 era—a survey of machine-learning solutions and key aspects.
[67]	H	M	M	H	H	Green IoT and edge AI as key technological enablers for a sustainable digital transition towards a smart circular economy: An industry 5.0 use case.
[73]	N/A	L	H	H	L	Main focus is on technologies, applications and open research issues I industry 4.0.
[74]	N/A	M	H	H	L	Main Focus is on industry 4.0: Adoption challenges and benefits for SMEs.
[75]	N/A	M	H	L	L	framework to achieve sustainability in manufacturing organizations of developing economies using industry 4.0 technologies' enablers.
[98]	N/A	M	H	H	H	investigation into emerging industry 4.0 technologies as drivers of supply chain innovation in Australia.
[122]	M	M	H	H	M	Main focus is on critical components of Industry 5.0 towards a successful adoption in the field of manufacturing
[128]	M	M	M	L	M	Main focus is on an exploratory bibliometric analysis of the birth and emergence of industry 5.0.
[132]	L	L	M	M	M	Main focus is on the birth of industry 5.0: Making sense of big data with artificial intelligence.
[138]	H	M	H	N/A	N/A	Main focus is on industry 5.0: Ethereum blockchain technology based DApp smart contract.
[156]	N/A	H	H	L	M	Main focus is on an approach and decision support tool for forming Industry 4.0 supply chain collaborations.

H High Focus M Medium Focus L Low Focus N/A Not Applicable

Note: references within the table [1, 5–19]

Challenges of industry 5.0

Approximately industry 5.0 makes it simpler to ignore the possible difficulties. The firm is identifying and resolving the obstacles to the success of industry 5.0 innovations.

1) Human workers must acquire competence abilities in order to deal with sophisticated robots. They must also learn about collaborating with smart machine and robot maker [110]. For human workers, acquiring technical skills is a challenge in addition to the soft skills needed [2, 101]. In the new roles, coordinating translation and programming to the industrial robot are challenging duties demanding a high degree of technical expertise.

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2) It will take more time and effort for human workers to adopt new technologies. Industry 5.0 requires the use of customized software-connected factories, internet of things, collaborative robots, artificial intelligence, and real-time information [50, 111–113].

3) Investments in cutting-edge technology are necessary. Robots are not inexpensive. The expenses of retraining human labour for new positions are increased. Upgrading manufacturing lines for industry 5.0 has proven to be challenging for the firms [114]. Adopting Industry 5.0 is costly since it calls for highly trained workers and intelligent machinery to boost output and efficiency.

4) Industry 5.0 has security challenges since ecosystem trust is essential. In order to defend against potential quantum computing applications and facilitate the deployment of Internet of Things nodes, authentication is employed on a large scale in the business [60, 94, 115]. Industry 5.0's use of automation and artificial intelligence poses risks to the company, therefore reliable security is necessary [88, 116–118]. Because Industry 5.0 applications are centred on ICT systems, stringent security regulations are necessary to avoid security issues

Definitions of industry 5.0

It is clear from definitions of Industry 5.0 that this novel production model places a strong emphasis on human-machine interaction [56, 119–122]. It involves making the most of human ingenuity and cooperation with more powerful and effective machines. The current projects that form the foundation of industry 5.0 are those that optimise artificial intelligence to produce specialised goods [18, 46, 123–128]. This industry is being adopted by worldwide norms.

Applications of industry 5.0

Industry 5.0 provides benefits for the industry for both the workers and society. There is also an increase in the competitiveness of the business and help attract the best talents [129–131]. Adoption of this industry supports technologies that make natural usage of the resources properly. Human robotics, such as Sophia, personifies dreams of the future of artificial intelligence [132, 133]. It helps in the decision making of humans and is supported by enabling technologies that help in revolutionize various sectors. Even various challenges are mentioned in this paper, like handling quantity of data, managing resources, and others.

Enabling technologies

Industry 5.0's enabling technologies are designed to integrate several technologies into complex systems, including big data analytics, cloud computing, smart materials, and human-machine interaction [134]. Utilizing software resources to transmit data about industrial sectors is made easier for businesses by smart manufacturing and intelligence, which also helps to minimize network traffic, expedite transactions, and maintain privacy [135]. Smart contracts handle security, authentication, and automated service-related tasks, while block chain technology automates agreement procedures among several stakeholders [136, 137]. The intelligent information standard that offers great energy

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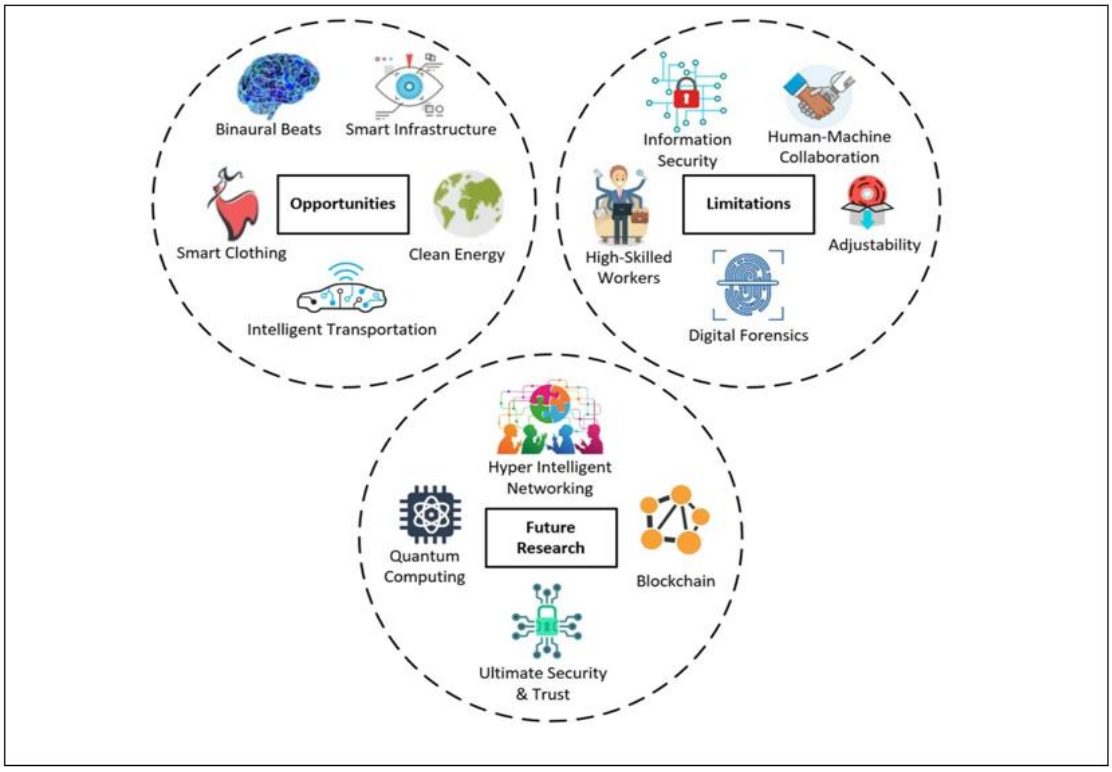
economy, high dependability, and traffic capacity is anticipated to be met by the 6G network. The technology that makes managing vast amounts of data possible is called big data analytics [17, 116, 138]. Industry 5.0 may benefit from the internet of things as well, since it can eliminate problems with waste management, supply chain management, communication networks, manufacturing process optimizations and other areas to save operating expenses.



LIMITATIONS OF INDUSTRY 5.0

It's essential to accept technology and have faith in it. Training users of the new technologies occurs concurrently with the technology's adaptation to humans [139–143]. The difficulties of today include security, privacy, a shortage of competent labour, labor-intensive procedures, and high costs. Adoption of industry 5.0 necessitates adherence to industrial laws and regulations that facilitate the coexistence of robots and intelligent machines. Quantum computing, human-machine interaction, and cognitive computing are the future directions for industry 5.0.

FUTURE DIRECTIONS

The goal of cognitive computing is to stimulate human mental processes into a computerised model [16, 144, 145]. Utilising self-learning algorithms makes advantage of data mining, pattern recognition, natural language, and other tasks that the human brain can perform and that the computer is able to read.

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Interaction between humans and machines through a user interface is referred to as human-machine interaction. Since they enable people to operate machines using instinctive and natural behaviours, natural user interfaces like gestures are employed to attract attention [86, 146–149]. It is the way that industry 5.0 will go in the future as it keeps people at the core of the system and allows for the integration of new technology. People may even learn about people's motives and behaviours via the user interface.

A sort of computer known as quantum computing uses the collective characteristics of quantum states, such as interference entanglement, to perform computations. Quantum computers, as described by the devices, are used to execute quantum computing [8, 150–153]. It is carrying out computations that are centred on the likelihood of the object's condition prior to measurement.

CONCLUSION

The study's findings indicate that the author began by defining industry 5.0 from the viewpoints of the academic and industrial communities. After talking about enabling technologies, even the apps that aid in comprehending industry 5.0's characteristics have been covered. The goal of the Industry 5.0 idea is to properly balance human and machine efficiency. This report also presents challenges that aid in managing the problems brought forth by industry 5.0. This article discusses future directions that need to be addressed more effectively in order to use this industry in the near future.

References

1) Longo F, Padovano A, Umbrella 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. Appl Sci 10(12):4182

2) Pathak A, Kothari R, Vinoba M, Habibi N, Tyagi VV (2021) Fungal bioleaching of metals from refinery spent catalysts: a critical review of current research, challenges, and future directions. J Environ Manag 80:111789

3) He D, Ma M, Zeadally S, Kumar N, Liang K (2017) Certificateless public key authenticated encryption with keyword search for industrial inter- net of things. IEEE Trans Ind Inf 14(8):3618–3627

4) Leone LA, Fleischhacker S, Anderson-Steeves B, Harpe K, Winkler M, Racin E, Baquero B, Gittelsohn J (2020) Healthy food retail during the COVID-19 pandemic: challenges and future directions. Int J Environ Res Public Health 17(20):7397

5) Majumdar A, Garg H, Jain R (2021) Managing the barriers of industry 4.0 adoption and implementation in textile and clothing industry: interpretive structural model and triple helix framework. Comput Ind 125:103372

6) Angelopoulos A, Michailidis ET, Nomikos N, Trakadas P, Hatziefremidis A, Voliotis S, Zahariadis T (2020) Tackling faults in the industry 4.0 era—a survey of machine-learning solutions and key aspects. Sensors. 20(1):109

7) Nahavandi S (2019) Industry 5.0—a human-centric solution. Sustain- ability 11(16):4371

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
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DOI: 10.5281/zenodo.10947478

8) Javaid M, Haleem A (2020) Critical components of industry 5.0 towards a successful adoption in the field of manufacturing. J Industr Integr Manag. 5(03):327–348

Deepa N, Pham QV, Nguyen DC, Bhattacharya S, Prabadevi B, Gadekallu TR, ..., Pathirana PN (2022) A survey on blockchain for big data: approaches, opportunities, and future directions. Future Generation Computer Systems

9) Pereira AG, Lima TM, Santos FC (2020) Industry 4.0 and society 5.0: opportunities and threats. Int J Recent Technol Eng 8(5):3305–3308

10) Fraga-Lamas P, Lopes SI, Fernández-Caramés TM (2021) Green IoT and edge AI as key technological enablers for a sustainable digital transition towards a smart circular economy: an industry 5.0 use case. Sensors 21(17):5745

11) Lu Y (2017) Industry 4.0: a survey on technologies, applications and open research issues. J Ind Inf Integr 6:1–10

12) Masood T, Sonntag P (2020) Industry 4.0: adoption challenges and benefits for SMEs. Comput Ind 121:103261

13) Yadav G et al (2020) A framework to achieve sustainability in manu- facturing organisations of developing economies using industry 4.0 technologies' enablers. Comput Ind 122:103280

14) Hopkins JL (2021) An investigation into emerging industry 4.0 tech- nologies as drivers of supply chain innovation in Australia. Comput Ind 125:103323

15) Madsen DO, Berg T (2021) An exploratory bibliometric analysis of the birth and emergence of industry 5.0. Appl Syst Innov 4(4):87

16) Özdemir V, Hekim N (2018) Birth of industry 5.0: Making sense of big data with artificial intelligence, "the internet of things" and next-genera- tion technology policy. Omics A J Integr Biol 22(1):65–76

17) Rupa CD, Hasan MK, Alhumyani H, Saeed RA (2021) Industry 5.0: Ethereum blockchain technology based DApp smart contract. Math Biosci Eng 18(5):7010–7027

18) Cisneros-Cabrera S et al (2021) An approach and decision support tool for forming industry 4.0 supply chain collaborations. Comput Ind 125:103391

19) Chen H, Simoska O, Lim K, Grattieri M, Yuan M, Dong F, Lee YS, Beaver K, Weliwatte S, Gaffne EM, Minteer SD (2020) Fundamentals, applications, and future directions of bioelectrocatalysis. Chem Rev 120(23):12903–12993

20) Zhang C, Chen YA (2020) Areview of research relevant to the emerging industry trends: industry 4.0, IoT, blockchain, and business analytics. J Industr Integr Manag. 5(01):165–180

21) Chowdhury MZ, Shahjalal M, Ahmed S, Jang YM (2020) 6G wireless communication systems: applications, requirements, technolo- gies, challenges, and research directions. IEEE Open J Commun Soc 1:957–975

22) Abubakr M, Abbas AT, Tomaz I, Soliman MS, Luqman M, Hegab H (2020) Sustainable and smart manufacturing: an integrated approach. Sustain- ability. 12(6):2280

23) Leong YK, Tan JH, Chew KW, Show PL (2020) Significance of industry 5.0. In: Show PL, Chew KW, Ling TC (eds) The Prospect of industry 5.0 in biomanufacturing. CRC Press, pp 1–20

24) Wang M, Wang CC, Sepasgozar S, Zlatanova S (2020) A systematic review of digital technology adoption in off-site construction: current status and future direction towards industry 4.0. Buildings. 10(11):204

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
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E-Publication: Online Open Access
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DOI: 10.5281/zenodo.10947478

25) Deepa N, Prabadevi B, Maddikunta PK, Gadekallu TR, Baker T, Khan MA, Tariq U (2021) An AI-based intelligent system for healthcare analysis using Ridge-Adaline Stochastic Gradient Descent Classifier. J Super- comput 77(2):1998–2017

26) Javaid M, Haleem A, Singh RP, Haq MI, Raina A, Suman R (2020) Industry 5.0: potential applications in COVID-19. J Industr Integr Manag 5(04):507–530

27) Martos V, Ahmad A, Cartujo P, Ordoñez J (2021) Ensuring agricultural sustainability through remote sensing in the era of agriculture 5.0. Appl Sci 11(13):5911

28) Imoize AL, Adedeji O, Tandiya N, Shetty S (2021) 6G enabled smart infrastructure for sustainable society: opportunities, challenges, and research roadmap. Sensors. 21(5):1709

29) Ocicka B, Turek J (2021) Supply chain sustainability risk management in a digitally VUCA changing world. In: The economics of sustainable transformation, pp 167–190 Routledge

30) Carayannis EG, Christodoulou K, Christodoulou P, Chatzichristofis SA, Zinonos Z (2021) Known unknowns in an era of technological and viral disruptions—implications for theory, policy, and practice. J Knowl Econ:1–24

Ietto B, Ancillai C, Sabatini A, Carayannis EG, Gregori GL (2022) The role of external actors in SMEs' human-centered industry 4.0 adoption: an empirical perspective on Italian competence centers. IEEE Trans Engi- neering Management

31) Adadi A, Berrada M (2018) Peeking inside the black-box: a survey on explainable artificial intelligence (xai). IEEE Access 6:52138–52160

32) Ali MH, Issayev G, Shehab E, Sarfraz S (2022) A critical review of 3D printing and digital manufacturing in construction engineering. Rapid Prototyping Journal

33) Sherburne C (2020) Textile industry 5.0? Fiber computing coming soon to a fabric near you. AATCC Rev 20(6):25–30

34) Saraswa V, Jacobberger RM, Arnold MS (2021) Materials science chal- lenges to graphene nanoribbon electronics. ACS Nano 15(3):3674–3708

35) Yu M, Lou S, Gonzalez-Bobes F (2018) Ring-closing metathesis in pharmaceutical development: fundamentals, applications, and future directions. Org Process Res Dev 22(8):918–946

36) Riedl R, Fischer T, Léger PM, Davis FD (2020) A decade of NeuroIS research: progress, challenges, and future directions. ACM SIGMIS Database: DATABASE Adv Inform Syst 51(3):13–54

37) Peck ME, Moore SK (2017) The blossoming of the blockchain. IEEE Spectr 54(10):24–25

38) Babamiri B, Bahari D, Salimi A (2019) Highly sensitive bioaffinity elec- trochemiluminescence sensors: recent advances and future directions. Biosens Bioelectron 142:111530

39) Llorens Duran JID (2019) TensiNet Symposium 2019: Softening the habitants: Report. TensiNews 37:16–23

40) Li L (2020) Education supply chain in the era of industry 4.0. Syst Res Behav Sci 37(4):579–592

41) Simchenko N, Tsohla S, Chyvatkin P (2019) IoT & digital twins concept integration effects on supply chain strategy: challenges and effect. Int J Supply Chain Manag 8(6):803–808

42) Föckler P, Zeidler T, Brombach B, Bruns E, Bimber O (2005) PhoneGuide: Museum guidance supported by on-device object recognition on mobile phones. In: Proceedings of the 4th International Conference on Mobile and Ubiquitous Multimedia. ACM, pp 3–10

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 57 Issue: 04:2024
DOI: 10.5281/zenodo.10947478

43) Wu H, Nguyen GT, Chorppath AK, Fitzek F (2017) Network slicing for con- ditional monitoring in the industrial internet of things. Transport 2018

44) Paschek D, Mocan A, Draghici A et al (2019) Industry 5.0-the expected impact of next industrial revolution. In: Thriving on future education, industry, business, and Society, Proceedings of the MakeLearn and TIIM International Conference, Piran, Slovenia, pp 15–17

45) Guidotti R, Monreale A, Ruggieri S, Turini F, Giannotti F, Pedreschi D (2018) A survey of methods for explaining black box models. ACM Comput Surv 51(5):1–42

46) Phuyal S, Bista D, Bista R (2020) Challenges, opportunities and future directions of smart manufacturing: a state of art review. Sustain Futures 2:100023

47) Lima F, De Carvalho CN, Acardi MB, Dos Santos EG, De Miranda GB, Maia RF, Massote AA (2019) Digital manufacturing tools in the simulation of collaborative robots: towards industry 4.0. Braz J Oper Prod Manag 16(2):261–280

48) Abdelmageed S, Zayed T (2020) A study of literature in modular inte- grated construction-critical review and future directions. J Clean Prod 277:124044

49) Lutz J, Memmert D, Raabe D, Dornberger R, Donath L (2020) Wearables for integrative performance and tactic analyses: opportunities, chal- lenges, and future directions. Int J Environ Res Public Health 17(1):59

50) Abid H, Javaid M (2019) Industry 5.0 and its applications in orhaleem thopaedics. J Clin Orthop Trauma 10(4):807–808

51) Saxena A, Pant D, Saxena A, Patel C (2020) Emergence of educators for industry 5.0: an Indological perspective. Int J Innov Technol Explor Eng 9(12):359–363

52) Latva-aho M (2017) Micro operators for vertical specifc service deliver in 5G

53) Tosh D, Galindo O, Kreinovich V, Kosheleva O Towards security of cyber- physical systems using quantum computing algorithms. In: 2020 IEEE 15th international conference of system of systems engineering (SoSE), vol 2020. IEEE, pp 313–320

54) Aslam F, Aimin W, Li M, Ur Rehman K (2020) Innovation in the era of IoT and industry 5.0: absolute innovation management (AIM) framework. Information. 11(2):124

55) Alhassan AB, Zhang X, Shen H, Xu H (2020) Power transmission line inspection robots: a review, trends and challenges for future research. Int J Electr Power Energy Syst 118:105862

56) Brown DG, Wobst HJ (2021) A decade of FDA-approved drugs (2010– 2019): trends and future directions. J Med Chem 64(5):2312–2338

57) Mahmood NH, Böcker S, Munari A, Clazzer F, Moerman I, Mikhaylov K, Lopez O, Park OS, Mercier E, Bartz H, Jäntti R (2020) White paper on critical and massive machine type communication towards 6G. arXiv preprint arXiv:2004.14146

58) Ghobakhloo M, Fathi M, Iranmanesh M, Maroufkhani P, Morales ME (2021) Industry 4.0 ten years on: a bibliometric and systematic review of concepts, sustainability value drivers, and success determinants. J Clean Prod 302:127052

59) Porambage P, Gür G, Osorio DP, Livanage M, Ylianttila M (2021) 6G secu- rity challenges and potential solutions. In: 2021 Joint European Confer- ence on Networks and Communications & 6G Summit (EuCNC/6G Summit), pp 622–627 IEEE

60) Nguyen TN, Ebrahim FM, Stylianou KC (2018) Photoluminescent, upconversion luminescent and nonlinear optical metal-organic frame- works: from fundamental photophysics to potential applications. Coord Chem Rev 377:259–306

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
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E-Publication: Online Open Access
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DOI: 10.5281/zenodo.10947478

61) Zambon I, Cecchini M, Egidi G, Saporito MG, Colantoni A (2019) Revolu- tion 4.0: industry vs. agriculture in a future development for SMEs. Processes. 7(1):36

62) Wang S, Wang H, Li J, Wang H, Chaudhry J, Alazab M, Song H (2020) A fast cp-abe system for cyber-physical security and privacy in mobile healthcare network. IEEE Trans Ind Appl 56(4):4467–4477

63) Adel A (2022) A conceptual framework to improve cyber forensic Administration in Industry 5.0: qualitative study approach. Forensic Sci 2(1):111–129

64) Priadythama I, Herdiman L, Susmartini S (2020) Role of rapid manu- facturing technology in wearable customized assistive technology for modern industry. AIP Conf Proc 2217(1):030076

65) Onik MM, Miraz MH, Kim CS (2018) A recruitment and human resource management technique using blockchain technology for industry 4.0. In: Smart Cities Symposium 2018, pp 1–6 IET

66) Wagg DJ, Worden K, Barthorpe RJ, Gardner P (2020) Digital twins: state-of-the-art and future directions for modeling and simulation in engineering dynamics applications. ASCE-ASME J Risk Uncert Engrg Sys Part B Mech Engrg 6(3)

67) Sarsaiya S, Jain A, Awasthi SK, Duan Y, Awasthi MK, Shi J (2019) Microbial dynamics for lignocellulosic waste bioconversion and its importance with modern circular economy, challenges and future perspectives. Bioresour Technol 291:121905

68) Matheus LE, Vieira AB, Vieira LF, Vieira MA, Gnawali O (2019) Visible light communication: concepts, applications and challenges. IEEE Commun Surveys Tutor. 21(4):3204–3237

69) Opare EO, Struhs E, Mirkouei A (2021) A comparative state-of-tech- nology review and future directions for rare earth element separation. Renew Sust Energ Rev 143:110917

70) Siriwardhana Y, Porambage P, Liyanage M, Ylianttila M (2021) A survey on mobile augmented reality with 5G mobile edge computing: architectures, applications, and technical aspects. IEEE Commun Surv Tutorials 23(2):1160–1192

71) Sheridan TB (2016) Human–robot interaction: status and challenges. Hum Factors 58(4):525–532

72) Cioffi R, Travaglioni M, Piscitelli G, Petrillo A, Parmentola A (2020) Smart manufacturing systems and applied industrial technologies for a sustainable industry: a systematic literature review. Appl Sci 10(8):2897

73) Haleem A, Javaid M, Khan IH (2019) Current status and applications of artificial intelligence (AI) in medical field: an overview. Curr Med Res Pract 9(6):231–237

74) Trakadas P, Simoens P, Gkonis P, Sarakis L, Angelopoulos A, Ramallo- González AP, Skarmet A, Trochoutsos C, Calv D, Pariente T, Chintamani K (2020) An artificial intelligence-based collaboration approach in industrial iot manufacturing: key concepts, architectural extensions and potential applications. Sensors. 20(19):5480

75) Sinclair LK, Tester JW, Thompson JF, Fox RV (2019) Supercritical extrac- tion of lanthanide tributyl phosphate complexes: current status and future directions. Ind Eng Chem Res 58(22):9199–9211

76) Massaro A, Galian A (2020) Re-engineering process in a food factory: an overview of technologies and approaches for the design of pasta production processes. Product Manufact Res 8(1):80–100.

77) Harman CL, Patel MA, Guldin S, Davies GL (2019) Recent developments in Pickering emulsions for biomedical applications. Curr Opin Colloid Interface Sci 39:173–189

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
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DOI: 10.5281/zenodo.10947478

78) Kiran D, Sharma I, Garg I (2020) Industry 5.0 and smart cities: a futuristic approach. Eur J Mol Clin Med 7(8):2750–2756. Taş R, Tanrıöver OO (2020) A systematic review of challenges and opportunities of blockchain for E-voting. Symmetry. 12(8):1328

79) Ramesh C, Vinithkumar NV, Kirubagaran R, Venil CK, Dufossé L (2019) Multifaceted applications of microbial pigments: current knowledge, challenges and future directions for public health implications. Microor- ganisms. 7(7):186

80) Zhai H (2019) Advanced membranes and learning scale required for cost-effective post-combustion carbon capture. Iscience. 13:440–451

81) Kharchenko V, Dotsenko S, Illiashenko O, Kamenskyi S (2019) Integrated cyber safety & security management system: industry 4.0 issue. In: 2019 10th International Conference on Dependable Systems, Services and Technologies (DESSERT), pp 197–201 IEEE

82) Mitra A (2021) On the capabilities of cellular automata-based MapRe- duce model in industry 4.0. J Ind Inf Integr 21:100195

83) Chander B, Pal S, De D, Buyya R (2022) Artificial intelligence-based inter- net of things for industry 5.0. In: Artificial Intelligence-based Internet of Things Systems. Springer, Cham, p 3–45

84) Javaid M, Haleem A (2019) Industry 4.0 applications in medical field: a brief review. Curr Med Res Pract. 9(3):102–109

85) Li B, Boiarkina II, Yu W, Huang HM, Munir T, Wang GQ, Young BR (2019) Phosphorous recovery through struvite crystallization: challenges for future design. Sci Total Environ 648:1244–1256

86) Deepa N, Pham Q-V, Nguyen DC, Bhattacharya S, Gadekallu TR, Mad- dikunta PKR, Fang F, Pathirana PN (2020) A survey on blockchain for big data: approaches, opportunities, and future directions. arXiv preprint arXiv 2009.00858

87) Kumar A, Choudhary A, Kaur H, Guha S, Mehta S, Husen A (2022) Potential applications of engineered nanoparticles in plant disease management: a critical update. Chemosphere. 295:133798

88) Roy S, Chowdhury C (2021) Remote health monitoring protocols for IoT-enabled healthcare infrastructure. In: Healthcare Paradigms in the Internet of Things Ecosystem. Elsevier, pp 163–188

89) Ya M, Chen H, Yu Y, Zhao H, Li CF, Hu ZY, Wu P, Chen L, Wang H, Peng D, Gao H (2018) 3D Ferroconcrete-Like Aminated Carbon Nanotubes Network Anchoring Sulfur for Advanced Lithium–Sulfur Battery. Adv Energy Mater 8(25):1801066

90) Furstenau LB, Sott MK, Kipper LM, Machado EL, Lopez-Robles JR, Dohan MS, Cobo MJ, Zahid A, Abbasi QH, Imran MA (2020) Link between sus- tainability and industry 4.0: trends, challenges and new perspectives. Ieee Access 8:140079–140096

91) Kent MD, Kopacek P (2020) Do we need synchronization of the human and robotics to make industry 5.0 a success story? In: The International Symposium for Production Research. Springer, pp 302–311

92) Adhikari M, Hazra A, Menon VG, Chaurasia BK, Mumtaz S (2021) A road- map of next-generation wireless technology for 6G-enabled vehicular networks. IEEE Internet Things Magazine 4(4):79–85

93) Tong Z, Huang L, Lei W, Zhang H, Zhang S (2021) Carbon-containing electrospun nanofibers for lithium–sulfur battery: current status and future directions. J Energy Chemistry 54:254–273

94) Wan Y, Singgih M, Wang J, Rit M (2019) Making sense of blockchain technology: how will it transform supply chains? Int J Prod Econ 1(211):221–236

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
Journal of Tianjin University Science and Technology
ISSN (Online):0493-2137
E-Publication: Online Open Access
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DOI: 10.5281/zenodo.10947478

95) Wu J, Tran NK (2018) Application of blockchain technology in sustain- able energy systems: an overview. Sustainability. 10(9):3067

96) Xie JH, Huang T, Yu FR, Xie R, Liu J, Liu Y (2019) A survey of blockchain technology applied to smart cities: research issues and challenges. IEEE Commun Surveys Tutorals 21(3):2794–2830

97) Serror M, Hack S, Henze M, Schuba M, Wehrle K (2020) Challenges and opportunities in securing the industrial internet of things. IEEE Trans Ind Inf 17(5):2985–2996

98) Liu Y, Yuan X, Xiong Z, Kang J, Wang X, Niyato D (2020) Federated learn- ing for 6G communications: challenges, methods, and future directions. China Commun 17(9):105–118

99) Bajic B, Rikalovic A, Suzic N, Piuri V (2020) Industry 4.0 implementation challenges and opportunities: a managerial perspective. IEEE Syst J 15(1):546–559

100) Melnyk L, Dehtyarova I, Kubatko O, Karintseva O, Derykolenk A (2019) Disruptive technologies for the transition of digital economies towards sustainability. Економічний часопис-XXI (9-10):22–30

101) Siriwardhana Y, Porambage P, Liyanage M, Ylianttila M (2021) AI And 6G security: Opportunities and challenges. In: 2021 Joint European Confer- ence on Networks and Communications (EuCNC) and 6G Summit. IEEE, pp 1–6

102) Li L (2018) China's manufacturing locus in 2025: with a comparison of "made-inchina 2025" and "industry 4.0". Technol Forecast Soc Change 135:66–74

103) Raj V, Shim JJ, Lee J (2020) Grafting modification of okra mucilage: recent findings, applications, and future directions. Carbohydr Polym 246:116653

104) Foresti R, Rossi S, Magnani M, Bianco CG, Delmonte N (2020) Smart soci- ety and artificial intelligence: big data scheduling and the global stand- ard method applied to smart maintenance. Engineering. 6(7):835–846

105) Sedlmeir J, Buhl HU, Fridgen G, Keller R (2020) The energy consumption of blockchain technology: beyond myth. Bus Inf Syst Eng 62(6):599–608

106) Siuly S, Bajaj V, Sengur A, Zhang Y (2019) An advanced analysis system for identifying alcoholic brain state through EEG signals. Int J Autom Comput 16(6):737–747

107) Narvaez Rojas C, Alomia Peñafiel GA, Loaiza Buitrago DF, Tavera Romero CA (2021) Society 5.0: a Japanese concept for a superintelligent society. Sustainability. 13(12):6567

108) Sun W, Wang Q, Zhou Y, Wu J (2020) Material and energy flows of the iron and steel industry: status quo, challenges and perspectives. Appl Energy 268:114946

109) Tripathy HP, Pattanaik P (2020) Birth of industry 5.0: "the internet of things" and next-generation technology policy. Int J Adv Res Eng Tech- nol 11(11):1904–1910

110) Wang Y, Han JH, Beynon-Davies P (2018) Understanding blockchain technology for future supply chains: a systematic literature review and research agenda. Supply Chain Management: An International Journal

111) Yin Z, Zhu L, Li S, Hu T, Chu R, Mo F, Hu D, Liu C, Li B (2020) A com- prehensive review on cultivation and harvesting of microalgae for biodiesel production: environmental pollution control and future directions. Bioresour Technol 301:122804

112) Rashidi M, Mohammadi M, Sadeghlou Kivi S, Abdolvan MM, Truong- Hong L, Samali B (2020) A decade of modern bridge monitoring using terrestrial laser scanning: Review and future directions. Remote Sensing 12(22):3796

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
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DOI: 10.5281/zenodo.10947478

113) Tanveer M (2022) Supply chain and logistics operations management under the era of advanced technology. In: Integrating Blockchain technology into the circular economy. IGI Global, pp 126–136

114) Tijan E, Aksentijević S, Ivanić K, Jardas M (2019) Blockchain technology implementation in logistics. Sustainability 11(4):1185

115) Tönnissen S, Teuteberg F (2020) Analysing the impact of blockchain- technology for operations and supply chain management: an explana- tory model drawn from multiple case studies. Int J Inf Manag 52:101953

116) Abu-Elezz I, Hassan A, Nazeemudeen A, Househ M, Abd-Alrazaq A (2020) The benefits and threats of blockchain technology in healthcare: a scoping review. Int J Med Inform 142:104246

117) Ahluwalia S, Mahto RV, Guerrero M (2020) Blockchain technology and startup financing: a transaction cost economics perspective. Technol Forecast Soc Chang 151:119854

118) Andoni M, Robu V, Flynn D, Abram S, Geach D, Jenkins D, McCallum P, Peacock A (2019) Blockchain technology in the energy sector: a systematic review of challenges and opportunities. Renew Sust Energ Rev 100:143–174

119) Broo DG, Kaynak O, Sait M (2022) Rethinking engineering education at the age of industry 5.0. Journal of industrial information. Integration. 25:100311

120) Paschek D, Luminosu CT, Ocakci E (2022) Industry 5.0 challenges and perspectives for manufacturing Systems in the Society 5.0. In: Sustainability and Innovation in Manufacturing Enterprises. Springer, Singapore, pp 17–63

121) Perera S, Nanayakkara S, Rodrigo MN, Senaratne S, Weinand R (2020) Blockchain technology: is it hype or real in the construction industry, 17:100125

122) Ponnusamy V, Natarajan S (2021) Precision agriculture using advanced technology of IoT, unmanned aerial vehicle, augmented reality, and machine learning. In: Smart Sensors for Industrial Internet of Things. Springer, Cham, pp 207–229

123) Radanović I, Likić R (2018) Opportunities for use of blockchain technol- ogy in medicine. Appl Health Econ Health Policy 16(5):583–590

124) Saberi S, Kouhizade M, Sarkis J, Shen L (2019) Blockchain technology and its relationships to sustainable supply chain management.57(7):2117–2135

125) Sandt A, Al-Deek H (2018) A wrong-way driving crash risk reduction approach for cost-effective installation of advanced technology wrong- way driving countermeasures. Transp Res Rec 2672(14):85–95

126) Bryndin E (2020) Creation of social self-sufficient digital natural ecologi- cal economy with industry 5.0 of social state. Internet Things Cloud Comput 8:17–23

127) Cabaj K, Domingos D, Kotulski Z, Respício A (2018) Cybersecurity education: evolution of the discipline and analysis of master programs. Computer Security 75:24–35

128) Siyal AA, Junej AZ, Zawish M, Ahme K, Khalil A, Soursou G (2019) Applications of blockchain technology in medicine and healthcare: challenges and future perspectives. Cryptography. 3(1):3

129) Han WB, Lee JH, Shin JW, Hwang SW (2020) Advanced materials and systems for biodegradable, transient electronics. Adv Mater 32(51):2002211

130) Smith D, Feldman M, Anderson G (2018) The longer term effects of fed- eral subsidies on firm survival: evidence from the advanced technology program. J Technol Transf 43(3):593–614

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
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131) Fazal N, Haleem A, Bahl S, Javaid M, Nandan D (2022) Digital Management Systems in Manufacturing Using Industry 5.0 technologies. In: Advancement in materials, manufacturing and energy engineering, Vol. II. Springer, Singapore, pp 221–234

132) Janssen M, Weerakkody V, Ismagilova E, Sivarajah U, Irani Z (2020) A framework for analysing blockchain technology adoption: inte- grating institutional, market and technical factors. International journal of Management 50:302–309

133) Long T, Liang Z, Liu Q (2019) Advanced technology of high-resolution radar: target detection, tracking, imaging, and recognition. Sci China Inf Sci 62(4):1–26

134) Maddikunta PK, Pham QV, Prabadevi B, Deepa N, Dev K, Gadekallu TR, Ruby R, Liyanage M (2021) Industry 5.0: a survey on enabling technologies and potential applications. J Industr Inform Integr 26:100257

135) Mohant BK, Panda SS, Jena D (2018) An overview of smart contract and use cases in blockchain technology. In: 2018 9th International Confer- ence on Computing, Communication and Networking Technologies (ICCCNT), pp 1–4 IEEE

136) Feng H, Wang X, Duan Y, Zhang J, Zhang X (2020) Applying blockchain technology to improve Agri-food traceability: a review of development methods, benefits and challenges. J Clean Prod 260:121031

137) Golosova J, Romanovs A (2018) The advantages and disadvantages of the blockchain technology. In: 2018 IEEE 6th workshop on advances in information, electronic and electrical engineering (AIEEE), pp 1–6 IEEE

138) Hakak S, Khan WZ, Gilkar GA, Imran M, Guizani N (2020) Securing smart cities through blockchain technology: architecture, requirements, and challenges. IEEE Netw 34(1):8–14

139) Haleem A, Javaid M (2019) Industry 5.0 and its applications in orthopedics. J Clin Orthop Trauma 10(4):807–808

140) Ha ER, Ye S, Kim MJ, Lee YH, Park KH, Roh H (2019) Medical education trends for future physicians in the era of advanced technology and artificial intelligence: an integrative review. BMC Med Educ 19(1):1–5

141) Martyno VV, Shavaleeva DN, Zaytseva AA (2019) Information technology as the basis for transformation into a digital society and industry 5.0. In: 2019 International Conference “Quality Management, Transport and Information Security, Information Technologies” (IT&QM&IS), pp 539–543 IEEE

142) Min H (2019) Blockchain technology for enhancing supply chain resilience. Bus Horizons 62(1):35–45

143) Chen G, Xu B, Lu M, Chen NS (2018) Exploring blockchain technology and its potential applications for education. Smart Learn Environ 5(1):1

144) Cole R, Stevenson M, Aitken J (2019) Blockchain technology: implications for operations and supply chain management. Supply Chain Management: An International Journal

145) Demir KA, Döven G, Sezen B (2019) Industry 5.0 and human-robot co- working. Proc Comput.Sci 158:688–695.