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A Review of Industry 5.0: From Key Facets to a Conceptual Implementation Framework

Abstract

Purpose: The purpose of this study is to review the different facets associated with Industry 5.0 (I5.0) and propose a conceptual framework to boost the applicability of this novel technological cum social aspects within industrial organizations for improved organizational sustainability.

Methodology: This research work adopted a bibliometric analysis that encapsulates a quantitative set of tools for bibliometric and bibliographic information. This study uses the database of Scopus to acquire data related to different facets of I5.0. The study implies a different spectrum of terms to reach the final corpus of 91 articles related to I5.0. Furthermore, a conceptual DMAIC-based framework based on different literature findings is proposed and validated based on the input of experts from different parts of the world.

Findings: The results indicate that I5.0 is still in its infancy. The wider applicability of I5.0 demands comprehensive theoretical knowledge of different facets of this new paradigm and the development of a framework to adopt it on a larger scale. Organizations that are in the race to adopt I5.0 face major challenges related to the digitization of processes along with well-defined cyber-physical systems and the lack of a dedicated framework to execute I5.0. Furthermore, the result also suggests that manufacturing industries are more ready to adopt I5.0 practices as compared to service industries, which can be attributed to well-defined technological measures available in manufacturing settings.

Originality: This is one of the first studies that explore different know-how, challenges, and provides a holistic view of I5.0 by providing a systematic adoption framework.

Keywords: Industry 5.0; Review; Bibliometric analysis; Human centric system; Digital technologies

1. Introduction

The emerging use of Industry 5.0 (I5.0) technologies within the supply chain (SC) is disrupting and transforming industries and societies to improve triple-bottom-line performance

(Maddikunta et al., 2022). To cope with the modern challenges of shorter product life cycles, customized products, and quick response to instructions, industries in most of the world have adopted the digital technologies of Industry 4.0 (I4.0) (Pongboonchai-Empl et al., 2023; Kumar at al., 2023; Gangaraju et al., 2023). Though the inner production mechanism of I4.0 increases production efficacy and environmental mitigation metrics of micro-environmental sustainability (Chiarini and Kumar, 2021; Ghobakhloo et al., 2022; Kumar et al., 2024; Malik et al., 2024), it cannot outstrip the revenue-centricity and production consumption and economic paradigms. Further, the critics argued that I4.0 is more centred towards a neoliberal capital model that underscores profitability and shareholder preeminence, escalating certain eco-socio concerns such as ecological deprivation, regional equality, and flimsy economy (Maddikunta et al., 2022; Mittal et al., 2023; Kaswan et al., 2023). Thus, to address the challenges of environmental and social aspects of sustainability, and mass production of customized products cognitive aspects of the human must be coupled with digital technologies of I4.0 (Carayannis & Morawska-Jancelewicz, 2022). I5.0 is a logical extension to I4.0 where human aspects are connected with digital technologies for the production of high-quality products with minimal environmental and social hazards (X. Xu et al., 2021). In the last decade, I5.0 has been classified as a strategic improvement model for competitive edge and improvement in metrics related to sustainability. I5.0 technologies enable the production system more responsive through systematic reduction of wastes, cycle time, and associated environmental impacts and make workplace ambience more work-friendly which leads to improved job satisfaction among workers (Demir et al., 2019). Increased use of fossil fuel-based energy methods and traditional production methods forced the industry to cut its current level of emission (Bag et al., 2021). I4.0 does not safeguard any environmental protection through the use of interactive technologies (Mittal et al., 2023; Kaswan et al., 2023). Hence, the need to provide technical solutions for reducing environmental emissions from operations takes the march towards a new industrial revolution (L. Da Xu et al., 2018). I5.0 ensures improved organizational sustainability by inducing circular economy coupled with a smart manufacturing paradigm. Figure 1 depicts the different industrial revolutions. Table 1 depicts key differences between Industry 4.0 and Industry 5.0.

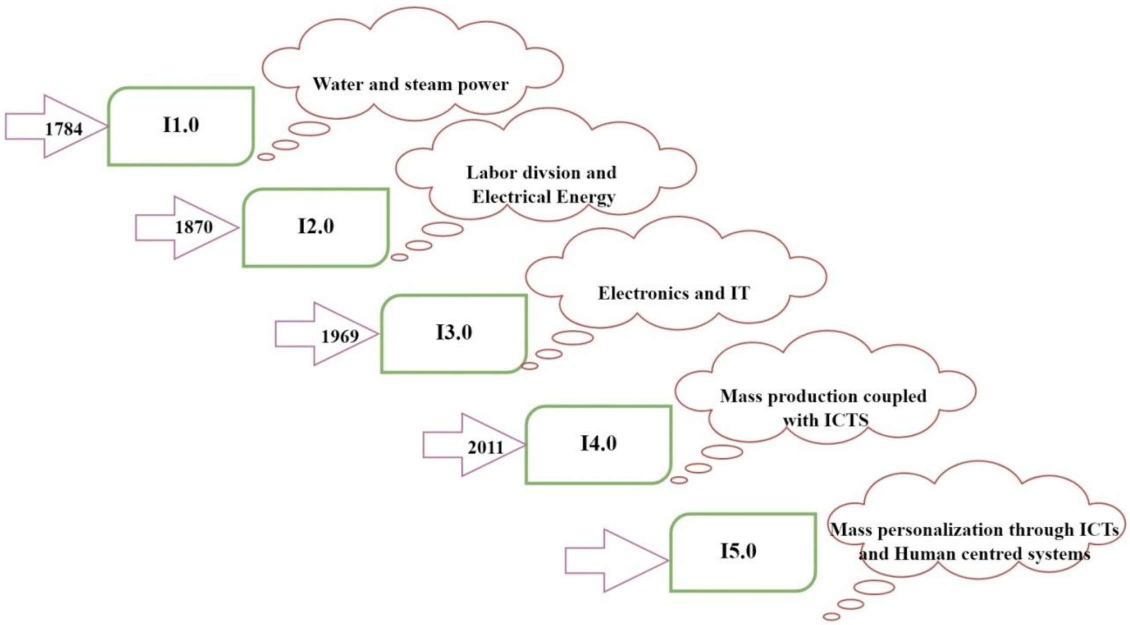

Figure 1: Different industrial revolutions

Table 1: Key differences between Industry 4.0 and Industry 5.0

Industry 4.0	Industry 5.0
Industry 4.0 is more centred towards productivity-driven competitiveness	Industry 5.0 encompasses productivity-led competitiveness and ecological development to make society more resilient
Industry 4.0 puts the technologies at the centre and revolves other actions towards the technologies	Industry 5.0 is human-centric and revolves technologies around the same with the focus on humanity aspects
Industry 4.0 advocates technological primacy in governance, innovation, and performance measurement	Industry 5.0 advocates stakeholder primacy in different aspects of the organization's performance and innovation assessment
Industry 4.0 is technology-oriented and does not encompass functions and principles to induce organisational sustainability	Industry 5.0 imbibes both technologies and human values to induce organizational sustainability
Industry advocates ecolgical and environmental sustainability and does not include aspects of social sustainability	Industry 5.0 prompts all dimensions of sustainability with a focus on making the industry more resilient and sustainable

Specified the prominence of digital technologies and human intelligence, together with the lack of research that combines the extant literature on the industrial applications of digital technologies, this study offers hindsight of the extant literature on digital technologies towards I5.0. For this, the paper applies bibliometric methodologies that encompass different quantitative techniques able to handle large data of the related literature. Through a bibliometric review of the literature, different themes and foundation areas in which I5.0 technologies are identified.

Furthermore, still, these newfangled service paradigms of I5.0 approaches, and practices are leftward with ICT experts, nifty businesspersons, and trade administrators. This advises that the notion of human aspects with digital technologies needs to be more explored to transform industries towards sustainable production and consumption models. Thus, there is a need to ensure the successful adoption of I5.0 to achieve more sustainable production environments. To ensure the successful execution of any novel set of technologies and facets it is imperative to comprehend different factors that ensure its success named success factors are also pre-requisite. Further to develop a thorough theoretical knowledge base and Know-how, it also becomes imperative to comprehend different barriers, application areas, and implementation challenges. So for this, this study also provides deep insights into different key aspects of I5.0 success factors, barriers, application areas, technologies and other related aspects of I5.0. Furthermore, the study also proposes a DMAIC-based conceptual framework to aid in the implementation of I5.0.

The rest of the article is organized as follows. Section 2 depcits adopted research methodology for the review of the I5.0. Section 3 illustrates findings and discussion, whereas Section 4 presents the conceptual framework of I5.0. Section 5 enumerates different viewpoints of the conducted review. Finally, inferences driven from the study are presented in the final section of the article.

2. Methodology

This research work adopted bibliometrics that encapsulates a quantitative set of tools for bibliometric and bibliographic information. The bibliometric review provides information on the domains characterized by large bibliometric and bibliographic information compared to the class literature review. Particularly, the study uses Donthu et al.'s four phases methodology to conduct a bibliometric review: (1) Establishing the scope for review (2) Identification of technique for analysis (3) Data fetching for analysis (4) Analysis of data and reporting.

The study infers different aspects of I5.0 by encapsulating the publication trend of articles, journals, country, industry-wise, and other different facets like key technologies, enablers' barriers, and application areas too. The scope of this extensive review is sublime as I5.0 is one of the disruptive approaches being widely embossed by industries to sustain in the modern industrial market.

2.1 Techniques for analysis

This study encompasses a wide range of bibliometric analysis techniques to unearth different facets related to I5.0 knowledge and execution. Besides, the handling of large quantity, the bibliometric analysis presents trends in articles, illustrative enlightened topics, and establish visualization of thematic evaluation (Goodell et al., 2021). This enables one to comprehend know-how of the concerned topic and provides different avenues for future research too. This study also conducted a performance analysis of the review corpus, selecting bibliometric analysis techniques of co-citation analysis, bibliographic coupling and co-word analysis. A co-citation is an effective tool for the demarcation of foundation knowledge. Bibliographic coupling explains the theme within the body of the knowledge, whereas co-occurrence analysis provides topical trajectories. The modularity of the networking nodes has been used for the co-citation of cited references, and bibliographic coupling of cited references.

2.2 Collection of data

This study uses the database of Scopus to acquire data related to different facets of I5.0. Authors in this study implied a different spectrum of terms to reach the final corpus of 91 articles related to I 5.0. Table 2 illustrates the systematic procedure to filter the final set of articles considered in this study for further analysis. As the data set directly grabbed from Scopus for bibliographic and bibliometric information may be prone to a false presentation of facts. So, direct processing of such records without data cleaning may lead to inappropriate results. Thus, data was cleaned through a systematic intersection of references. This strategy leads to an appropriate exploration of bibliometric and bibliographic data as well as the illustration and interpretation of the results. The authors also cleaned terms appearing in the title and keywords using the natural language processing function embedded in the VOSviewer. For example, terms like Industry 4.0 coupled with human-centric, human intervention in digital systems and Industry 5.0 were unified to simple Industry 5.0. Similarly, the authors integrated short forms of their expanded versions like I5.0, I4.0 and Human Centric systems. These cleaning mechanisms provided a uniform set of terms for further exploration of I5.0.

Table 2: Article selection for review

Filtering criteria	**Reject**	**Accept**
Search criteria		
Search Engine: Scopus		
Search date: 12: January 2023		
Search Term: TITLE ("industry 5.0") AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (PUBYEAR, 2023))		225
Article Selection		
Wrong record screening: Only articles with valid author information included	12	213
Language screening: English language document only included	45	168
Quality screening: Only high-quality articles with impact factors are included	77	91
Content screening: Includes articles if the title and keywords encompass the study's scope		

3. Bibliometric Analysis Findings

The top authors, in the I5.0 research area with several documents and their respective citations, are presented in Table 3. Based on the number of citations Nahavandi S. has been found as the most influential researcher in the area of I5.0, with 247 citations followed by Wang L., with 161 citations. Based on the number of articles published Wang L. is the most contributing author with four articles, followed by Dev K. with three articles. Table 4 represents the top institutions in terms of documents and citations. It has been found that the "Institute for intelligent systems research and Innovation, Deakin University, Waurn Ponds, 3216, Australia" is the most significant in terms of the number of citation got for I5.0 articles followed by the Department of production engineering, kth royal institute of technology, Stockholm, Sweden. In terms of the number of articles contributing to the I5.0 "Department of production engineering, kth royal institute of Technology, Stockholm, Sweden" has been found as the top contributor.

Table 3: Top cited authors for Industry 5.0

Author	**Documents**	**Citations**
Nahavandi S.	1	247
Wang L.	4	161
Dev k.	3	159
B P.	1	152

Deepa N.	1	152
Gadekallu T.R.	1	152
Liyanage M.	1	152
Maddikunta P.K.R.	1	152
Pham q.-V.	1	152
Ruby R.	1	152
Lu Y.	2	151
Xu X.	2	151
Vogel-heuser B.	2	128
Haleem A.	2	111
Javaid M.	2	111
Longo F.	1	86
Padovano A.	1	86
Umbrello S.	1	86
Raina A.	1	59
Singh R.P.	1	59
Suman R.	1	59
Ul Haq M.I.	1	59
Aimin W.	1	52
Aslam F.	1	52
Li M.	1	52
Rehman K.U.	1	52

Table 4: Top institutions for Industry 5.0

Organization	**Documents**	**Citations**
Institute for intelligent systems research and Innovation, Deakin university, Waurn ponds, 3216, Australia	1	247
Department of production engineering, kth royal institute of Technology, Stockholm, Sweden	4	161
College of computer science and software engineering, Shenzhen University, China	1	152
Department of Institute of intelligent systems, university of Johannesburg, South Africa	1	152
Korean southeast centre for the 4th industrial revolution leader education, Pusan national university, Busan, South Korea	1	152
School of computer science, university collage Dublin, Ireland and centre for wireless communications, university of Oulu, Finland	1	152
School of information technology and Engineering, Vellore Institute of Technology, Vellore, India	1	152
Department of Mechanical and mechatronics engineering, the University of Auckland, Auckland, New Zealand	2	151
Institute of Automation and information systems, technical university of Munich, Munich, Germany	1	128
Department of Mechanical Engineering, Jamia Millia Islamia, New Delhi, India	2	111
Department of Mechanical, energy and management engineering, university of Calabria, Rende, 87036, Italy	1	86

Department of Philosophy and educational sciences, university of Turin, Turin, 10124, Italy	1	86
Department of Industrial & production engineering, g. B. Pant University of Agriculture &, technology, Pantnagar, Uttarakhand, India	1	59
Department of Industrial and production engineering, dr b r Ambedkar national institute, of Technology, Jalandhar, Punjab, India	1	59
School of mechanical engineering, Shri Mata Vaishno devi university, Katra, Jammu and Kashmir, India	1	59
School of Management, Wuhan University of Technology, Wuhan, 430070, China	1	52
College of Chemical and biological engineering, Zhejiang University, Hangzhou, 310027, China	1	38
Department of Chemical and environmental engineering, faculty of Science and Engineering, University of Nottingham Malaysia, Jalan Broga, Semenyih, Selangor Darul Ehsan 43500, Malaysia	1	38
Department of chemical engineering and materials science, yuan ze university, no. 135, yuan-tung road, Chungli, Taoyuan, 320, Taiwan	1	38
School of energy and chemical engineering, xiamen university malaysia, jalan sunsuria, bandar sunsuria, sepang, selangor darul ehsan 43900, Malaysia	1	38
School of Pharmacy, Faculty of Science and Engineering, University of Nottingham Malaysia, Jalan Broga, Semenyih, Selangor Darul Ehsan 43500, Malaysia	1	38
Adit-lab, instituto politécnico de viana do castelo, rua da escola industrial e comercial de nun'alvares, viana do castelo, 4900-347, Portugal	1	26
Centro de investigación citic, universidade da coruña, a coruña, 15071, spain	2	26

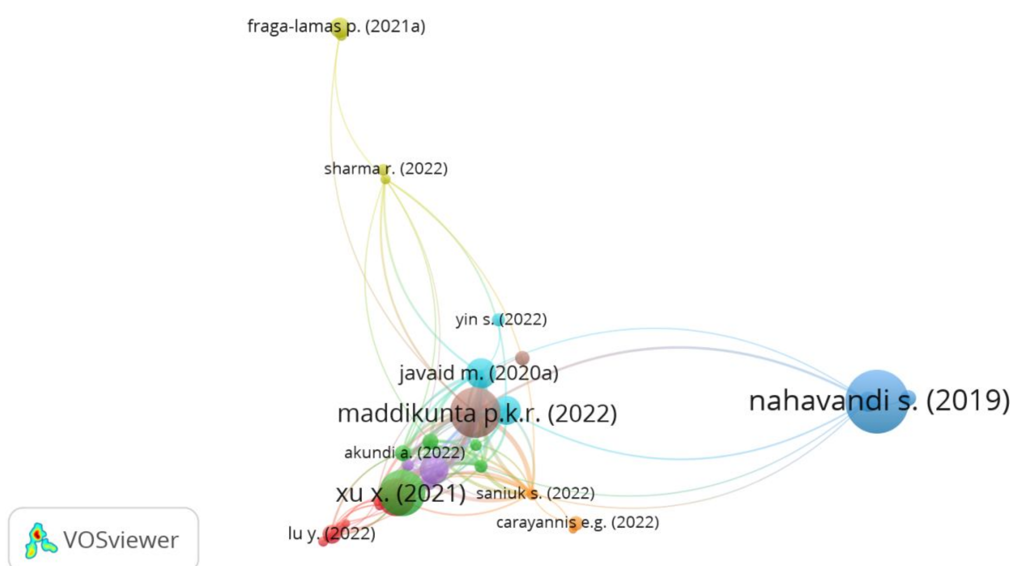

Figure 2: bibliographic coupling

Figure 2 depicts bibliographic coupling and different clusters associated with the domain of I5.0.

Bibliographic coupling and cocitation are methods used to analyze relationships within a citation network (Rousseau, 2008). While direct citations show usage, cocitation and bibliographic coupling reveal similarities between researchers or publications. Cocitation analysis examines how often papers or researchers are mentioned together in reference lists, suggesting connections between them. It operates on the assumption that when two papers are co-cited, there's a connection between them, and the frequency of this co-citation indicates the strength of that connection (Otte & Rousseau, 2002). By utilizing the number of links between papers, topical clusters can be depicted and examined using social network analysis techniques. These connections illustrate how researchers are interconnected or how their work is similar. Co-citation analysis reveals the structure of research fields, the interconnections between them, and potential changes over time. It's valuable for mapping scientific structures and identifying emerging research areas, as highlighted in various studies (e.g., Boyack, 2004). Bibliographic coupling is a method used to organize technical and scientific documents to aid in information retrieval. It entails identifying shared references between two documents, indicating a connection based on subject similarity (Kessler, 1963). When two publications both reference a third publication, they are considered bibliographically coupled. The more references they share, the more similar their subjects are assumed to be. Like co-citation analysis, bibliographic coupling can be utilized to map scientific structures and track changes over time. Some researchers argue that it may offer the most accurate depiction of scientific relationships, as it considers recently published articles with fewer citations (Pandey et al., 2023). Compared to co-citation clustering, the bibliographic coupling has distinct advantages, notably its ability to detect the initial phases of a speciality's development (Jarneving, 2007). These are also presented in Table 5. The major cluster that has focused on I5.0 is related to enablers, supporting technologies and applications. Human-robot integration, social aspects, I5.0 and innovations are relatively less explored fields of I5.0. Thus, this suggests that more explorative research in the fields of innovation, human-related collaboration with machines, and social aspects related to I5.0 is needed.

Table 5: Bibliographic clusters of Industry 5.0

Thematic Clusters	**Authors**	**Total Citations**
Human-machine interaction	Aceta *et al.* 2020	86
	Huang *et al.* 2022	23
Enablers of Industry 5.0	Xu *et al.* 2021	128

	Sindhwani *et al.* 2022	16
Applications of industry 5.0	Nahavandi 2019	247
	Gürdür *et al.* 2022	25
Industrial IOT in the era of industry 5.0	Fraga-Lamas *et al.* 2021	26
	Fatima *et al.* 2022	7
Developing Frameworks to deal with industry 5.0	Aslam *et al.* 2020	52
	Mihardjo *et al.* 2019	5
Digital innovation and personalisation under industry 5.0	Javaid and Haleem, 2020	52
	Yin and Yu, 2022	11
Social expectations of industry 5.0 (society 5.0 and industry 5.0)	Carayannis and Morawska-Jancelewicz, 2022	13
	Saniuk *et al.* 2022	9
Supporting technologies of industry 5.0	Maddikunta *et al.*2022	152
	2. Rupa *et al.* 2021	13

Figure 3 illustrates the countries' network for the documents and citations on I5.0. China leads the research related to I5.0 with a number of documents, citations, and link strength of 21, 339, and 94 link strength respectively. India is situated in number two with 14 documents, 307 citations, and 76 link strength. Australia is one of the most prominent countries in terms of research in the field of I5.0 with 5 documents but 257 citations and 69 link strength, other prominent countries in the field of I5.0 research include USA, UK, Spain and Sweden.

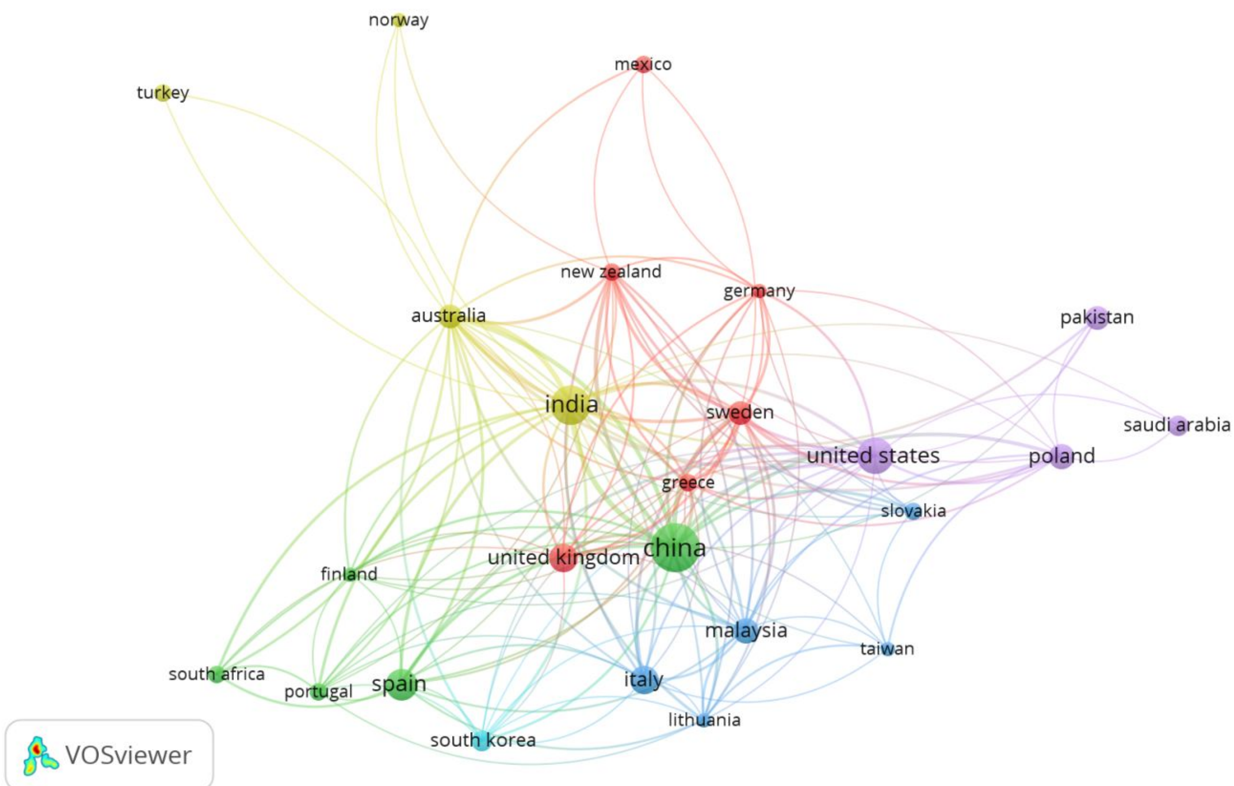

Figure 3: Countries' network

Figure 4 illustrates a co-citation map of the cited authors. The notion behind the conduct of the co-citation analysis is to depict the knowledge foundation of the intended area of the review. The co-citation analysis leads to five different clusters: yellow, green blue, purple and red. The first cluster yellow depicts the articles related to the application field of I5.0. Green cluster demonstrates the studies related to the human-centric system for enabling technologies of I5.0. Similarly, the blue cluster exhibits the actual execution area of I5.0. Further blue cluster shows the role of blockchain, and how it can enhance security systems within I5.0. The red cluster of the co-citation elucidates the more theoretical studies that illustrate the notion and know-how of I5.0.

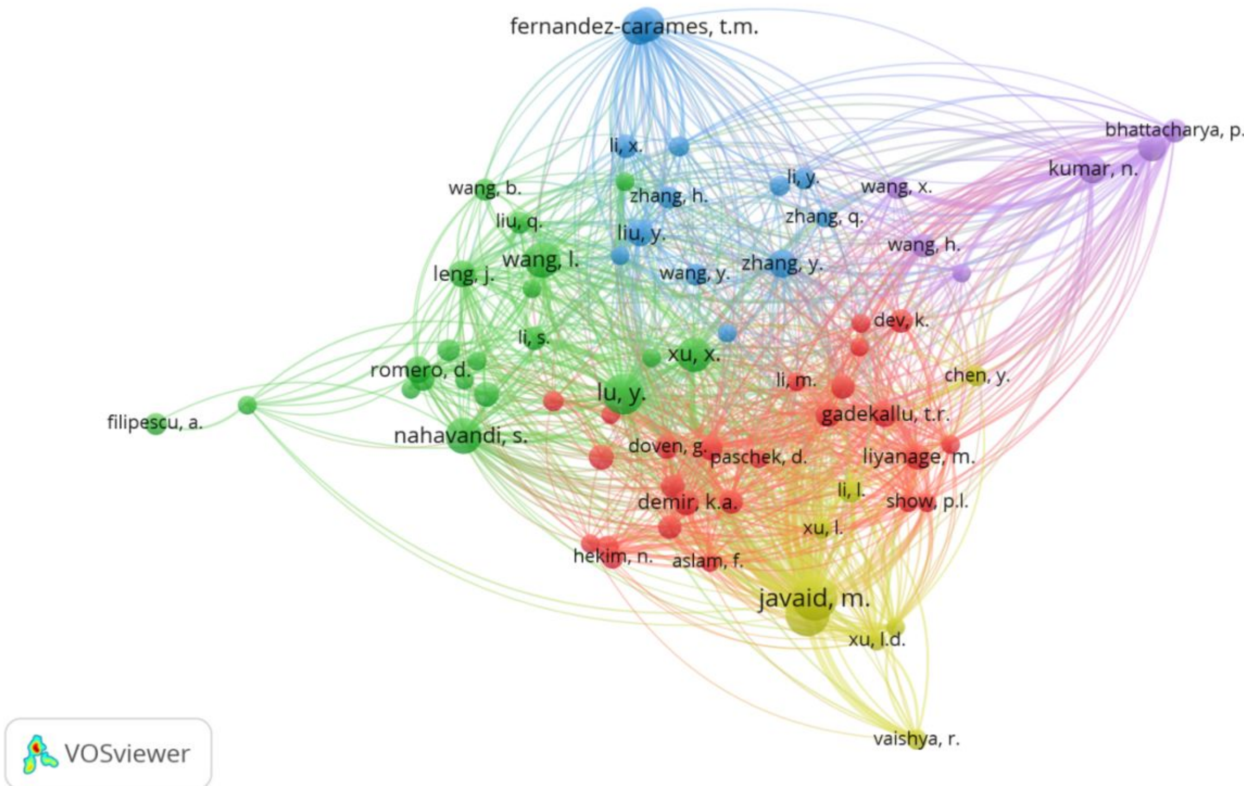

Figure 4: Co-citation authors

The text mining software VOSviewer was used to visualize relevant topics and associations, and how they are related. Figure 5 illustrates the key terms used in the screened articles and the size of the dots depicts the term's frequency. In the academic literature, the most used keywords or related themes out of keywords are Industry 4.0, and Industry 5.0 with green and red colour. Undoubtedly, the green Industry 4.0 clusters terms are closely related to digital transformation and Industry 5.0 aspects. As I5.0 carries forward the march of I 4.0, it imbibes key technologies of I4.0. Small dots of IoT, smart manufacturing, edge computing and digital twin are closely associated, and these are being frequently used in combination in the recent articles on the I5.0. The blue cluster on the left-hand side imbibes general terms such as 'Society 5.0', 'Digital Transformation' and 'Operator 5.0', suggesting that these are high-level conceptual works rather than case studies that supply specific tools and techniques. Overall repeated occurrence of the themes in numerous clusters exhibits that they are closely related.

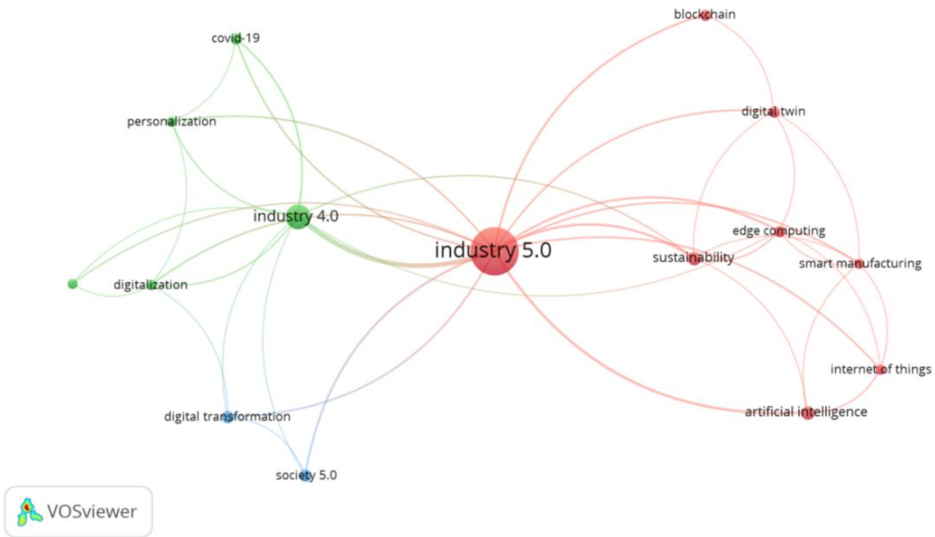

Figure 5: Co-citation author keyword

The adoption of I5.0 is hindered by different factors called 'barriers'. Table 6 depicts different barriers that obstruct the implementation of I5.0. To remove these barriers, a comprehensive understanding of the barriers, and understanding of the I5.0 technologies and application area is needed. Table 7 depicts different application areas while Table 8 and figure 7 illustrates enabling technologies of I5.0. Figure 6 depcits industry wise manuscript and 7 illustrated different enabling technologies that foster execution of I5.0.

Table 6: Barriers to the adoption of Industry 5.0

Barriers to I5.0	**Label**	**Description**	**Reference**
Resistive culture	BA1	Adoptions of advanced technologies coupled with I5.0 are resisted by organizational personnel due to their limited knowledge base towards new facets of manufacturing. As organizational members are adept at traditional methods of working and new technology adoption is resisted due to a lack of change management, continuous learning, and a march towards excellence culture within the industrial setting.	(Kamble et al., 2018) (Horváth & Szabó, 2019)
Digitization and automation of the process	BA2	Entwining physical processes and digital technologies adds to better management of operations in the transformation process of the realization of a product or service. This integration supports better management of transportation, and inventory, and promotes resource sharing, mutual collaboration, and trustworthiness among partners of SC. But entwining technologies of I5.0 with traditional methods of work is also challenging due to non-availability standards and established benchmarks for comparison standards.	(M. Sharma et al., 2022) (Kamble et al., 2018)

Integration challenges in the value chain	BA3	Adoption of I5.0 technologies demands collaboration, information exchange, and resource sharing among different of the SC and value chain. Mutual collaboration and trustworthiness among partners must be developed so that the adoption of I5.0 technologies will bring harmony for all partners of SC and its will improve productivity, profitability, and will bring a competitive edge for all partners at the global level	(Raj et al., 2019) (Q. Liu et al., 2019)
Establish a linkage between reality and computer-generated reality	BA4	It is imperative to integrate all the aspects of virtual engineering, virtual factories, and virtual objects using a systematized CPS to have a virtual production system. A well set of technologies, security, and standard are demanded to exchange information between virtual and real production.	(Rajput & Singh, 2019) (Q. Liu et al., 2019)
Concerted paradigm	BA5	I5.0 demands effective collaboration between robots and human actions to make an intelligent and accident-free workspace where robots can mimic and can sense and analyze human intention. The collaborative model of the robot and human intelligence boosts research and development actions, creation of smart devices coupled with the human touch, and ensures the development of a human-machine safety system that will reduce accidents and induces enhanced work satisfaction.	(Q. Liu et al., 2019)
Regularization of infrastructure	BA6	Making the ready industrial setting for the adoption of I5.0 demands considerable changes in the existing infrastructure for introducing automation and introducing integration among numerous components.	(M. Sharma et al., 2022)
Well-defined standards for CPS	BA7	As CPS built integration of the physical facilities with the virtual world, it becomes imperative to validate the framework of CPS with well-known established standards so that the product manufacturing system comprehends the required specified constraints.	(Rajput & Singh, 2019)
Lack of sustainability pursuits	BA8	The use of sustainable business practices and methods leads to a reduction in the cost associated with material handling and transportation. Resistive culture and lack of go-forward march culture further inhibit organizations to adopt sustainable practices like I5.0, circular economy, Green Lean Six Sigma, etc.	(M. Sharma et al., 2022)
Prone to accidents due to increased use of technologies	BA9	Due to dissension and improper feedback, there are chances of more accidents due to the high level of automation. The use of smart robots that can comprehend human intentions and emotions is the next level of revolution that is demanded to make the workplace accident free.	(Kamble et al., 2018)
Financial constraints	BA10	The adoption of I5.0 technologies demands considerable investment in the procurement of new technologies related to ICTs, the establishment of required infrastructure, and the research and development of collaborative robots that can interact and comprehend human interactions. The lack of funds from industrial organizations especially in developing nations like India further constrains the adoption of I5.0 incorporation methods.	(Kamble et al., 2018) (Horváth & Szabó, 2019)

Table 7: Industry 5.0 applications in different industrial sectors

Sector	**Applications area**
Healthcare	Machine learning methods can be adopted by healthcare doctors to diagnose different diseases (Hanif & Iftikhar, 2020). This will bring accuracy in diagnosis and will also save a considerable proportion of time and money for the patients. But in the current scenario is essential to take care of the personalized requirement of the patients through their monitoring of key health parameters using personalized monitoring devices and providing patients with personalized treatments to the patients from doctors. ICTs devices and sensors can be used to take a constant record of key healthcare parameters of the patients and the same, and ML-based can be used for the medical condition of the patient. The intelligent devices equipped with I5.0 technologies interact with each other and can feed alerts to doctors if something abnormal is reported in the data of patient health parameters (Madsen & Berg, 2021). Cobots can be used in the medical industry for assisting in surgery, diagnosis, and other allied medical matters. Technologies like digital twins can be used for the personalized prescription of drugs to patients. I5.0 can play a tremendous role in the manufacturing of custom implants in orthopaedics, and also assist in precision surgery work. I5.0 helps to prevent front lines workers from infection during COVID-19 through the use of smart robots for scanning and treating the affected population of COVID (Javaid et al., 2020). I5.0 's assistive technologies like additive manufacturing are used for manufacturing personalized equipment and accessories like orthoses, and prostheses for disabled or handicapped persons.
Education	IoT-based devices and the cloud has revolutionized the education sector during the COVID era (Javaid et al., 2020). Many universities in developing nations already started their online degree program through enabling technologies of the I4.0 But to be more pragmatic and more intelligent is always expected to introduce human intervention in education to understand different practical and Engineering concepts (X. Xu et al., 2021). The use of different intelligent devices, and simulation software's already drastically reduced costs associated with the manufacturing of precision electronic devices but the incorporation of human involvement with cognition to manufacture devices with minimal rejection is already demanded. The use of I5.0 technologies with human intention can revolutionize education where all theoretical aspects can be covered in online mode and real-time execution is performed in the field with human intelligence and assistance of the other physical objects.
Manufacturing	I4.0 with the evolution of robots brought a tremendous shift in the world's manufacturing systems. Robots have already been utilized in industry to perform risky and monotonous jobs in the industry, ranging from welding, and painting to loading and unloading heavy items. I5.0 combines cognitive computing skills with human intelligence to make the machine smarter and connected to make the workplace safer (Carayannis & Morawska-Jancelewicz, 2022). This will bring fundamental changes within the industrial setting related to workplace norms. The I5.0 environment makes COBOT more intelligent to analyze human intent before analyzing the work so that COBOT can decide whether human interaction is demanded in the particular task or not (Nahavandi, 2019). I5.0 will create more jobs due to increased human and men interaction in the coming times. To prompt applications of I5.0 Javid and Halem identified different critical factors and concluded that execution of I5.0 technologies driven by human intelligence will bring increased productivity, and more job and customer specification.
Disaster Management	I5.0-enabled technologies can be used for effective management under different disasters. AI and ML-based devices, IoT based system helps to comprehend pattern and different assessment related to COVID. The COVID-19 pandemic brings considerable changes in the disaster management strategies of many organizations to make the plan for disaster mitigation more resilient (Haleem & Javaid, 2019). Integration of AI and IoT coupled with human intelligence can help in solving the different issues related to disaster mitigation.

Agriculture	It can be easily presumed that the use of an advanced digital set of technologies coupled with human intelligence is not only beneficial to the agriculture sector but leads to improved social dynamics of the society. Agriculture sector as compared to other industrial domains characterized by low productivity, low managerial manpower due to limited farm size, weather uncertainties and a volatile balance between food consumption and production. All these make agriculture a high-risk factor in terms of making it a win-win sector to boost a nation's economy. But at the same juncture, effective management of operations, and a real-time decision support system coupled with human intelligence can help this sector to extensive leap. Effective use IoT based devices, AI, use of big data can be used to adjudge different parameters related to the growth of the plant, and systematic analysis of all sets of data gathered through big data provides some concrete facets that can undertake into consideration for quick action through human intelligence to support different corrective action that will lead to improved health of the plant (Doyle-Kent & Kopacek, 2021). Systematic use of I5.0 technologies provides effective information about nearby stores, warehouses, pricing policies in the area, and demand pattern that ultimately helps tellers to cultivate crops that are highly beneficial to the farmers. So, all sets of I5.0 technologies will lead to producing food more efficiently, of higher dietary quality, in more steady supplies, with a reduced amount of ecological damage.
Cloud manufacturing	Cloud manufacturing is a new manufacturing paradigm where different stakeholders from different parts of the world collaborate with the use of technologies like IoT, EC, and virtual and service technologies to provide products of high quality at a low rate (Reddy et al., 2021) (Longo et al., 2020). Cloud manufacturing induces environmental sustainability in the system as it eliminates the long-haul delivery requirement of the raw material (Chiarini et al., 2020). It enables designers to protect their designs with high cyber security systems with access to manufacturing systems throughout the world. This permits design people to establish manufacturing units in remote nations where there is the availability of raw materials and low-cost labour. Under a cloud manufacturing environment different control related to manufacturing, scheduling, and services are managed by the cloud (Skobelev & Borovik, 2017). Different parameters related to the manufacturing process are monitored through IoT-enabled sensors and are analyzed in the cloud. There are increasing numbers of evidence of the cloud-based manufacturing system in the academic literature to tap the potential of different business models (Rahardjo & Wang, 2022). The advent of the technologies of I5.0 with the next generation cloud manufacturing will be able to meet the high specifications of customers with improved organizational sustainability (Y. Liu et al., 2016). The advent of 5G technologies and a new paradigm shift in IoT and AI will open different prospects for future cloud manufacturing systems to cater for different prospects related to customer and sustainability.

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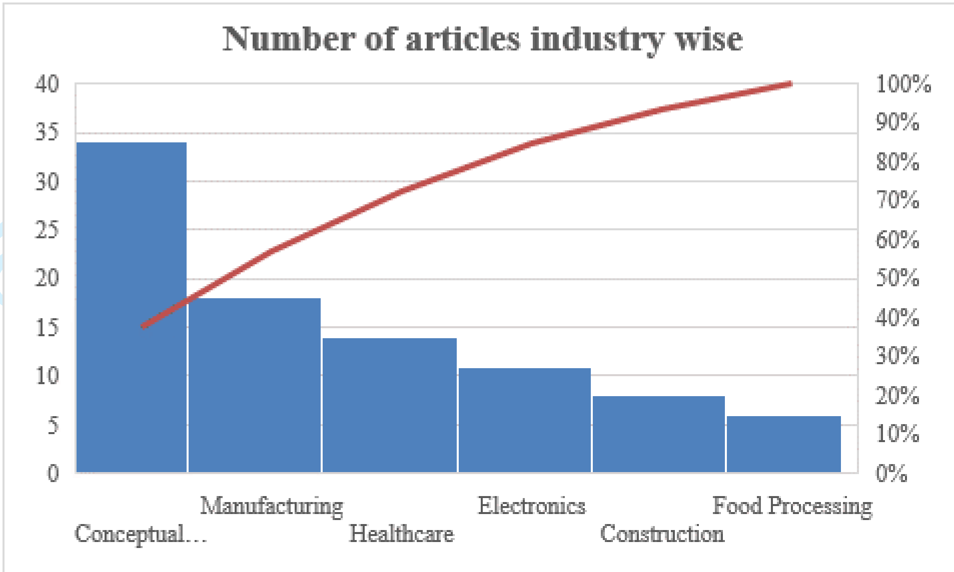

Figure 6: Industry-wise number of articles

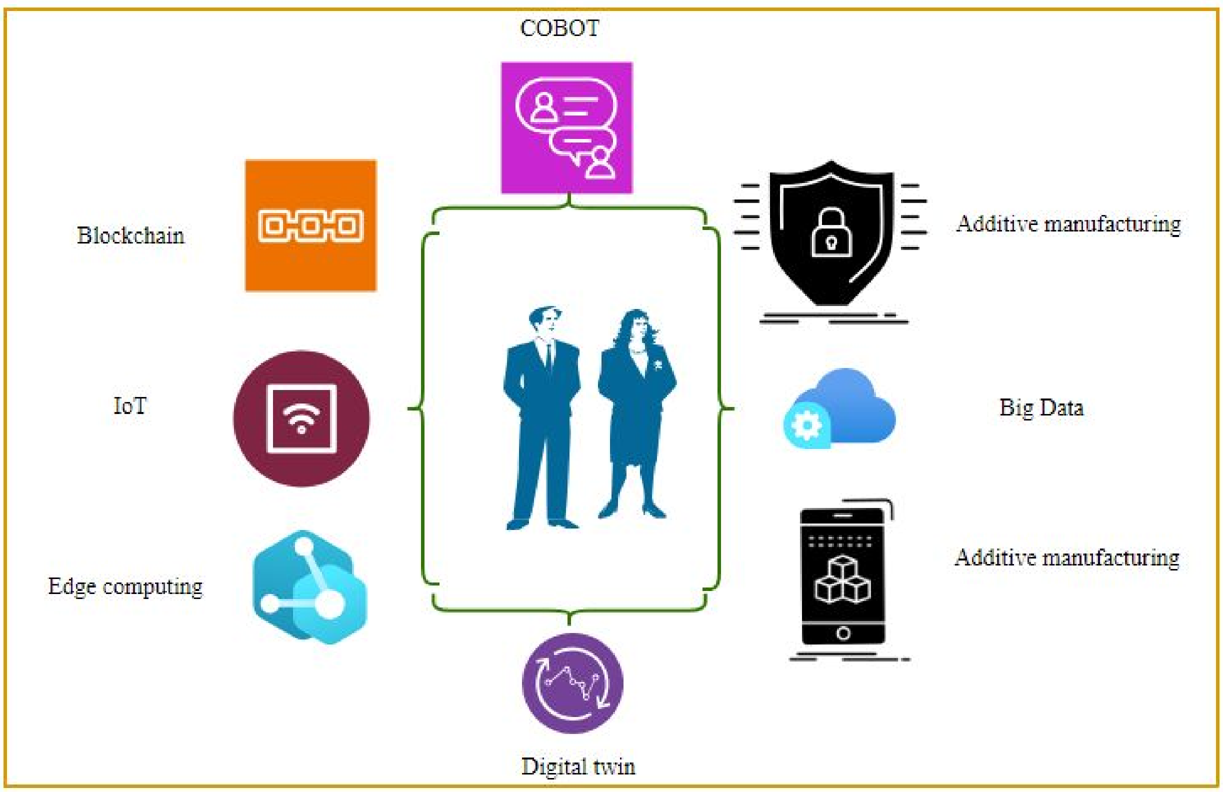

Figure 7: Key technologies of Industry 5.0

Table 8: Key technologies of Industry 5.0

Enablers of Industry 5.0	Description	Reference
Ergonomics	Ergonomics is one of the key areas to comprehend, analyze, and design human work in the I5.0 era. It is the interaction between engineering, human ergonomics, and human-robot ambience to understand human work optimization. With human beings at the centre, different sciences of human are applied to design and operation management taking into consideration work safety. Human-centric systems make the system free from worker errors and optimize the performance of human-machine collaborative systems under the premise of enabling the system as comfortable, safe and satisfying as possible for workers (Madsen & Berg, 2021). So, in nutshell, ergonomics leads to improve work efficacy and satisfied human value. The research content of ergonomics pinpoint interactions between human, product, facilities, and work ambience and the research method of ergonomics focus on capabilities, limitation and preference e of human being and use them to design and manufacture products, operating procedures and work ambience in which they are used. With the rapid advancement in the field of I5.0, it is imperative to pay more attention to the technological integration of ergonomics and human-robot safety considering worker well-being and psychological needs.	(Leng et al., 2022)
Zero effect zero defect	Every industrial to sustain itself in the modern era of competition must produce high-quality sustainable products for right first time and without any defects (Saptaningtyas & Rahayu, 2020). A defective product once manufactured then at the place of the same a new product is manufactured then again leads to the incorporation of more material, energy and other associated wastes that can be saved if the product is manufactured right the first time. ZED is one of the key technological enablers to flourish an industry and productive system in the I5.0 era. It makes the system more focused on SDGs (Fatima et al., 2022) as compared to other traditional quality characteristics. Human factors in manufacturing cannot be ignored as it makes different decisions and cognitive aspects to realize high-quality products. ZED combined with human thinking is capable to identify where defects will occur and thus drives the proactive system to prevent defects and realize a value-driven system of I5.0 as compared to traditional quality-based systems. The quality-oriented system based on ZED is expected to become a new standard for the industrial organization in the I5.0 era.	(Doyle-Kent & Kopacek, 2021)
Increased human-robot collaboration	As humans are at the centre of the I5.0 system, they have to work in the collaboration with intelligent machines and robots (Noble et al., 2022). It is imperative to enhance the high level of collaboration to make the workplace more productive, responsive and safer to meet social aspects of sustainability. Under human-robot collaboration (HRC) workers can work side by side with the robots. Here, the strength, endurance, repetabilty and accuracy of robots with intuition, flexibility, and versatile problem-solving skill of human beings are used to take advantage of human-robot collaboration. Human intelligence with cognitive computing is used in conjunction to deliver user-centred products and services. HRC leads to improved work efficacy with worker well-being by removing faults from human and robotic manufacturing while increasing flexibility and reconfiguration (Carayannis et al., 2021). Further extension of HRC is a symbiotic HRC that place human being and robot in a cyber-physical	(Leng et al., 2022)

	interconnected system where human and robot work in a shared context to full fill complex production work. Symbiotic HRC possesses key features of adaptive execution, decision-making, reasoning, and self-learning through real-time multi-model communication. Further proactive HRC not only helps physically but also proactivity understanding and empathising at the cognitive level of thinking, using knowledge as a medium of communication. During the collaboration, humans are aware of the adaptive execution of the updates for improved productivity and the robot can learn human attention and present better compatibility with human beings during real-time work execution. With further advancements in the field of AR, IoT, and cognitive computing the capabilities of proactive HRC can be unfolded many times to help future manufacturing systems. With value-driven at the core of I5.0 proactive HRC system can be foreseen as a flag bearer to make industrial organizations more sustainable and competitive in the era of I5.0.	
IoT-enabled big data analytics	The incorporation of IoT in modern industries and society has enabled communication between devices connected and humans as well (R. Sharma & Arya, 2022). Today a large set of data is being produced through IoT-enabled devices and transferred throughout the globe. For this, big data analytics come to the fore to grab this data set and extract useful information from the same. The data can be transferred across the globe at a high pace through the evolution of 5 G. But at the same time, there is a limitation adhered to the large data: transmission storage and extracting insightful data from the same. So, it is imperative to explore and further fine-tune existing methods to avoid such situations. Semantics and ontology can be used to tackle issues of interoperability and thus can collect real-time information from real-world systems to analyze processes and provide insightful information and decision to support the workers (Panopoulos, 2022). Using cognitive technologies, I5.0 provide big data with a symmetric innovation platform. Cognitive technologies and big data are providing many opportunities in the different applications under I5.0. Big data find applications to adjudge customer behaviour to make pricing policies for the products that are supported in quality checking and making adaptive decisions. Big data analytics can be used to remove non-essential things to improve predictability, this feature of big data is being used in manufacturing healthcare, and the agriculture sector for optimization in the value chain.	(Reddy et al., 2021)
Digital twin	Digital twins are gaining momentum due to rapid advancement in AI, IoT-enabled sensors, big data analytics, and increased computing infrastructure for improving performance and reduction in cost (Rakesh & Manish, 2022). Digital tools provide an emulation tool to support design, manufacturing, reconfiguration, and assist in optimization in a human-centric cyber-physical system. AI technologies can also help digital twins for performing dynamic optimization based on real-time data to enhance the design and operational efficacy. Digital twins lead to saving costs in the design and manufacturing aspects of CPS enabled by real-time emulation and simulation of the different designs and other databases.	(Javaid & Haleem, 2020)
Extended reality	Extended reality includes three key aspects, virtual, mixed and augmented reality. Extended reality framework provides the projection of digital or virtual information using a physical system (Rupa et al., 2021). augmented worker concept comes to the fore due to the extended reality frameworks. Extended reality can be used to find defects, breaks, and other flaws in the whole process of manufacturing thus assisting in the quality control aspects. It can store data related to workers and provide the structure of human beings that can be useful during planning complex operations under the entire domain of operations management.	(Paschek et al., 2019)
Blockchain	Blockchain is a secure, shareable, and decentralized computing model that adds values in I5.0 (Demir et al., 2019) (Rahate et al., 2022). For effective system	(Leng et al., 2022)

	management blockchain can create digital identities for workers, machines, and robots. It provides a secure cyber system that solves the authentication problem of heterogeneity and privacy protection of workers under human-robot collaborative systems. It can also be used to develop smart contacts that can be used to develop smart contracts by automating the agreement between different stakeholders to get remove inconsistency in planning and production. It can also be used to protect intellectual property and share at the product life cycle stage to main the design and manufacturing copyrights and property. Blockchain is considered a next-generation IT that promotes the paradigm of I5.0 that leads to the shaping of a resilient society through the use of a decentralized computing system to serve people, industry and the entire human society (Akundi et al., 2022). In the value-driven era of I5.0, blockchain data management systems will reduce the cost of activities related to supervision and continuous monitoring.	

4. Industry 5.0 conceptual implementation framework

I5.0 is a new industrial paradigm that improves organizational efficacy, improves social and environmental sustainability (Paschek et al., 2019). However, to implement a new concept or approach within an organization there need to be major technical and infrastructure changes to meet the expectation sought from the paradigm concerned. Thus, it is advisable to implement a new approach, first as a pilot project and then launch the same through the industry, once the pilot project's success is ascertained. This study proposes a systematic framework (figure 8) to execute a DMAIC-based I5.0 framework for manufacturing industries. The research design to constitute the framework consists of two steps:

In the ***first step***, to develop conceptual framework, existing literature was reviewed that explore different facets related to application, integration, and tools of I5.0 Then,. The reviewed frameworks are summarized in table 2. The overall structure of the preliminary framework, as well as the recommendations for the incorporation of different performance metrics and execution phase, were modelled on the Integrated I4.0-GLSS frameworks of Kaswan and Rathi (2020a) and Rathi et al. (2022), who organized their frameworks around the five DMAIC steps. Meanwhile, the suggestions for the incorporation of different I5.0 technologies were based on the reviewed literature related to Industry 4.0. As described below, this introductory framework was then reformed based on inputs from an expert panel to make more validated from the application point of view.

In the ***second step***, the proposed theoretical framework was validated through practitioners of digital technologies-enabled human-centric systems throughout the world. This validation scheme follows the same approach as a study that validated a conceptual framework of Lean with I4.0 using opinions from experts (Tortorella et al., 2021). Since this research focused on the framework development of an integrated I5.0 approach, the authors aimed at involving practitioner experts that had utilized human-centred systems enabled through digital technologies and I5.0 practices for sustainability enhancement. To verify the authenticity of the developed framework, the authors developed a questionnaire that encompassed different questions to check whether the available tools were appropriate at different stages, the potential of the framework to enrich sustainability and future adoption of the framework. The questionnaire was sent to 50 expert practitioners around the world that had significant experience in conducting operational excellence approaches and I5.0 practices. 25 complete questionnaires were received; the details of the expert practitioners are presented in Table 9. The inputs from the expert panel and corresponding modification made are presented in the table 10.

Table 9: Demographic details for the experts to validate and fine-tune the proposed framework

Expert	Description	Experience to execute digital, and sustainable business practices (in years)	Country/Province
E1	Deputy general manager	24	United Kingdom
E2	Senior engineer	36	United Arab Emirates
E3	Continuous improvement manager	31	China
E4	Senior engineer	16	Italy
E5	Quality Manager	21	Scotland
E6	Sustainable development lab head	22	Brazil
E7	Manager	34	Portugal
E8	Professor	19	Spain
E9	Quality improvement manager	26	Ireland
E10	Professor	25	Denmark
E11	Quality assurance engineer	23	France
E12	Senior lead engineer	16	Japan
E13	Professor	27	Taiwan
E14	Manager	13	China
E15	Senior manager	29	USA
E16	Quality assurance manager	23	Poland
E17	Technology officer	18	Finaland
E18	Executive engineer	22	Russia
E19	Value assurance manager	26	Japan
E20	Value control inspector	24	United States of America
E21	Product Manager	27	Pakistan
E22	Quality officer	14	Canada

E23	Assistant plant manager	15	India
E24	Chief executive engineer	18	South Africa
E25	Senior product engineer	22	Switzerland

Table 10: Experts inputs to finetune the intial framework

Framework phases	**Experts inputs**	**Adjustments made in the framework**
Identify a suitable project	The preliminary framework consists of to select a project for I5.0 implementation. But it not included the criteria related to social, environmental metrics that are crucial to be included to improve the overall sustainability of the organization.	To make a real judgement of organization sustainability different criteria of sustainable performace are also included in the preliminary framework. Further, weights for criteria were also assigned to select the criteria that is having most influence on the organization performance view point.
Assessment of key metrics	Experts suggested including more metrics related to social and environmental performance to provide a real picture to estimate organization sustainability. Experts also suggested using integrated application of sensor and IoT to provide real time performance data from the shop floor. Further experts suggested using LCA and SLCA to access current level of different environmental and social metrics associated with the selected project.	With inputs from the experts more metrics related to social and environmental performance were included to provide better estimate of the sustainability.
Explore the main causes for low performance and social and environmental sustainability	Need for classification of the different reasons for low enactment is demanded to narrow down the prominent reasons for wastes and inefficiencies	The early framework did not include a classification of the causes for low performance. Constructed through input from experts, diverse causes for low performance are now classified and the exploration is contracted to recognize the noticeable groups of reasons.

Explore and execute the best solution to produce mass-customized products at a high frequency	Experts suggested to include metrics related pugh to check strength and weakness of the proposed best solutions. Experts also suggested using integrated application of different technologies of I5.0 and traditional quality improvement tools.	Based on suggestion, in this step framework integrated application of different technologies of I5.0 with human cognitive thinking are applied to find the better solution that leads to increased productivity, profitability, social and environmental sustainability.
Sustain the best practices with continuous monitoring and always keep on changing perspectives	Experts advised using the best practice for enhanced duration and assessing numerous metrics connected to social and environmental aspects for long run using SLCA and LCA in conjunction with data gathered from different IoT enabled sensors	Based on suggestion, organization performance is rechecked after every six month, action plans are initiated to make the necessary modifications, as per the goal of the project.

The associated phase of the framework are ilssutate below:

Phase 1: Identify a suitable project

Being a new aspect of the industry, it becomes imperative to launch the I5.0 framework as a pilot project within the industrial setting. The very first phase of the framework is to identify a suitable project that taps the maximum potential for sustainability enhancement. Based on the large data set of the industry, the voice of stakeholders and careful estimation of the different associated wastes the project is identified integrated application of IoT and big data is used to kick off this sustainable approach. To select a suitable project firstly different criteria are selected (material, productivity, social, environmental, and facility). Afterwards, different weights are assigned to the criteria based on the need of the organization. Subsequently, different projects are evaluated and the project that finds the best score is selected for further proceeding. It is imperative to use the feedback and opinions from the persons who are performing tasks on the shop floor, which will reflect the maximum potential of the organization to select a suitable project within the existing capacity constraints of the organization. In a completely automatic scenario the human intelligence to explore a project which is ignored that can ultimately lead to the selection of a project that will not be effective to enhance organizational sustainability.

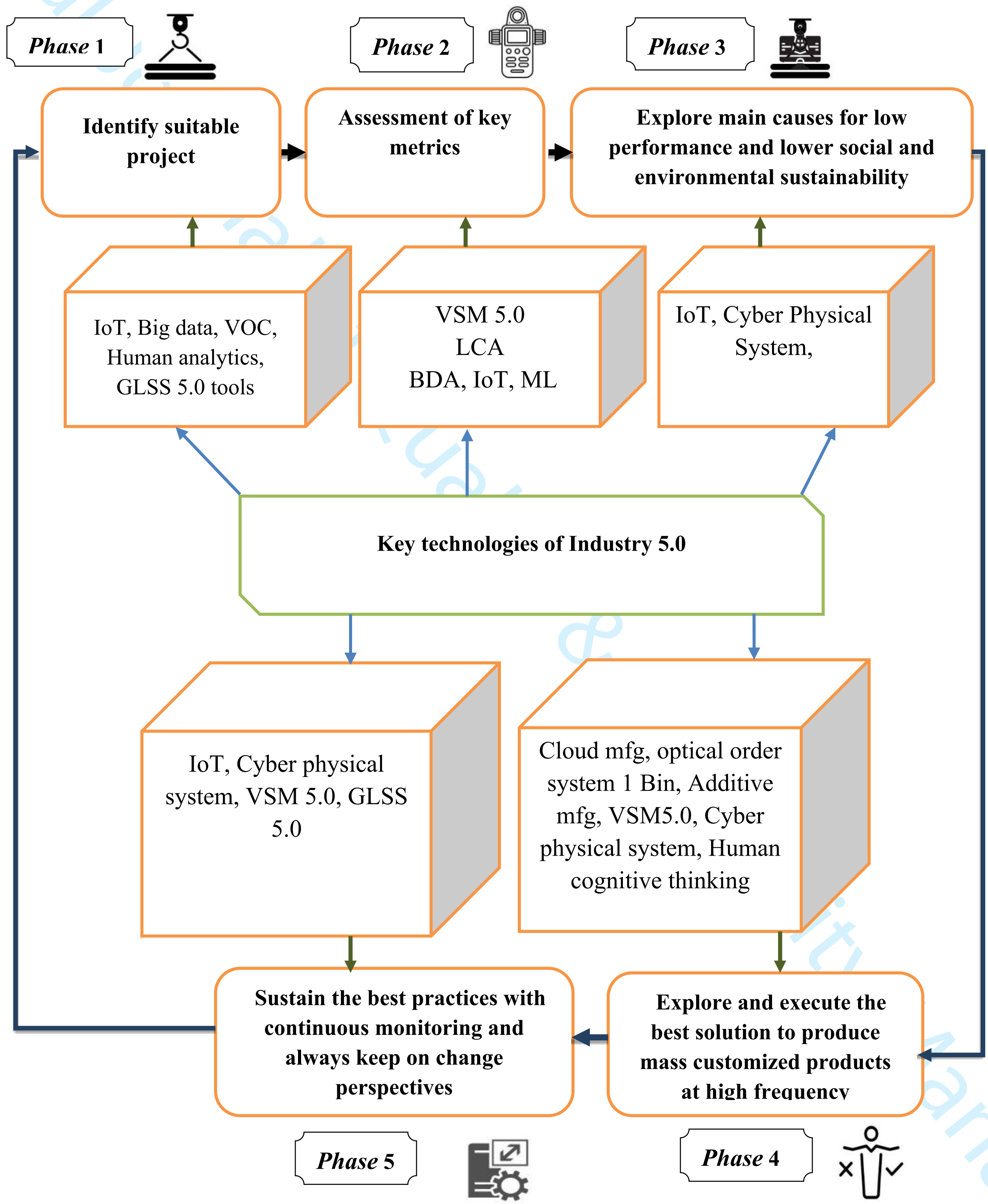
Phase 1
Identify suitable project
IoT, Big data, VOC, Human analytics, GLSS 5.0 tools
Phase 2
Assessment of key metrics
VSM 5.0
LCA
BDA, IoT, ML
Phase 3
Explore main causes for low performance and lower social and environmental sustainability
IoT, Cyber Physical System,
Key technologies of Industry 5.0
IoT, Cyber physical system, VSM 5.0, GLSS 5.0
Cloud mfg, optical order system 1 Bin, Additive mfg, VSM5.0, Cyber physical system, Human cognitive thinking
Sustain the best practices with continuous monitoring and always keep on change perspectives
Explore and execute the best solution to produce mass customized products at high frequency
Phase 5
Phase 4

Figure 8: Proposed Industry 5.0 conceptual implementation framework

Phase 2: Assessment of key metrics

Being on the popular note that if you can estimate something inefficient, you can find out the reason for the same, and the ultimate solutions to improve the efficacy, this phase of the framework is related to the assessment of the key metrics related to inefficiencies in the selected project. The extensive set of data provided by IoT-enabled devices, direct observation from the human capital; different key metrics are assessed. Installation of diverse devices in the I5.0 provides a extensive set of data on the different parameters of the machines related to power and other energy consumption (EC). ML'deep neural network (DNN) is then applied to find the EC trends centred on data collected using constant observation through sensors. Further use of VSM5.0 adds to the estimation of metrics related to traditional quality characteristics like downtime, cycle time, etc. To assess different metrics related to environmental aspects of sustainability extensive data set of big data is processed through LCA to find metrics like GHG consumption, green energy coefficients, eutrophication, and acidification. To assess social sustainability parameters data set based on the subjective aspects from the different persons working at a different level of the organization is collected against the different sets of sub-parameters of industrial social sustainability and finally, a key score of industrial social sustainability is calculated. Human aspects are in high demand in this phase of the framework as the person who is working on the shop floor can provide key information on different metrics and most of the social aspects are directly connected with subjectivity so to estimate social sustainability aspects human evolvement along with advance technologies is highly demanded at this stage to identify key metrics related to improvement in the organizational overall sustainability.

Phase 3: Explore the main causes for low performance and social and environmental sustainability

This phase of the framework deals with the identification of potential and key reasons for low organizational sustainability. To unearth different entire processes is mapped against value-added and non-value-added activities. The entire flow of processes is analyzed to assess different bottlenecks, fallout, and rework points. The comprehensive data gathered in the estimation phase is thoroughly investigated using big data to cope with measure causes for lower industrial sustainability. Human intelligence to find different know-how and causes for failure and inefficiency is highly desired as most of the time persons are directly involved with the process of the production of either product or services. Thus, the inclusive application of Bigdata and geometric tools can be used to classify groups of conceivable reasons for squat industrial ecology. Once the likely reasons for different inefficacy have been identified then the search is narrowed down to find the main reasons for low organization sustainability. Tools like Pareto charts and hypothesis techniques are used at this juncture to identify the main reasons for low organizational sustainability. Furthermore, to verify prominent causes, scatter charts and other tools like ANOVA and regression can also be used to comprehend the relationship among the different prominent reasons. For this reason, this phase results in the leading causes for low organizational sustainability that are tacked in the next phase to improve the sustainability of the organization.

Phase 4: Explore and execute the best solution to produce mass-customized products at a high frequency

This phase of the framework is related to the identification of the best solutions and implements the same to improve organizational sustainability. Inclusive application of I5.0 technologies together with human intelligence is used to make the workplace safer, more responsive and quick to changeover to lead for the mass production of customized products with minimal impacts on Mother Nature. To gather, different solutions for the existing inefficiencies improvement viewpoints from the different personnel working even on the shop floor are gathered, the technical and communication teams check the adaptability of the same, and digital twin technology is used to replicate how the solutions will like after implementation of a particular solution. A high degree of creativity is demanded at this juncture for all the organizational personnel, their deep knowledge sense on different operations, knowledge based on the existing capacity of the organizations in terms of resources and technology, with a high level of human thinking is desired to select the best solutions at this juncture.

The solutions provided at this juncture can consist of different kaizen and other process improvement measures. For the improvement in water utilization in the system solutions like the adoption of the recirculation system of coolant and water, non-stick linking of water tanks to prevent loss due to evaporation, usage of a power management system to investigate wasteful energy practices, change of process parameters to reduce the wastes of the material and energy induced, use of optical bin system to access the usage of the material. Furthermore, to make the manufacturing system more responsive solutions related to additive and cloud manufacturing are proposed and implemented to make the system more eco-friendly and enhance self-decision capability. I4.0 with the evolution of robots brought a tremendous shift in the world's manufacturing systems. Robots have already been utilized in industry to perform risky and monotonous jobs in the industry, ranging from welding, and painting to loading and unloading heavy items. I5.0 combine cognitive computing skills with human intelligence to make the machine smarter and connected to make the workplace safer. Cloud manufacturing induces environmental sustainability in the system as it eliminates the long-haul delivery requirement of the raw material. It enables designers to protect their designs with high cyber security systems with access to manufacturing systems throughout the world. This permits design people to establish manufacturing units in remote nations where there is the availability of raw materials and low-cost labour. Under a cloud manufacturing environment, different control related to manufacturing, scheduling, and services are managed by the cloud. Different parameters related to the manufacturing process are monitored through IoT-enabled sensors and are analyzed in the cloud. There are increasing numbers of evidence of the cloud-based manufacturing system in the academic literature to tap the potential of different business models. The advent technologies of I5.0 with next-generation cloud manufacturing will be able to meet the high specifications of customers with improved organizational sustainability. The advent of 5 G technologies and a new paradigm shift in IoT and AI will open different prospects for future cloud manufacturing systems to cater for different prospects related to customer and sustainability.

To improve the social sustainability of organizational tools like SLCA is sued that use human cognitive thinking aspects to estimate organizational social sustainability. Social sustainability is estimated based on opinions of the organizational member scores are given to different factors of societal sustainability finally, overall societal sustainability is estimated. If the organization is lagging in parameters different solutions and methods are implemented to improve the same. Furthermore, to improve the social economy, organizations can induce plans on capacity building through knowledge enhancement of nearby people of the industry through different technical institutions by building different memorandum of understanding. Moreover, to enhance value creation, organizations can prepare future workforce from the local community by providing training to people nearby in different areas of waste disposal and improving the organizational efficacy by proving 'on the job' training to local institutions' students. This will enhance the well-being of organizations by also coming to the fore in the increase in sales and a ready-made workforce for future activities of the organization in long run.

Phase 5: Sustain the best practices with continuous monitoring and always keep on changing perspectives

The main theme of the final phase of the I5.0 sustainability-focused DMAIC framework is to complete the project selected in the first phase and hand off the improved work process and plan to the concerned authority to maintain the gain achieved in organizational sustainability. This phase of the framework also provides a complete system for monitoring the implemented solutions (identified and implemented in the previous), along with the specific metrics to be used for regular auditing. To certify continued improvements through implemented systems, augmented reality/sensor-assisted mistake proofing and Jidoka are used to confirm protection and diminish inaccuracies in processes. To monitor the process, techniques such as cyber technologies are used to permit visual control of the execution process. To assure the success of the project, the different data sets related to the process and different metrics are evaluated for a long duration to assure whether the implemented plan can sustain the long run, if some deviation is observed immediate out-of-control action plans are initiated at the point of deviation from the standard. If the performance of espoused solutions is superior to estimation (phase 2), then solutions are sustained and would be propelled in the rest parts of the industry.

5. Viewpoint

This section briefly discusses the outlook for the future research agenda of I5.0.

5.1 Know-how of Industry 5.0

To boost the widespread applications and tap the full potential of I5.0, it is imperative to unify different theoretical and other related aspects of I5.0. But this action may haze bounders of different systems. In future, researchers can initiate different comparative studies on commonalities and differences among I5.0, society 5.0, and operator 5.0 to unearth commonalities and differences between different notions that will precisely describe the value and innovation of I5.0. Further based on the EU white paper's I5.0 characteristics i.e.

sustainable, resilient, and human-centric. Subsequent future research can be initiated to enrich different features related to the different applications field.

5.2 Framework of Industry 5.0

This study presents a theoretical DMAIC-based I5.0 framework based on academic literature and then further validates the same based on the opinion of I5.0 practitioners from different parts of the world. So, the said framework provides a reference for I5.0 execution within industrial settings. There is no doubt as time will run over the research disposition on I5.0, more associated frameworks of I5.0 will come into existence. This is where the significance of the research paper's framework lies. In future based on the foundation of the developed framework, the researcher and practitioners can develop a generalized framework of I5.0 and a dedicated I5.0 framework for different manufacturing and services industries for improved organizational sustainability.

5.3 *Applications of Industry 5.0*

This study provides applications of I5.0 in different industrial fields like manufacturing, healthcare, education, disaster management, etc. But how I5.0 will be comprehensively executed to improve the sustainability dynamics of different industrial settings is still in its infancy. Moreover, deliberate planning, and comprehensive on-floor assessment of the industry, together with a deep study of existing facilities and the potential of different technologies to integrate with Industry 5.0 needs to be explored in future for enhancing the application domains in different service sectors. There is a need to learn different aspects of human-robot collaboration on different activities evolved within the production of goods and services.

5.4 Existing status quo of Industry 5.0

I5.0 is a new industrial paradigm and is still in its infancy. Most of the studies related to I5.0 are conceptual but the practical execution of I5.0 is not explored in detail. Most of the studies are related to theoretical facets like know-how, and technologies, and related to aspects of the human-robot collaboration mechanism. But still, studies on how I5.0 will enhance societal and environmental aspects in different industrial fields are not explored with full details and validation. Most of the studies related to I5.0 have been executed within the manufacturing sector. But a detailed exploration of I5.0 in service sectors like education, banking, hospitality, hotel, and transportation needs to be explored. This provides avenues for researchers to develop comprehensive facilitators-based frameworks to boost the application of I5.0 in a field other than manufacturing. Furthermore, there is also a need to explore studies related to the intelligent collaboration of human thinking with robots for making the industry more sustainable and resilient by making work accident free together and quickly responsive to different situations.

5.5 Enablers to Industry 5.0

This systematic study of the literature also elaborates on different enabling technologies of I5.0 along with their application domain. As I5.0 is a new paradigm, inclusive implementation of the same required firstly complete know-how of its aspects, finance for infrastructure upgradation, training, integration among technologies, and a high level of robot-human collaboration. Researchers in offing can develop enablers that enabled the I5.0 framework to boost the execution of this novel aspect of social sustainability.

5.6 Barriers and mitigation action to Industry 5.0

Being a new paradigm for industry the adoption of Industry 5.0 is faced with different challenges like the resistive culture of the organization, well-defined CPS standards, the connection between virtual reality and physical systems, and establishing mechanisms between robot and human thinking. The manufacturing industries of developing nations like India are facing the main issue to integrate data backed mechanism of virtual manufacturing with the physical system of production. The reason for the same can be attributed to traditional-based methods of production adopted by a large set of manufacturing industries and resistance of the employee to adopt a new set of technologies of manufacturing like additive manufacturing. The next pressing issue for developing nations is ‘Digitization and automation of the processes.' A large proportion of the industry especially MSMEs are using physical systems to produce products; they do not have self-corrective measures and decision capability to make the corrective mention and methods to make predictive maintenance. So, there is a need for a complete overhaul of the system to make the system automated with the use of advanced technologies paradigm to ensure faster, timely, errors and defects-free production of customized products in large quantities. The next pressing issues with the manufacturing sector of most nations are the lack of funds to purchase an advanced set of technologies, funds for training on the different aspects of I5.0, and finance for updating the infrastructure suitable to induct I5.0 technologies. Availability of funds and costs has been identified as one of the key issues to impede the successful execution of new approaches. Poor regulations and fiscal policies make credit transfer more difficult for the industrial organization to procure new technologies. The next pressing issue in this line is the interaction between the virtual and real world using established standards and a set of rules. Although, there are a few defined safety standards but no defined preset of rules whenever humans interact with robots. To ensure full throttle safety of the employee there is a demand for a collaborative framework or well-established approach.

6. Inferences

On the eve of this dawn when new concepts like I4.0, and reconfiguration systems are in their full strike, I5.0 booms out of hush. To be continuous stakeholders organizations have to adopt concrete measures for securing environmental and social sustainability. I5.0 is a new notion for industries to mitigate their current level of carbon footprint and scale up social sustainability with qualitative integration between human aspects and a digital set of technologies. This study pioneers a systematic bibliometric analysis of I5.0, together with different theoretical notions, and also proposes a conceptual I5.0 adoption framework. I5.0 is in its infancy and to alleviate its application the study provides complete knowledge of I5.0 by proving its different technologies, enablers, barriers, and execution framework. The practitioners can comprehend how I5.0 can facilitate different application areas in their respective industries by understanding technologies and readiness measures of this aspect of sustainability. Further framework provides complete guidelines right from the selection of suitable projects to sustain the solution for the adoption of I5.0. The study also provides a quick reference guide for the practitioners on which tools and technologies to be implemented at different stages of the DMAIC-enabled I5.0 framework. The present work will make the organization, to rethink its business operations and provides a booster to practitioners to sustain their business run by adopting different technologies, applications, tools and human-centric systems of I5.0.

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