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State of Industry 5.0—Analysis and Identification of Current Research Trends

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Abstract: The term Industry 4.0, coined to be the fourth industrial revolution, refers to a higher level of automation for operational productivity and efficiency by connecting virtual and physical worlds in an industry. With Industry 4.0 being unable to address and meet increased drive of personalization, the term Industry 5.0 was coined for addressing personalized manufacturing and empowering humans in manufacturing processes. The onset of the term Industry 5.0 is observed to have various views of how it is defined and what constitutes the reconciliation between humans and machines. This serves as the motivation of this paper in identifying and analyzing the various themes and research trends of what Industry 5.0 is using text mining tools and techniques. Toward this, the abstracts of 196 published papers based on the keyword "Industry 5.0" search in IEEE, science direct and MDPI data bases were extracted. Data cleaning and preprocessing were performed for further analysis to apply text mining techniques of key terms extraction and frequency analysis. Further topic mining i.e., unsupervised machine learning method was used for exploring the data. It is observed that the terms artificial intelligence (AI), big data, supply chain, digital transformation, machine learning, internet of things (IoT), are among the most often used and among several enablers that have been identified by researchers to drive Industry 5.0. Five major themes of Industry 5.0 addressing, supply chain evaluation and optimization, enterprise innovation and digitization, smart and sustainable manufacturing, transformation driven by IoT, AI, and Big Data, and Human-machine connectivity were classified among the published literature, highlighting the research themes that can be further explored. It is observed that the theme of Industry 5.0 as a gateway towards human machine connectivity and co-existence is gaining more interest among the research community in the recent years.

Keywords: Industry 5.0; artificial intelligence; smart manufacturing; big data; internet of things; human-machine coexistence

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1. Introduction

Today's manufacturing industry is currently experiencing a rapid transformation due to the onset of fast-growing digital technologies and Artificial Intelligence (AI)-based solutions. Manufacturers throughout the world are faced with the challenge of increasing productivity while keeping humans in loop at manufacturing industries. This task becomes even more difficult as robots become more crucial to the manufacturing process by means of emerging technologies such as brain-machine interfaces and advances in AI. These challenges can be addressed by the next industrial revolution, known as Industry 5.0. In short, the concept of Industry 5.0 refers to humans and robots working as collaborators rather than competitors [1]. This follows the previous revolutions Industry 1.0, Industry 2.0, Industry 3.0, and Industry 4.0.

Industry 1.0 came about in the 18th century and focused on the sectors of textiles, steam power, iron, tools, cement, chemicals, gas, lighting, glass, paper, mining, agriculture, and transportation. The achievements of this revolution include employability, agriculture development, transportation, and sustained growth. The noted drawbacks to Industry 1.0 include pollution and the time needed to implement the associated methodologies. Industry 1.0 utilized the mathematical tools of linear programming and geometry [2]. Industry 2.0 started in the 19th century and focused on iron, steel, rail, electrification, machine tools, paper, petroleum, chemical, maritime technology, rubber, bicycles, automobiles, applied science, fertilizer, engines, turbines, telecommunications, and modern business management. The achievements of this revolution include the emergence of the electrical power grid, telephones, telegraph, and internal combustion engines. The primary drawback of Industry 2.0 is the high cost to consume electrical power. Industry 2.0 utilized the mathematical tools of differential equations, linear equations, and geometry [2]. Industry 3.0 started in the 20th century and focused on the semiconductor industry, digital circuits, programmable integrated circuits, telecommunication, wireless communication, the renewable energy sector, and automation [2]. The achievements of this revolution include telecommunication, renewable energy, automated industries, and robots. The primary drawback to Industry 3.0 is that automated system would not work in certain situations [2]. For example, one of the primary aspects of Industry 3.0 involved implementing Flexible manufacturing Systems. (FMS). However, these systems are very complex and added extra operational costs that were not feasible for some organizations. The complexity and added costs deterred many companies [3]. Industry 3.0 utilized the mathematical tools of differential equations, linear programming, and logical controllers. Industry 4.0 came about in the 21st century and focused on all types of industries with intelligent systems. The achievements of this revolution include fully automated systems, artificial intelligent systems that work in uncertain situations, with machine learning having a positive influence on the fourth industrial revolution. The drawbacks of Industry 4.0 are that all the data in the cloud may not be protectable, and fully expert systems are not yet developed for industries. The mathematical tools utilized by Industry 4.0 include optimization techniques and network theory [2].

The term "Industry 5.0" was coined by Michael Rada [4]. One of the key aspects which Industry 5.0 entails is the use of collaborative robots that will help mitigate risk. These robots can notice, understand, and feel the human operator as well as the goals and expectations for the tasks being performed. The intention is that these robots will watch and learn how an individual performs a task and help human operators in performing the task. Furthermore, Industry 5.0 entails the penetration of AI into human life with the aim of enhancing the man capacity. In Industry 5.0 advanced IT technologies, IoT, robots, AI, and augmented reality are actively used in the industry for benefit and convenience of human workers [5].

Industry 5.0 recognizes the capacity of industry to fulfill social objectives beyond employment and development, to become a sustainable source of development, by making production regard the limitations of our planet and prioritizing employee health first. To be a trusted system for individuals seeking a satisfying and healthy career, Industry 5.0 contributes to the technology upgrade required by industry. It prioritizes worker welfare and employs new technology to create wealth beyond employment and growth while respecting the planet's constraints. It empowers workers and meets their changing skill and training requirements. It boosts industry's competitiveness and attracts top personnel. "An economy that works for people", "European Green Deal" and "Europe fit for the digital age" are three goals of the Commission in implementing Industry 5.0. Therefore, Industry 5.0 is not founded on technology but on principles such as human-centricity, environmental stewardship, and social benefit. This reorientation is grounded in the notion that technology may be tailored to encourage values, and that technological innovation can be built on ethical objectives, not the other way around [6].

The overall current state of understanding of Industry 5.0 describes it as the movement to bring the human touch back to the manufacturing industry. This is driven by the consumer's desire for mass personalization. This understanding means that Industry 5.0 products provide consumers with a way of realizing their urge to express themselves, and they will pay a premium to do so [7]. To summarize, Industry 5.0 is a concept that seeks to make industry more sustainable, human centric, and resilient. Some view it as an evolutionary, incremental advancement that builds on the concepts and practices of industry 4.0 and others view Industry 5.0 as a complement to the Industry 4.0 paradigm. Table 1 contrasts objectives, systemic approaches, human factors, enabling technologies and concepts, and environmental consideration of Industry 4.0 and 5.0 [7,8]. Since Industry 5.0 is a new concept there is little agreement on how it is defined. However, it is observed that the primary trend of Industry 5.0 is the introduction of human-robot co-working environment and the creation of smart society.

Table 1. Contrast of Industry 4.0 and Industry 5.0.

	Industry 4.0	**Industry 5.0**
Objective	• Smart manufacturing (smart mass production, smart products, smart working, smart supply-chain), • System(s) optimization.	• Sustainability, • Environmental stewardship, • Human-Centricity, • Social benefit.
Systemic Approaches	• Real-time data monitoring, • Integrated chain that follows through end of life-cycle phases.	• Utilization of technology ethically to advance human values and needs, • Socio-centric technological decisions, • 6R methodology and logistics efficiency design principles.
Human Factors	• Human Reliability, • Human-computer interaction, • Repetitive movements.	• Employee safety and management, • Learning/training for employees.
Enabling Technologies and Concepts	• Cloud Computing, • Internet of Things, • Big Data and Analytics, • Cyber Security, • Digitization (simulation, digital twins, artificial intelligence, augmented, virtual, or mixed technology), • Automation (advanced robotics, remote monitoring, autonomous robots, machine-to-machine communication), • Cyber-physical systems, • Horizontal and Vertical Integration (PLC, Supervisory Control and Data Acquisition (SCADA), Manufacturing Execution System (MES), Enterprise Resource Planning (ERP)), • Additive Manufacturing.	• Cloud Computing, • Internet Of Things, • Big Data and Analytics, • Cyber Security, • Digitization (simulation, digital twins, artificial intelligence, augmented, virtual, or mixed technology), • Human-machine-interaction, • Multi-lingual speech and gesture recognition, • Tracking technologies for mental and physical occupational strain, • Collaborative Robots, • Bio-Inspired safety and support Equipment, • Decision support systems, • Smart Grids, • Predictive maintenance.
Environmental Implications	• Systems are economic, • Waste prevention per data analytics, additive manufacturing, and optimized systems, • Increased material consumption, • Increased energy usage, • Extended product life cycle.	• Waste prevention and recycling, • Renewable Energy sources, • Energy-efficient data storage, transmission, and analysis, • Smart and energy-autonomous sensors.

To understand the perspective of what Industry 5.0 is, its evolution, and the technologies and domains that enable meeting Industry 5.0, in this paper text mining tools and techniques are used to explore the published literature landscape to identify commonalities and identify future directions of research in spearheading the transformation towards Industry 5.0.

The remainder of the paper is organized as follows, Section 2 details on the data gathering process detailing on the databases from which the data is extracted and analyzed, Section 3 expands on the text mining approach used and highlights the findings on the current state of Industry 5.0 research, and Section 4 concludes the article and identified the contributions.

2. Data Gathering and Preprocessing

The data gathering process involved identifying and extracting data of published research articles from scholarly databases. The databases used to extract data for this study include IEEE (Institute of Electrical and Electronic Engineers), Science Direct, and MDPI. These databases have a wider variety of coverage in terms of sources than other databases which is important since publications focusing on Industry 5.0 may be outside the "top" journals in the field [9]. Further, the restricted access to the authors of the databases available is another factor in choosing the identified sources and restricting the analysis to the abstracts. To identify published articles addressing the topic of Industry 5.0, key term "Industry 5.0" was used to search the metadata and identify published articles.

This included any published articles mentioning "Industry 5.0" in the title, abstract, or the keywords. This is because Industry 5.0 is still an emerging term, and it is still unclear what other key terms and synonyms are used [9]. The keyword search produced a total of 196 documents which included 26 from IEEE, 76 from MDPI, and 94 from Science Direct. The time range for these documents is 2016–2022 indicating the earliest publication on Industry 5.0 in 2016. The data collected included the publisher, title, publication year, and abstract for each publication retrieved. The data was then sorted by the database it was retrieved from and converted for further analysis into an .xlsx file. Once sorted, the data was labeled to identify the publisher, title, and the abstract corresponding to each published article retrieved. To analyze the gathered data, "R" a statistical language widely used by statisticians and data miners was utilized to transform, visualize, and analyze the data. This included data preprocessing, transformation, key term extraction, frequency analysis, and topic modeling. Table 2 illustrates the search results of each individual data base the abstracts were extracted from.

Table 2. Key Term 'Industry 5.0' Search Results.

Database	Abstracts	Timeline
IEEE Explore	26	2019–2022
Science Direct	94	2016–2021
MDPI	76	2018–2021
Total	196	

The data is converted into a. csv format to be imported to R and then cleaned for further analysis by removing unwanted characters such as white spaces, numbers, symbols, and tag from the abstracts. Once these characters are removed the next steps were to delete stop words and convert words to lower case. Several text mining tasks, facilitated by Quanteda package [10] and dpylr package in R, include removing common words from documents. Stop word removal is a process of removing commonly occurring words for conjunction and propositions such as, *a*, *I*, *in*, *for*, *with*, *the*, *not*, *on*, and several similar other words that do not usually contribute much to the meaning of a given sentence. Most text written in English language follows punctuation and use of lower case and upper-case text. Though capitalizations enable humans to differentiate between nouns and proper nouns, in text analysis, words irrespective of where they are capitalized are treated equally and thereby converting all the characters to either lower case or upper case. There is also the process of stemming and creating vectors. Stemming helps to standardize the text by prefixes, suffixes, and inappropriate pluralization's in the text document. Creating vectors involves transforming the data into a representation to act as a suitable input for text mining algorithms.

3. Data Analysis and Discussion

Text mining, which is also referred to intelligent text analytics, text data mining, and text knowledge discovery, is defined as the discovery of either new or previously unknown information through the extraction of information from various written resources. Text mining help to uncover new information and knowledge by identifying patterns in documents from several sources [11]. Text mining may involve several other methods such as Natural Language Progression (NLP), Information retrieval, Clustering, Document Classification, Web mining, Information Extraction, and Concept Extraction [12]. It has been widely recognized among researchers that text mining's feasibility for exploring published literature and discovering concepts and trends across a given domain has seen tremendous growth. For example, Bach et al. discuss the advantage of using text mining in the financial sector for stock market predictions [13], Aureli portrays the applicability of text mining for studying organizations' social and environmental reports [14], Namugera et al. use text mining to study the social media usage of traditional media houses in Uganda to understand the topics these media houses discuss and determine if they are positively or negatively correlated [15], and use of text mining tools and techniques to analyze the landscape of Model based Systems Engineering [16].

In this paper the text mining framework as illustrated in Figure 1 [17] is used for exploring and analyzing the published articles on Industry 5.0 to identify key terms often used and the themes into which Industry 5.0 research can be classified into using the text data extracted.

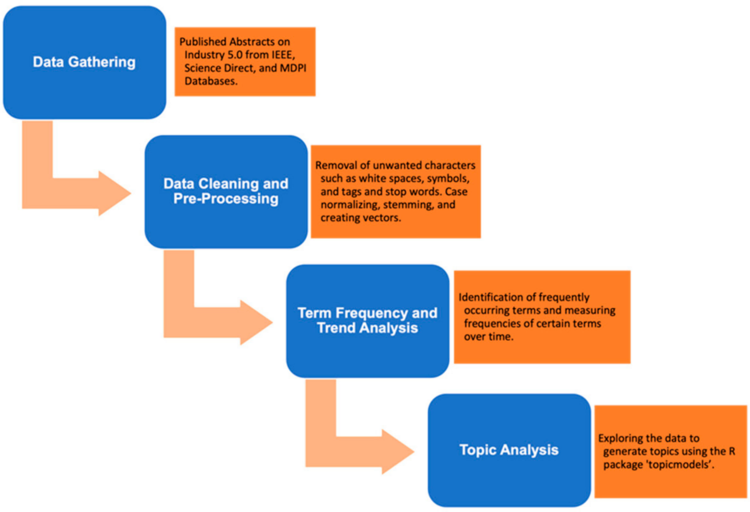

Figure 1. Framework used for the analysis of Industry 5.0 abstracts.

3.1. Frequently Used Terms Extraction from the Data

Term extraction and frequency analysis is focused on pinpointing the relevant terms in each collection of text. Identifying the unique terms with statistical techniques such as calculating relative term frequency among the documents in a dataset enables better understanding of the information provided from the text [18]. The Inverse Documentation Frequency (IDF) measure is a widely utilized method for determining the contribution of terms. The greatest advantage of IDF is that it can aid in determining the influence of term in a group of given documents by identifying the frequency of term in a document and the number of times it occurs in a document [18,19]. When it comes to "low" and "high"

IDF values, low values represent less informative terms appearing in several documents, and high values represent more informative terms appearing in only a few documents. In this paper, frequency analysis was utilized to identify the primary terms associated with Industry 5.0. Table 3 represents the top 20 frequently observed terms in the data along with their corresponding frequency.

Table 3. Top 20 terms identified from the database of Industry 5.0.

Terms Usage Identified	Term Frequency
industrial revolution	45
artificial intelligence	43
supply chain	32
big data	28
digital transformation	24
machine learn	23
industry technology	22
digital twin	19
recent year	18
cloud compute	18
thing iot	18
sustainable development	17
future research	17
intelligence ai	16
smart manufacture	16
digital technology	16
fourth industrial	16
manufacture industry	16
production system	15
manufacture system	15

The term "Industrial Revolution" was observed to occur the most in the database. This is indeed expected since Industry 5.0 is referred quite often to as the fifth industrial revolution. Several publications in the data gathered use this term in comparing the different industrial revolutions throughout the years. Industry 5.0, just as past industrial revolutions, is predicted to have major impacts on the dynamics of socio-economic systems more specifically to have a large impact in industrial production systems [20]. The term "Artificial Intelligence" is observed to have the second highest count. Artificial intelligence seems to be one of the central components of Industry 5.0, mostly addressed for automating manufacturing processes, furthering the primary focus of cooperation between man and machine [21]. The term with the third highest count was "Supply Chain." This is highly significant since it is believed that Industry 5.0 will influence supply chains to an unprecedented level. The trends for Industry 5.0 supply chains include the incorporation of collaborative robots (co-bots), intelligent systems, mass personalization, and mass customization [22]. The term with the fourth highest count is "Big Data." Big Data is integral to Industry 5.0. It is believed that Industry 5.0 will introduce new innovations in management framework that takes Big Data into consideration. Furthermore, Big Data will be crucial for reaping the maximum benefit of Industry 5.0 such as modern technologies and new innovations in Internet of Things (IoT) and artificial intelligence [23]. The term "Digital Transformation" has the fifth highest count. This follows the prediction that Industry 5.0 will bring about a transformation towards digital platforms and a digital economy. In all, it is predicted that there will be a digital ecosystem, an open, distributed, self-organizing, system of system. The intention of this digital transformation is to unite subsystems to provide a common information space with access to a rich set of re-usable applied services that can support resource planning and control in real time. The digital transformation for Industry 5.0 should also provide standard access to cloud resources and services and to data perceived by external smart sensor networks [24]. The use of terms "manufacture industry", "production system", and "manufacture system" are centered on the dialogue from the research community discussing the shift from Industry 4.0 to 5.0 in the manufacturing and production engineering domain for the plausibility of advanced human machine interfaces for improved integration and better automation.

3.2. Term Frequency Analysis

The terms identified from the overall data set enabled to gain understanding on what specific terms were more focused upon by the researchers addressing Industry 5.0 paradigm. A measure of frequency for the identified terms is used to plot on a line graph, the relative use of terms over the years to identify their usage trends by the researchers. Based on the terms extracted in Section 3.2, the following terms were identified for analysis (a) "twin"—to understand the trend on exploring the use of digital twins in enabling Industry 5.0, (b) "data"—for exploring the trend on use of big data i.e., set of diverse actionable data to empower Industry 5.0, (c) "intelligence"—to understand the trend on the use of artificial intelligence to aid Industry 5.0, (d) "cloud"—for understanding the trend in exploring the use of cloud based technologies and cloud computing as an enabler of Industry 5.0, (e) "IoT"—for exploring the trend on identifying IoT as an enabler for Industry 5.0, and (f) "machine"—for exploring the dialogue on the use of machine learning towards Industry 5.0 transformation. Figure 2 illustrates the trends on the use of the aforementioned terms over the past years. The use of the terms starting from year 2016 in the graph indicates to the limitation of the data that was gathered for analysis, starting from year 2016 where the first peer reviewed publication on Industry 5.0 was observed. Please see Table 1. The use of term "twin" in 2016 indicates to the initial attempt at exploring the use of digital twins to address Industry 5.0. Starting year 2018 the use of terms "intelligence" "cloud", and "IoT" are observed, indicating an initial interest in exploring artificial intelligence, IoT, and cloud computing technologies as enabler of Industry 5.0, with more interest in IoT. A peak in use of actionable data sets i.e., Big Data in the year 2021 followed by IoT and machine learning indicate more interest among the research communities to explore from an integration perspective toward a well-connected, distributed, intelligent, and actionable human centric systems. Please note that the abrupt drop in the term usage reflects to the limitation on the data gathered on publications until early 2022 considered for the analysis.

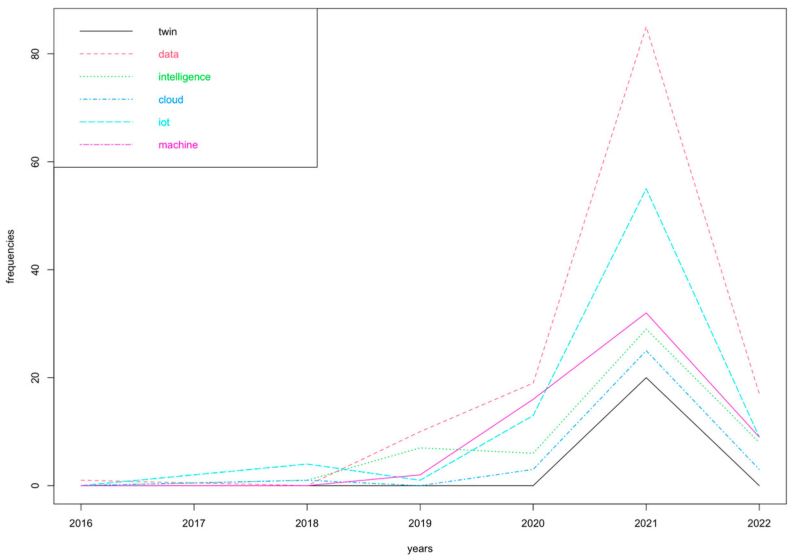

Figure 2. Terms usage trends in the context of Industry 5.0.

3.3. Topic Analysis

Topic Analysis was used to understand the major themes around which the published literature on Industry 5.0 can be classified. Topic analysis from text mining is defined as the act of extracting topics or thematic elements from a given set of documents. Topic analysis focuses on the characterization of a topic based on distribution of terms and the mixture of each topic in a document [25]. One of the most common methods of topic analysis from text mining is "Latent Dirichlet Allocation" (LDA) [26]. LDA is an unsupervised machine learning method mostly used for applications such as opinion modeling, extracting topics from source codes, and hashtag recommendations [17]. One of the greatest advantages of LDA is its pertinence to several domains while taking three domains into consideration, documents, words, and topics. LDA enables the user to define the number of topics as a parameter that the textural data must be characterized into. It is to be noted that, if this parameter is small, the topic identified provide only few semantic contexts whereas when the parameter to too large there is a scope for the topics identified to overlap. This, after several trails the authors limit the number of topics the data is to be characterized into 5 to be more reflective and coherent to Industry 5.0. Table 4 depicts the top five topics, and ten most likely terms observed in each topic, and a representative label for each topic provided by the authors.

Table 4. Topics and Topic Labels identified in context of published Industry 5.0 articles.

Topic Number	Topic Terms	Topic Label in Context of Industry 5.0
Topic 1	supply, approach, engineer, model, result, safety, analysis, method, performance, key	Supply Chain Evaluation and Optimization
Topic 2	digital, research, study, industry, innovation, company, review, business, organization, future	Enterprise Management, Innovation, and Digitization
Topic 3	manufacture, smart, industry, revolution, sustainable, technology, industrial, energy, technological, challenge	Smart and Sustainable Manufacturing
Topic 4	IoT, security, internet, datum, thing, compute, system, device, health, cloud	Transformation driven by IoT, Bigdata, and AI
Topic 5	human, robot, system, production, process, task, industry, intelligent, robotic, manufacture	Human Machine connectivity and co-existence

Figure 3 represents the topic distribution across the entire dataset of 196 abstracts on Industry 5.0 and Figure 4 portrays the spread of the identified topics among the data gathered over the period of years 2016 to 2022.

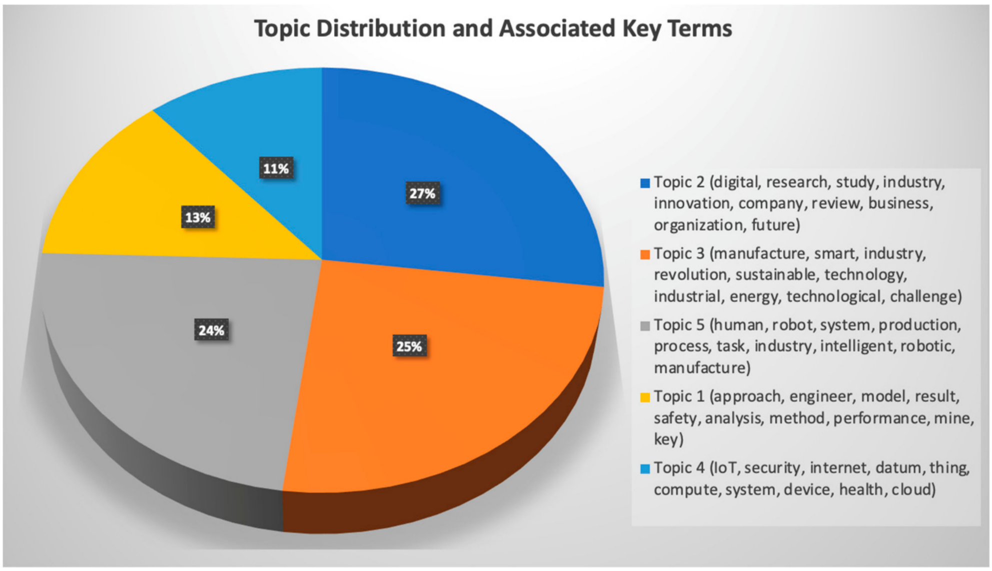

Figure 3. Topic distribution in the data extracted.

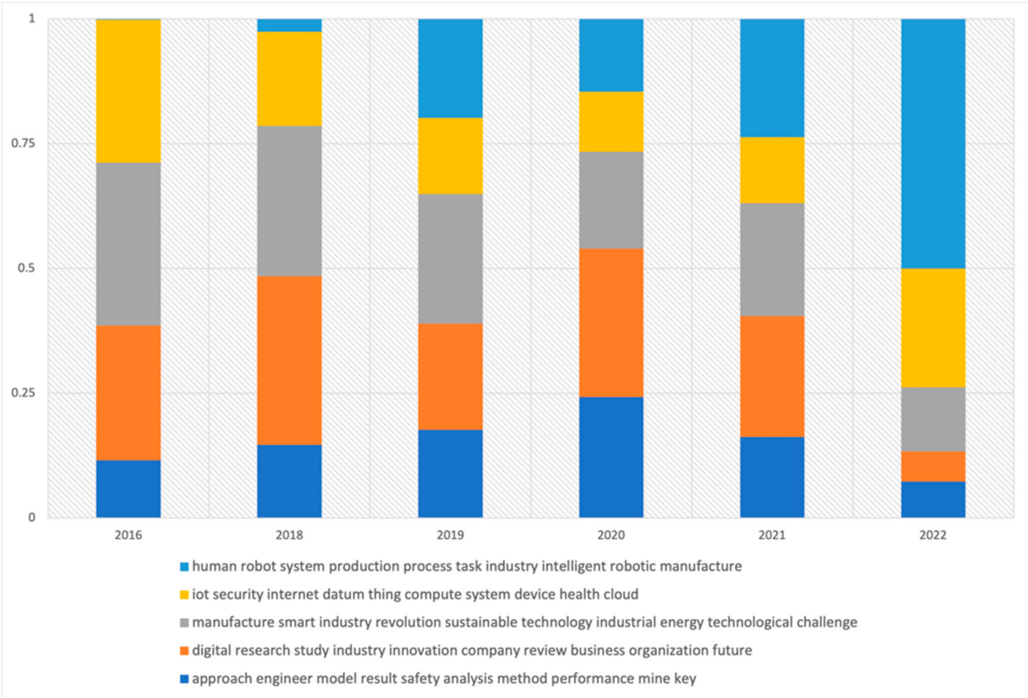

Figure 4. Industry 5.0 Themes and their respective spread over time.

The top abstracts, in a descending order, that represent each individual topics (Table 4) have been summarized to explore and better understand the perspective in the context of Industry 5.0 being addressed so far through published articles

Theme 1—Industry 5.0 in context of supply chain evaluation and optimization in manufacturing processes: This topic supports the exploration of how Industry 5.0 can enable supply chain evaluation and optimization in manufacturing processes. More specifically, use of a multi-objective mathematical model to design a sustainable-resilient supply chain based on strategic and tactical decision levels [27], optimization of mining methods using multi-level, multi-factor, multi-objective, and multi-index comprehensive evaluation system involving technology, economy, and safety [28], exploring Social Value Orientation theory for understanding decision making preferences for join resource allocation [29], exploring the constructs of Industry 5.0 for supporting supply chain operations [22], research directions for supply chain transformations [30], influence of industrial internet of things and emerging technologies on digital transformation capabilities of organizations [31], effectiveness indicators for enterprise resource planning systems to aid digitization of information flows [32], enabling constructs of Industry 5.0 to control and manage supply chains in emergency [33], future of supply chains in context of Industry 5.0 [34], and approaches for supply chain digitization [35]. Addressing the 13% of the data gathered, a constant interest among the researchers is observed over time on this topic. Figure 4 portrays this trend.

Theme 2—Industry 5.0 in context of enterprise management, innovation, and digitization: Composed of 27% of the data analyzed, this thematic topic addresses the construct of Industry 5.0 in context of Enterprise Management, Innovation, and Digitization. This theme addresses research on translating critical success factors of project management in relation to Industry 4.0 for sustainability in manufacturing enterprise [36], an absolute innovation management framework for addressing the importance making innovation more understandable, implementable, and part of routine in organizations [23] required for adopting to the constructs of Industry 5.0, importance of addressing the nexus of entrepreneurial leadership and product innovation through design thinking [37] a core need for moving towards the notion of Industry 5.0 in organizations, identification of how digital product and process innovations might affect profitable customer strategies in a global context [38], use of biological resources and policy to drive Industry 5.0 [39], using sustainability based metrics for digital technologies [40] to enhance production operations, identification of value drives for successful digital transformations [41], significance and adoption of global reporting initiative standards in context of technology sustainability [42], enablers and challenges of digitization [43], and the importance of technological adoption and development based on the needs and demands of society [44]. This thematic aspect is observed to have a constant interest among the researchers over time for addressing Industry 5.0. Figure 4 portrays this trend.

Theme 3—Industry 5.0 in context of smart and sustainable manufacturing: Representing 25% of the data gathered, this major thematic aspect addresses Industry 5.0 in context of enabling smart and sustainable manufacturing. This thematic aspect is also observed to have a constant interest among the researchers over time for addressing Industry 5.0. Figure 4 portrays this trend. This theme majorly addresses pathways to manufacturing systems that can adopt by exploring the drivers and barriers manufacturing systems might face when seeking a transition to smart and sustainable paradigms towards Industry 4.0 and beyond [45], impact of industrial mathematics on industrial revolutions and how it can enable smart industries to meet customer need for future uncertain business environments [2], incorporating sustainable manufacturing measures for opportunities towards smart manufacturing [46], identification of components that enable Industry 5.0 for intelligent production systems [47], applicability of cloud based decision making based on information acquired from sensors [48], enabling smart manufacturing processes [49], machine learning enabled power dispatch systems [50], digital twins for sustainable operations [51], biomimetic designs for industry 5.0 [52], and integration of software suites and digital technologies for effective manufacturing quality management systems [53].

Theme 4—Industry 5.0 transformation driven by IoT, Bigdata, and AI: This theme addressing the use of IoT, big data, and AI towards Industry 5.0 is observed gain a lot of attention recently among the research community (illustrated in Figure 4) though it encompasses only 11% of published research articles so far (illustrated in Figure 3). This topic further relates to utilizing IoT technology such as sensors and actuators into the industrial process of Industry 5.0 to aid in the mass customization of products [54]. Research in theme is addressed on, taxonomy for integration of blockchain and machine learning in an IoT environment [55], expanding technological infrastructure, provision of budgetary support based on sustainable business models, standardization, and synchronization protocols, improving stakeholders' engagement and involvement [56], taxonomy analysis to aid in implementing methods and algorithms for different IoT application [57], in identifying techniques to improve the security and efficiency of data transmission between the IoT devices [58], exploring the use of deep learning and AI for monitoring [59], use of amazon web services using IoT and cyber physical systems for equipment monitoring [60], challenges and impediments of IoT [61,62], and energy efficiency and assessment models using big data and AI [63].

Theme 5—Human machine connectivity and co-existence: This theme relates to emergence of Industry 5.0 as the concept of human-robot/human-machine coexistence. This refers to the aspect of humans and robots in loop supporting and assisting each other in manufacturing and production engineering processes [64]. Research addressed in this theme include knowledge-based tasks and automation for humans and robots to measure cycle times [65], exploring the application of social value orientation theory to human machine contexts and multiagent systems [29], scientific improvements transforming the production lines and machines in intelligent systems [47], soft robotics for industrial applications involving manipulation of fragile objects [66], achieving a balance between capital and labor welfare by deploying Industry 4.0 technologies with a worker centric approach [67], and use of AI for robust solutions in mobile robotics [68]. Further, research in this theme also addresses the need for resilient workforce for adapting to workplaces and enterprises [69], perspectives on human centricity in future smart manufacturing [70], and use of agent-based approach to explore effects of human-robot interactions [71].

4. Conclusions

Enabled by the capabilities of text mining techniques, in this paper an attempt to understand and classify Industry 5.0 based on the published research articles with the time frame of when the term was first coined i.e., 2016 to the year 2022 is portrayed. Addressing the objective of the paper, term extraction technique was used to identify the most often occurring terms in the abstract text data gathered on Industry 5.0 related publications. The terms artificial intelligence, big data, supply chain, digital transformation, machine learning were observed to be most referred to. This coincides with the fact that Industry 5.0 is seen to facilitate repetitive tasks with the use of artificial intelligence and machine learning technologies, parallelly assisting humans for cognitive support. Further, big data and digital transformation are foreseen to provide an information space rich with data that can be used for resource planning and control in real time. Topic analysis technique was used to identify the thematic aspects of papers published addressing Industry 5.0. Five different thematic aspects were observed across the landscape, with most of them in the context of smart and sustainable manufacturing followed by human machine connectivity and co-existence. More specifically, the theme of Industry 5.0 as a gateway towards human machine connectivity and co-existence is observed to gain a lot of interest among the research community. Further a brief description of the top ten papers from the data defining the topics is provided for the audience to understand the perspective and relevance of topics.

By examining the analysis provided future research directions can be identified and predicted on how Industry 5.0 will impact the manufacturing landscape in the years to come. The results obtained are limited to the data i.e., 196 abstracts extracted. It is to be noted that these the results are subject to change with increase in the number of abstracts used for analysis along with expanding the digital libraries used for extracting the data. As a future work, it is believed a comprehensive analysis along with integration of data crawling techniques will provide a better perspective on what Industry 5.0 is and how it is perceived among the research community.

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References

1. Nahavandi, S. Industry 5.0—A human-centric solution. *Sustainability* **2019**, *11*, 4371. [CrossRef]
2. Vinitha, K.; Prabhu, R.A.; Bhaskar, R.; Hariharan, R. Review on industrial mathematics and materials at Industry 1.0 to Industry 4.0. *Mater. Today Proc.* **2020**, *33*, 3956–3960. [CrossRef]
3. Madsen, E.S.; Bilberg, A.; Hansen, D.G. Industry 4.0 and digitalization call for vocational skills, applied industrial engineering, and less for pure academics. In Proceedings of the 5th P&OM World Conference, Production and Operations Management, P&OM, Havana, Cuba, 6–10 September 2016.
4. Rada, M. Industry 5.0-from Virtual to Physical. LinkedIn. 7 March 2018. Available online: https://www.linkedin.com/pulse/industry-50-from-virtual-physical-michael-rada (accessed on 3 February 2022).
5. Skobelev, P.O.; Borovik, S.Y. On the way from Industry 4.0 to Industry 5.0: From digital manufacturing to digital society. *Industry 4.0* **2017**, *2*, 307–311.
6. Müller, J. *Enabling Technologies for Industry 5.0: Results of a Workshop with Europe's Technology Leaders*; European Commission: Brussels, Belgium, 2020.

7. Østergaard, E.H. Welcome to Industry 5.0. Available online: https://info.universal-robots.com/hubfs/Enablers/White%20papers/Welcome%20to%20Industry%205.0_Esben%20%C3%98stergaard.pdf?submissionGuid=00c4d11f-80f2-4683-a12a-e821221793e3 (accessed on 3 February 2022).
8. Saurabh, S.; Ambad, P.; Bhosle, S. Industry 4.0–A glimpse. *Procedia Manuf.* **2018**, *20*, 233–238.
9. Madsen Øivind, D.; Berg, T. An Exploratory Bibliometric Analysis of the Birth and Emergence of Industry 5. *Appl. Syst. Innov.* **2021**, *4*, 87. [CrossRef]
10. Welbers, K.; Van Atteveldt, W.; Benoit, K. Text Analysis in R. *Commun. Methods Meas.* **2017**, *11*, 245–265. [CrossRef]
11. Hearst, M. What is text mining. *SpringerPlus* **2016**, *5*, 1608.
12. Feng, L.; Chiam, Y.K.; Lo, S.K. Text-Mining Techniques and Tools for Systematic Literature Reviews: A Systematic Literature Review. In Proceedings of the 2017 24th Asia-Pacific Software Engineering Conference (APSEC), Nanjing, China, 4–8 December 2017; pp. 41–50.
13. Bach, M.P.; Krstić, Ž.; Seljan, S.; Turulja, L. Text Mining for Big Data Analysis in Financial Sector: A Literature Review. *Sustainability* **2019**, *11*, 1277. [CrossRef]
14. Aureli, S. A comparison of content analysis usage and text mining in CSR corporate disclosure. *Int. J. Digit. Account. Res.* **2017**, *17*, 1–32. [CrossRef]
15. Namugera, F.; Wesonga, R.; Jehopio, P. Text mining and determinants of sentiments: Twitter social media usage by tradi-tional media houses in Uganda. *Comput. Soc. Netw.* **2019**, *6*, 3. [CrossRef]
16. Akundi, A.; Mondragon, O. Model based systems engineering—A text mining based structured comprehensive overview. *Syst. Eng.* **2021**, *25*, 51–67. [CrossRef]
17. Wiedemann, G.; Niekler, A. Hands-On: A Five Day Text Mining Course for Humanists and Social Scientists in R. Available online: http://ceur-ws.org/Vol-1918/wiedemann.pdf (accessed on 10 November 2021).
18. Christian, H.; Pramodana, A.M.; Suhartono, D. Single document automatic text summarization using term frequency-inverse document frequency (TF-IDF). *ComTech Comput. Math. Eng. Appl.* **2016**, *7*, 285–294. [CrossRef]
19. Neto, J.L.; Santos, A.D.; Kaestner, C.A.A.; Alexandre, N.; Santos, D.; Celso, A.A.; Alex, K.; Freitas, A.A.; Parana, C. Document Clustering and Text Summarization. 2000. Available online: https://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.43.4634 (accessed on 10 November 2021).
20. Melnyk, L.; Kubatko, O.; Dehtyarova, I.; Matsenko, O.; Rozhko, O. The effect of industrial revolutions on the transformation of social and economic systems. *Probl. Perspect. Manag.* **2019**, *17*, 381–391. [CrossRef]
21. Haleem, A.; Javaid, M. Industry 5.0 and its applications in orthopedics. *J. Clin. Orthop. Trauma* **2019**, *10*, 807. [CrossRef]
22. Frederico, G.F. From supply chain 4.0 to supply chain 5.0: Findings from a systematic literature review and research direc-tions. *Logistics* **2021**, *5*, 49. [CrossRef]
23. Aslam, F.; Aimin, W.; Li, M.; Rehman, K.U. Innovation in the Era of IoT and Industry 5.0: Absolute Innovation Management (AIM) Framework. *Information* **2020**, *11*, 124. [CrossRef]
24. Gorodetsky, V.; Larukchin, V.; Skobelev, P. Conceptual Model of Digital Platform for Enterprises of Industry 5.0. In Proceedings of the Foundations of Computational Intelligence; Springer Science and Business Media: Saint-Petersburg, Russia, 2020; Volume 3, pp. 35–40.
25. Liu, L.; Tang, L.; Dong, W.; Yao, S.; Zhou, W. An overview of topic modeling and its current applications in bioinformatics. *SpringerPlus* **2016**, *5*, 1608. [CrossRef]
26. Jelodar, H.; Wang, Y.; Yuan, C.; Feng, X.; Jiang, X.; Li, Y.; Zhao, L. Latent Dirichlet allocation (LDA) and topic modeling: Models, applications, a survey. *Multimed. Tools Appl.* **2019**, *78*, 15169–15211. [CrossRef]
27. Sazvar, Z.; Tafakkori, K.; Oladzad, N.; Nayeri, S. A capacity planning approach for sustainable-resilient supply chain network design under uncertainty: A case study of vaccine supply chain. *Comput. Ind. Eng.* **2021**, *159*, 107406. [CrossRef]
28. Guo, Q.; Yu, H.; Dan, Z.; Li, S. Mining Method Optimization of Gently Inclined and Soft Broken Complex Ore Body Based on AHP and TOPSIS: Taking Miao-Ling Gold Mine of China as an Example. *Sustainability* **2021**, *13*, 12503. [CrossRef]
29. Mizrahi, D.; Zuckerman, I.; Laufer, I. Using a Stochastic Agent Model to Optimize Performance in Divergent Interest Tacit Coordination Games. *Sensors* **2020**, *20*, 7026. [CrossRef] [PubMed]
30. Barata, J. The fourth industrial revolution of supply chains: A tertiary study. *J. Eng. Technol. Manag.* **2021**, *60*, 101624. [CrossRef]
31. Ghosh, S.; Hughes, M.; Hodgkinson, I.; Hughes, P. Digital transformation of industrial businesses: A dynamic capability approach. *Technovation* **2021**, 102414. [CrossRef]
32. Anguelov, K. Indicators for the Effectiveness and Efficiency of the Implementation of an Enterprise Resource Planning System. In Proceedings of the 2021 12th National Conference with International Participation (ELECTRONICA), Sofia, Bulgaria, 27–28 May 2021; pp. 1–4.
33. Khurana, S.; Haleem, A.; Luthra, S.; Huisingh, D.; Mannan, B. Now is the time to press the reset button: Helping India's companies to become more resilient and effective in overcoming the impacts of COVID-19, climate changes and other crises. *J. Clean. Prod.* **2021**, *280*, 124466. [CrossRef] [PubMed]
34. Maddikunta, P.K.R.; Pham, Q.-V.; Prabadevi, B.; Deepa, N.; Dev, K.; Gadekallu, T.R.; Ruby, R.; Liyanage, M. Industry 5.0: A survey on enabling technologies and potential applications. *J. Ind. Inf. Integr.* **2021**, 100257. [CrossRef]
35. Deepu, T.S.; Ravi, V. A conceptual framework for supply chain digitalization using integrated systems model approach and DIKW hierarchy. *Intell. Syst. Appl.* **2021**, *10–11*, 200048. [CrossRef]

36. Vrchota, J.; Řehoř, P.; Maříková, M.; Pech, M. Critical Success Factors of the Project Management in Relation to Industry 4.0 for Sustainability of Projects. *Sustainability* **2020**, *13*, 281. [CrossRef]
37. Rehman, K.; Aslam, F.; Mata, M.; Martins, J.; Abreu, A.; Lourenço, A.M.; Mariam, S. Impact of Entrepreneurial Leadership on Product Innovation Performance: Intervening Effect of Absorptive Capacity, Intra-Firm Networks, and Design Thinking. *Sustainability* **2021**, *13*, 7054. [CrossRef]
38. Petersen, J.A.; Paulich, J.B.; Khodakarami, F.; Spyropoulou, S.; Kumar, V. Customer-based Execution Strategy in a Global Digital Economy. *Int. J. Res. Mark.* 2021, in press. [CrossRef]
39. Schütte, G. What kind of innovation policy does the bioeconomy need? *New Biotechnol.* **2018**, *40*, 82–86. [CrossRef]
40. Cricelli, L.; Strazzullo, S. The Economic Aspect of Digital Sustainability: A Systematic Review. *Sustainability* **2021**, *13*, 8241. [CrossRef]
41. Ghobakhloo, M.; Fathi, M.; Iranmanesh, M.; Maroufkhani, P.; Morales, M.E. Industry 4.0 ten years on: A bibliometric and systematic review of concepts, sustainability value drivers, and success determinants. *J. Clean. Prod.* **2021**, *302*, 127052. [CrossRef]
42. Narula, S.; Puppala, H.; Kumar, A.; Frederico, G.F.; Dwivedy, M.; Prakash, S.; Talwar, V. Applicability of industry 4.0 technologies in the adoption of global reporting initiative standards for achieving sustainability. *J. Clean. Prod.* **2021**, *305*, 127141. [CrossRef]
43. Kalsoom, T.; Ahmed, S.; Rafi-Ul-Shan, P.M.; Azmat, M.; Akhtar, P.; Pervez, Z.; Imran, M.A.; Ur-Rehman, M. Impact of IoT on Manufacturing Industry 4.0: A New Triangular Systematic Review. *Sustainability* **2021**, *13*, 12506. [CrossRef]
44. Potocan, V. Technology and Corporate Social Responsibility. *Sustainability* **2021**, *13*, 8658. [CrossRef]
45. Bellandi, M.; De Propris, L. Local Productive Systems' Transitions to Industry 4.0+. *Sustainability* **2021**, *13*, 13052. [CrossRef]
46. Abubakr, M.; Abbas, A.T.; Tomaz, I.; Soliman, M.S.; Luqman, M.; Hegab, H. Sustainable and smart manufacturing: An in-tegrated approach. *Sustainability* **2020**, *12*, 2280. [CrossRef]
47. Massaro, A. Information Technology Infrastructures Supporting Industry 5.0 Facilities. In *Electronics in Advanced Research Industries*; Wiley-IEEE Press: Hoboken, NJ, USA, 2021; pp. 51–101.
48. Coito, T.; Firme, B.; Martins, M.; Vieira, S.; Figueiredo, J.; Sousa, J. Intelligent Sensors for Real-Time Decision-Making. *Automation* **2021**, *2*, 62–82. [CrossRef]
49. Shariati, M.; Weber, W.E.; Bohlen, J.; Kurz, G.; Letzig, D.; Höche, D. Enabling intelligent Mg-sheet processing utilizing efficient machine-learning algorithm. *Mater. Sci. Eng. A* **2020**, *794*, 139846. [CrossRef]
50. Yin, L.; Gao, Q.; Zhao, L.; Zhang, B.; Wang, T.; Li, S.; Liu, H. A review of machine learning for new generation smart dispatch in power systems. *Eng. Appl. Artif. Intell.* **2020**, *88*, 103372. [CrossRef]
51. Coupry, C.; Noblecourt, S.; Richard, P.; Baudry, D.; Bigaud, D. BIM-Based Digital Twin and XR Devices to Improve Maintenance Procedures in Smart Buildings: A Literature Review. *Appl. Sci.* **2021**, *11*, 6810. [CrossRef]
52. Du Plessis, A.; Broeckhoven, C.; Yadroitsava, I.; Yadroitsev, I.; Hands, C.H.; Kunju, R.; Bhate, D. Beautiful and functional: A review of biomimetic design in additive manufacturing. *Addit. Manuf.* **2019**, *27*, 408–427. [CrossRef]
53. Ammar, M.; Haleem, A.; Javaid, M.; Bahl, S.; Verma, A.S. Implementing Industry 4.0 technologies in self-healing materials and digitally managing the quality of manufacturing. *Mater. Today Proc.* **2021**, *51*. [CrossRef]
54. Fraga-Lamas, P.; Lopes, S.I.; Fernández-Caramés, T.M. 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* **2021**, *21*, 5745. [CrossRef]
55. Miglani, A.; Kumar, N. Blockchain management and machine learning adaptation for IoT environment in 5G and beyond networks: A systematic review. *Comput. Commun.* **2021**, *178*, 37–63. [CrossRef]
56. Mbunge, E.; Muchemwa, B.; Jiyane, S.; Batani, J. Sensors and healthcare 5.0: Transformative shift in virtual care through emerging digital health technologies. *Glob. Health J.* **2021**, *5*, 169–177. [CrossRef]
57. Chegini, H.; Naha, R.K.; Mahanti, A.; Thulasiraman, P. Process Automation in an IoT–Fog–Cloud Ecosystem: A Survey and Taxonomy. *IoT* **2021**, *2*, 6. [CrossRef]
58. Vithanage, N.N.N.; Thanthrige, S.S.H.; Kapuge, M.C.K.P.; Malwenna, T.H.; Liyanapathirana, C.; Wijekoon, J.L. A Secure Corroboration Protocol for Internet of Things (IoT) Devices Using MQTT Version 5 and LDAP. In Proceedings of the 2021 International Conference on Information Networking (ICOIN), Jeju Island, Korea, 13–16 January 2021; pp. 837–841.
59. Sujith, A.; Sajja, G.S.; Mahalakshmi, V.; Nuhmani, S.; Prasanalakshmi, B. Systematic review of smart health monitoring using deep learning and Artificial intelligence. *Neurosci. Inform.* **2021**, *2*, 100028. [CrossRef]
60. Dineva, K.; Atanasova, T. Design of Scalable IoT Architecture Based on AWS for Smart Livestock. *Animals* **2021**, *11*, 2697. [CrossRef]
61. Omolara, A.E.; Alabdulatif, A.; Abiodun, O.I.; Alawida, M.; Alabdulatif, A.; Alshoura, W.H.; Arshad, H. The internet of things security: A survey encompassing unexplored areas and new in-sights. *Comput. Secur.* **2022**, *112*, 102494. [CrossRef]
62. Miraz, M.H.; Ali, M.; Excell, P.S.; Picking, R. Internet of Nano-Things, Things and Everything: Future Growth Trends. *Future Internet* **2018**, *10*, 68. [CrossRef]
63. Anthopoulos, L.; Kazantzi, V. Urban energy efficiency assessment models from an AI and big data per-spective: Tools for policy makers. *Sustain. Cities Soc.* **2022**, *76*, 103492. [CrossRef]
64. Demir, K.A.; Döven, G.; Sezen, B. Industry 5.0 and Human-Robot Co-working. *Procedia Comput. Sci.* **2019**, *158*, 688–695. [CrossRef]
65. Fast-Berglund, Åsa; Thorvald, P. Variations in cycle-time when using knowledge-based tasks for humans and robots. *IFAC-PapersOnLine* **2021**, *54*, 152–157. [CrossRef]

66. Massaro, A. State of the Art and Technology Innovation. In *Electronics in Advanced Research Industries*; Wiley-IEEE Press: Hoboken, NJ, USA, 2021; pp. 1–49.
67. Margherita, E.G.; Braccini, A.M. Socio-technical perspectives in the Fourth Industrial Revolution-Analysing the three main visions: Industry 4.0, the socially sustainable factory of Operator 4.0 and Industry 5.0. In Proceedings of the 7th International Workshop on Socio-Technical Perspective in IS Development (STPIS 2021), Trento, Italy, 14–15 October 2021.
68. Cebollada, S.; Payá, L.; Flores, M.; Peidró, A.; Reinoso, O. A state-of-the-art review on mobile robotics tasks using artificial intelligence and visual data. *Expert Syst. Appl.* **2021**, *167*, 114195. [CrossRef]
69. Romero, D.; Stahre, J. Towards the Resilient Operator 5.0: The Future of Work in Smart Resilient Manufacturing Systems. *Procedia CIRP* **2021**, *104*, 1089–1094. [CrossRef]
70. Wang, L. A futuristic perspective on human-centric assembly. *J. Manuf. Syst.* **2021**, *62*, 199–201. [CrossRef]
71. Martin, L.; Gonzalez-Romo, M.; Sahnoun, M.; Bettayeb, B.; He, N.; Gao, J. Effect of Human-Robot Interaction on the Fleet Size of AIV Transporters in FMS. In Proceedings of the 2021 1st International Conference on Cyber Management and Engineering (CyMaEn), Hammamet, Tunisia, 26–28 May 2021; pp. 1–5.