

Review Article

Industry 4.0 Disruption and Its Neologisms in Major Industrial Sectors: A State of the Art

Ocident Bongomin ¹, **Aregawi Yemane** ², **Brendah Kembabazi**,³ **Clement Malanda**,⁴ **Mwewa Chikonkolo Mwape**,^{5,6} **Nonsikelelo Sheron Mpfu**,^{1,7} and **Dan Tigalana**^{1,8}

¹Department of Manufacturing, Industrial and Textile Engineering, School of Engineering, Moi University, P.O. Box 3900-30100, Eldoret, Kenya

²Department of Industrial Engineering, Mekelle University, P.O. Box 231, Mek'ele, Ethiopia

³Department of Animal Science, Faculty of Agriculture, Egerton University, P.O. Box 536-20115, Nakuru, Kenya

⁴Department of Applied Studies, Malawi University of Science and Technology, P.O. Box 5196, Limbe, Malawi

⁵Department of Mechanical, Production and Energy Engineering, School of Engineering, Moi University, P.O. Box 3900-30100, Eldoret, Kenya

⁶Department of Renewable Energy, Zambia Electricity Supply Corporation Limited (ZESCO), P.O. Box 33304-10101, Lusaka, Zambia

⁷Department of Fibre, Polymer and Materials Engineering, P.O. Box AC939, Bulawayo, Zimbabwe

⁸Department of Polymer, Industrial and Textile Engineering, Faculty of Engineering, Busitema University, P.O. Box 236, Tororo, Uganda

Correspondence should be addressed to Ocident Bongomin; ocidentbongomin@gmail.com

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Very well into the dawn of the fourth industrial revolution (industry 4.0), humankind can hardly distinguish between what is artificial and what is natural (e.g., man-made virus and natural virus). Thus, the level of discombobulation among people, companies, or countries is indeed unprecedented. The fact that industry 4.0 is explosively disrupting or retrofitting each and every industrial sector makes industry 4.0 the famous buzzword amongst researchers today. However, the insight of industry 4.0 disruption into the industrial sectors remains ill-defined in both academic and nonacademic literature. The present study aimed at identifying industry 4.0 neologisms, understanding the industry 4.0 disruption and illustrating the disruptive technology convergence in the major industrial sectors. A total of 99 neologisms of industry 4.0 were identified. Industry 4.0 disruption in the education industry (education 4.0), energy industry (energy 4.0), agriculture industry (agriculture 4.0), healthcare industry (healthcare 4.0), and logistics industry (logistics 4.0) was described. The convergence of 12 disruptive technologies including 3D printing, artificial intelligence, augmented reality, big data, blockchain, cloud computing, drones, Internet of Things, nanotechnology, robotics, simulation, and synthetic biology in agriculture, healthcare, and logistics industries was illustrated. The study divulged the need for extensive research to expand the application areas of the disruptive technologies in the industrial sectors.

1. Introduction

In the second decade of the twenty-first century, the world stands on the cusp of industry 4.0 paradigm which has remarkably become global emergence with a core of industrial transformation, revitalization, and development [1]. Simply put, industry 4.0 is the integration of cyber and

physical worlds through introduction of new technologies in the industrial fields [2, 3]. In other words, it is a technological revolution in every production system including operator and maintenance [4], which is quite unique from the previous revolutions as shown in Table 1 [5–9]. Industry 4.0 is the digitization of the industrial value chain which has become unexampled for economic and social development

TABLE 1: Transition in industry, operator, and maintenance.

Transition	Industry	Operator	Maintenance
Level 1	Industry 1.0 Mechanical production, rail road, steam power	Operator 1.0 Manual and dexterous work Machine tools	Maintenance 1.0 Visual inspection
Level 2	Industry 2.0 Mass production Assembly line Electrical power	Operator 2.0 Assisted work Numerical control	Maintenance 2.0 Instrument inspection
Level 3	Industry 3.0 Automated production Electronics, computers, and IT First PLC system	Operator 3.0 Cooperative work Industrial robots	Maintenance 3.0 Real-time condition monitoring
Level 4	Industry 4.0 Fusion of virtual, physical, digital, and biological sphere (CPPS) Convergence of technologies: AI, IoT, VR/AR, big data, etc.	Operator 4.0 Work-aided human-CPS	Maintenance 4.0 Predictive maintenance Use of big data Statistical analysis Smart sensors and IoT Use of digital twins

IT: information technology, PLC: programmable logic controller, CPPS: cyber-physical production system, AI: artificial intelligence, IoT: Internet of Things, VR: virtual reality, AR: augmented reality, and CPS: cyber-physical system.

in the recent years [10–12]. On the one hand, it allows high-wage countries to maintain their business responsiveness and competitiveness [13]. On the other hand, research and development units are organizationally, personally, and methodically being aligned for innovation competitiveness [14, 15].

Industry 4.0 is a data-driven production system which is progressing exponentially while reshaping the way individuals live and work essentially. Therefore, the public remains optimistic regarding the opportunities it may offer for sustainability and the future of quality work in the global digital economy [16–20]. Actually, industry 4.0 is increasingly being promoted as the key for improving productivity, promoting economic growth, and ensuring the sustainability of manufacturing companies [21–23]. Moreover, it aims to improve the flexibility, adaptability, and resilience of the industrial systems [24, 25].

Industry 4.0 has been considered a new industrial stage in which several emerging or disruptive technologies including Internet of Things (IoT), artificial intelligence (AI), 3D printing, and big data are converging to provide digital solutions [26, 27]. Industry 4.0 is characterized by the mass employment of smart objects in highly reconfigurable and thoroughly connected industrial product-service systems [28]. In this respect, industry 4.0 phenomenon is bringing unprecedented disruptions for all traditional production/service systems and business models (value chains) and hotfooting the need for redesign and digitization of activities [29–32]. Tout ensemble is retrofitting and/or redefining the patterns of value creation and annexations, production networks, and supplier base and customer interfaces [33–35].

The concept of industry 4.0 is greatly linked to other concepts such as servitization [36, 37], crowdsourcing [38], circular economy (sharing economy) [39–44], green economy, and bioeconomy [45]. Besides being complementary to a vast number of existing concepts, the main strength of

industry 4.0 is the promises for shorter delivery time, more efficient and automated processes, higher quality, agility in production, and profitable and customized products [46, 47]. Furthermore, it is expected to create extra values as the world is massively experiencing digital transformation [48]. In this regard, industry 4.0 has not only opened windows of opportunity for emerging economies but also brought its own bureaucracy in terms of the main challenges that these changes pose to firms, industrial systems, and policy approaches [49].

The curiosity and the need to contemplate the meaning and concept of industry 4.0 have been ubiquitous among academic and business communities and thus make industry 4.0 to be one of the most important topics in the modern world as a result of digital milestones in the innovation area [50]. So far so good, there are several ambiguities with almost 100 definitions and related concepts of industry 4.0 already in existence among academic and nonacademic literature [51]. In the academic community, engineering has incredibly gained more attention to the industry 4.0 topic than other subject areas including computer science, chemistry, and energy (Figure 1) [52].

The rapid and fascinating adoption of the industry 4.0 topic among academic and business entities has led to the massive use of icon or neologism “4.0” to depict industry 4.0 disruption in the systems, processes, activities, or even industrial sectors. However, the collective numbers and names of the existing industry 4.0 neologisms have remained unclear [53]. In addition, industry 4.0 disruption through the convergence of its technologies has been ill-defined among previous researchers [26]. To this end, the outstanding contributions of the present study are trifold: (1) identify industry 4.0 neologisms used among the academic and business communities, (2) clearly understand industry 4.0 disruption in education industry (education 4.0), energy industry (energy 4.0), agriculture industry (agriculture 4.0), healthcare industry (healthcare 4.0), and logistics industry

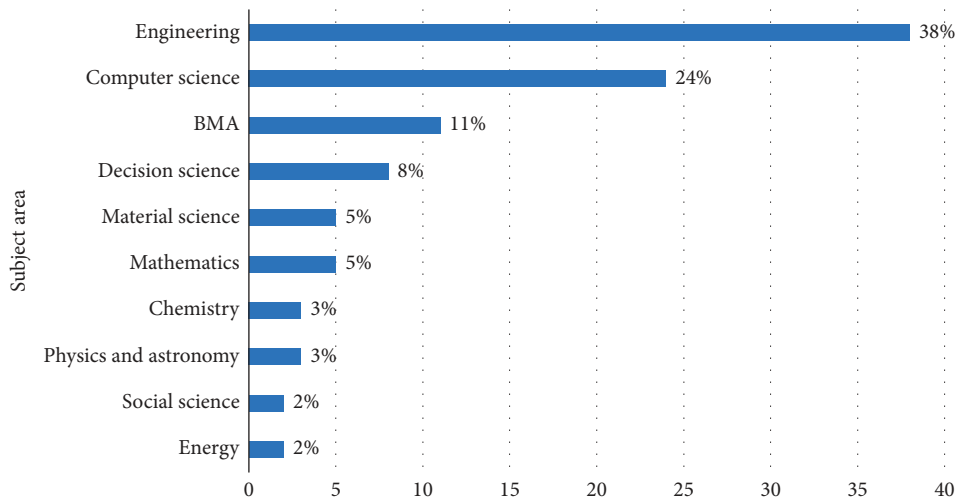


FIGURE 1: Percentage of industry 4.0 published papers per subject area (adapted from Chiarello et al. [52]). BMA: business, management and accounting.

4.0 (logistics 4.0), and (3) illustrate the convergence of industry 4.0 technologies in the agriculture, healthcare, and logistics industries.

2. Methodology

A comprehensive literature search was conducted in electronic databases Google Scholar, ScienceDirect, Taylor & Francis, Springer, and Emerald Insight from January 2020 to May 2020 following procedures employed in previous studies [27, 54]. The search was performed independently in all the databases and then combined with “and” operators. The multidisciplinary databases included peer-reviewed journal articles, conference papers, books, theses, working papers, white papers, discussion papers, patents, and reports published between 2015 and 2020. Thus, articles in the returned results were assessed concerning their inclusion in this study, and further searches were carried out at the Google search engine.

The literature search from the databases was done using the following search terms: “Agriculture 4.0,” “Education 4.0,” “Energy 4.0,” “Healthcare 4.0,” and “Logistics 4.0.” On the contrary, the search on the Google search engine was accomplished with the following search terms: “3D printing and Agriculture,” “Artificial intelligence and Agriculture,” “Augmented reality and Agriculture,” “Big data and Agriculture,” “Blockchain and Agriculture,” “Cloud computing and Agriculture,” “Drones and Agriculture,” “Internet of things and Agriculture,” “Nanotechnology and Agriculture,” “Robotics and Agriculture,” “Simulation and Agriculture,” “Synthetic biology and Agriculture,” “3D printing and Healthcare,” “Artificial intelligence and Healthcare,” “Augmented reality and Healthcare,” “Big data and Healthcare,” “Blockchain and Healthcare,” “Cloud computing and Healthcare,” “Drones and Healthcare,” “Internet of things and Healthcare,” “Nanotechnology and Healthcare,” “Robotics and Healthcare,” “Simulation and Healthcare,” “Synthetic biology and Healthcare,” “3D printing and Logistics,” “Artificial intelligence and

Logistics,” “Augmented reality and Logistics,” “Big data and Logistics,” “Blockchain and Logistics,” “Cloud computing and Logistics,” “Drones and Logistics,” “Internet of things and Logistics,” “Nanotechnology and Logistics,” “Robotics and Logistics,” “Simulation and Logistics,” and “Synthetic biology and Logistics.”

All the relevant literature studies were downloaded (PDF files) and saved on the computer, but only important literature studies that meet the scope of the present study were considered for in-depth literature study. The first screening was done through evaluation of the title and abstract (TA) followed by full-text (FT) screening for inclusion in the study in terms of availability of requisite information for the present study (Figure 2). The last search was done on 20th May 2020. The search outputs were saved on databases, and the authors received notification of any new searches meeting the search criteria (from ScienceDirect, Taylor & Francis, Emerald Insight, and Google Scholar).

3. Industry 4.0 Neologisms

The concept of industry 4.0 originated from the manufacturing industry purposely to improve the engineering excellence from machine building to informatization [55]. However, nowadays, the concept of industry 4.0 has expanded enormously, and its definition spans beyond engineering, smart and connected machines, and systems and has become a more general concept with mainstream appeal and applicability [56]. This can be evidenced by a multitude of neologisms such as fashion 4.0 and care 4.0. Interestingly, the icon “4.0” and beyond (e.g., “5.0”) have spread exceedingly as witnessed by the fact that the combination of a noun and the icon “4.0” is used to signal and usher in discussions about the future of business and society [53]. In this study, 99 industry 4.0 neologisms were identified and categorized into 6 areas based on the subject of the published literature as depicted in Table 2. However, the previous study done by Madsen [53] reported only 37 neologisms. This alone can divulge that there is an increasing

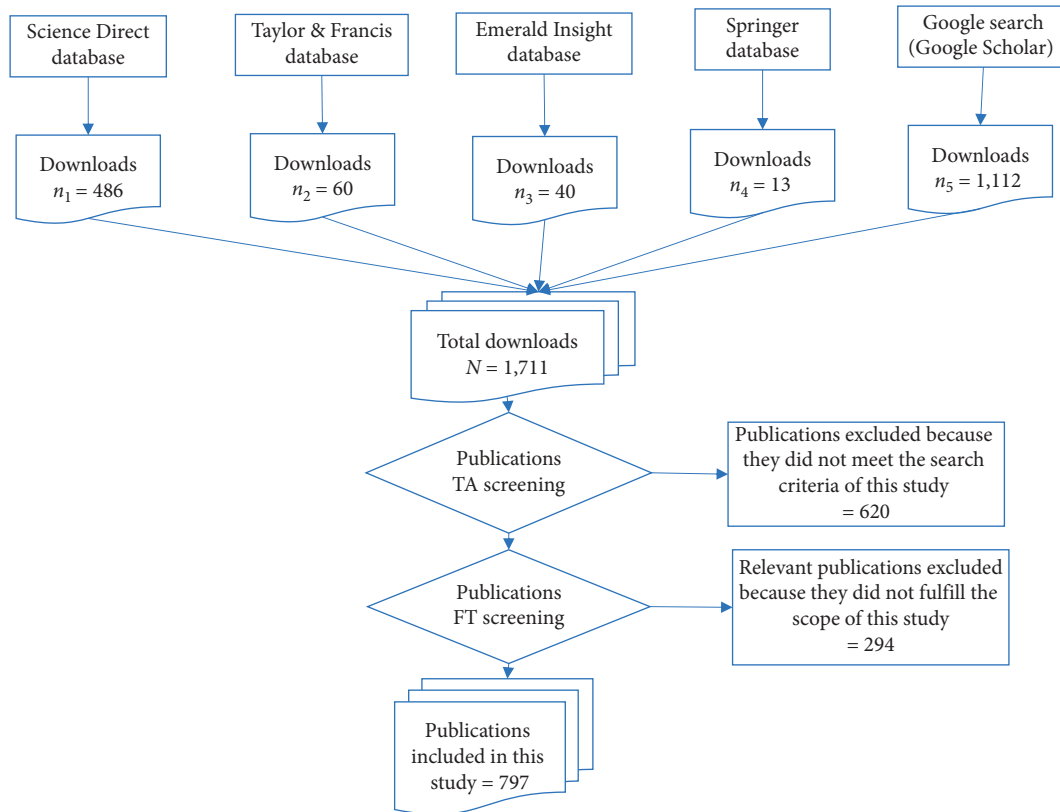


FIGURE 2: The flowchart diagram for the literature search strategy used in this study. $N = n_1 + n_2 + n_3 + n_4 + n_5$ represents the total number of PDF files downloaded from the respective databases.

disruptive landscape of industry 4.0 in business, society, service, and industry sectors.

4. Major Industrial Sectors

4.1. Education 4.0

4.1.1. Overview of Education 4.0. The disruptive landscape of industry 4.0 is so strong that change is inevitable, including within the education industry [176], making education 4.0 the illustrious cant among educationists today [177, 178]. Education 4.0 is an advanced education and networked ecosystem capable of developing skills and building competences for the new era of manufacturing [106]. In other words, education 4.0 is advanced engineering education for industry 4.0 [179, 180]. Furthermore, it is termed as higher education in the fourth industrial revolution [181–184]. Moreover, education 4.0 can be defined in terms of OECD future education and skills 2030 [185] and PhD program in the era of industry 4.0 [186]. Simply put, education 4.0 is creativity-focused technology education in the age of industry 4.0 [187].

Generally, education 4.0 came forth in response to industry 4.0 which is a technology- and data-fueled world [188]. It has similar remarkable trends of (r)evolution just as industry 4.0. Table 3 shows the characteristics of each education evolution [189–195]. Education 4.0 is the most complex system as compared to the previous evolutions. This is derived from the fact that industry 4.0 disruption is

introducing rapid and unbelievable changes and challenges including the issue of skills and job profiles [196]. Therefore, it poses the question of how to educate and prepare new logical innovations and to develop not only left-brain skills but also right-brain skills [197]. As a result, education 4.0 topic has attracted a number of researchers in the recent year. Lately, the World Economic Forum developed education 4.0 framework that can be easily adopted and implemented by any institution, government, or university as presented in Table 4 [198].

4.1.2. Learning Factory. As far as education 4.0 is concerned, adequate and innovative manufacturing education and training are required in order to prepare employees for changes in their working environment related to quickly advancing digitalization. Most importantly, theoretical knowledge and practical skills regarding data acquisition, processing, visualization, and interpretation are needed to exploit the full potential of digitalization [199]. Consequently, the concepts of learning factory (LF)/teaching factory and innovation laboratory have egressed in the recent epoch as the lucrative approaches for qualification of participants from the field of engineering, especially industrial and mechanical engineering [200–204].

LFs offer a suitable environment to combine theoretical learning and practical application and are therefore predestined to impart industry 4.0 knowledge and skills [205]. LFs are employed to teach students how the methods and

TABLE 2: Industry 4.0 neologisms.

S/N	Category	Neologism	Reference
1	Process, operation, quality, materials, machine, methods, maintenance	Six Sigma 4.0	[57]
		Service 4.0	[58, 59]
		Excellence 4.0	[60]
		Workstation Interaction 4.0, OWI 4.0	[61]
		Operator 4.0, O4.0	[6, 62, 63]
		Machine Tool 4.0	[64]
		Forming 4.0	[65]
		Robotics 4.0	[66]
		Lean 4.0	[67, 68]
		Quality 4.0	[69, 70]
		Machine Shop 4.0	[71]
		Value Stream Method 4.0	[72]
		Maintenance 4.0	[8]
		Assembly 4.0	[73, 74]
		Material 4.0	[75]
		Paint Shop 4.0	[76]
2	Industry (oil and gas, manufacturing, agriculture, engineering and technology, construction, pharmaceutical, textiles and apparel, energy, and web)	Industrial Maintenance 4.0	[77]
		Fashion 4.0	[78, 79]
		Airport 4.0	[58]
		Industrial 4.0	[80]
		Agriculture 4.0	[81]
		Farming 4.0	[82, 83]
		Landwirtschaft 4.0	[82]
		Pharma 4.0	[84]
		Industrial Revolution 4.0, IR4.0	[85–89]
		Apparel 4.0	[90]
		Technology 4.0	[91]
		Service Engineering 4.0	[92]
		Construction 4.0	[93]
		Oil and Gas 4.0	[94]
		Agri-Food 4.0	[95–98]
		Energy 4.0	[99, 100]
3	Education and training	Web 4.0	[101]
		Energy Cloud 4.0	[102]
		Energy System 4.0	[103]
		Manufacturing 4.0	[104]
		Education 4.0	[105]
		Teaching Factory 4.0	[106]
		Literacy 4.0	[107]
		Learning 4.0	[108]
		Teaching I4.0	[109]
		Academic Course 4.0	[110]
		University 4.0	[111]
		University in the Form 4.0	[112]
		ECLECTIC 4.0	[113]
		Human Capital 4.0	[114]
		Engineering Education 4.0	[115]
		iNduce 4.0	[116]

TABLE 2: Continued.

S/N	Category	Neologism	Reference
4	Logistics, supply chain, services and financial inclusion, healthcare	Healthcare Logistic 4.0	[117, 118]
		Logistics 4.0	[119]
		Healthcare 4.0, H4.0	[120]
		Health 4.0	[121]
		Hospital 4.0	[122, 123]
		Electric Utility 4.0	[124]
		Logistics Center 4.0	[125]
		Market 4.0	[126]
		Marketing 4.0	[127, 128]
		Maritime 4.0	[129]
		Shipping 4.0	[130]
		Enterprise 4.0	[131]
		Supply Chain 4.0	[132, 133]
		Care 4.0	[134]
		Retail 4.0	[135, 136]
		Post 4.0	[137]
		Distribution 4.0	[138]
		Warehousing 4.0	[138]
		Warehouse 4.0	[139, 140]
		5	Society, government, economy, human resource, workforce, management, leadership, globalization
Procurement 4.0	[142]		
Customer 4.0	[127]		
Consumer 4.0	[143]		
Finance 4.0	[144]		
Bank 4.0	[145]		
Smart HR 4.0, SHR 4.0	[146]		
Knowledge Management 4.0, KM 4.0	[147, 148]		
Leadership 4.0	[149, 150]		
Building Management 4.0	[151]		
Neighborhood 4.0	[152]		
Arbeit 4.0	[153]		
Work 4.0	[53, 154]		
HR 4.0	[155]		
HRM 4.0	[156]		
Controlling 4.0	[157]		
Globalization 4.0	[158]		
Society 4.0	[159]		
Supply Chain Management 4.0	[160]		
Inventory Management 4.0	[138]		
Order Management 4.0	[138]		
E-government 4.0 or e-Government 4.0	[161]		
Development 4.0	[162]		
Skills 4.0	[163]		
Professional Competence 4.0	[164]		
6	Others and beyond "4.0"	Thailand 4.0	[165, 166]
		Generation 4.0	[167]
		Revolution 4.0	[168]
		Digital 4.0	[142]
		Quality 5.0	[70]
		Society 5.0	[169, 170]
		Agriculture 5.0	[171, 172]
Industry 5.0	[173–175]		

concepts are learned in theory work in a hands-on and industry-related environment [200]. Elaborately, LFs are a platform created to provide an effective learning environment that will bring about human capacity development in a

bid to bridge the gap between learning and practice (i.e., the gap between academia and industry) [206, 207]. The promising strength of LFs is the ability to solve problems in a structured way which is an essential competence of people in

TABLE 3: Characteristics of education generations.

S/N	Characteristics	Education 1.0	Education 2.0	Education 3.0	Education 4.0
1	Students' behaviour	Largely passive	Passive to active	Active, enthusiastic, string and confidence	Independent, active, innovative, and self-directed learning style
2	Primary roles for teacher/ professor	Authoritarian and source of knowledge	Guide and source of knowledge	Facilitator of collaborative knowledge creation	Monitor and observer of learning
3	Teacher/ professor source of content	Traditional books and copyright handouts	Copyright and free educational materials for students	E-books and educational websites	Technology-based dynamic and 3D materials
4	Institutional arrangement	Campus-based with fixed boundary institution involving traditional paragraphs, test assignments, and, sometimes, group classroom	Increasing collaboration between universities but one-to-one between students and universities	Open, collaborative, and creative activities with loose international affiliations and relation	Creative, skillful innovative, and dynamic activities are performed; universities are boundaryless
5	Methods	Dictation and direct transfer of information Guru-shishya method of teaching	Progressivism and openness to internet	Knowledge production and co-constructivism	Innovation production and classroom replacement
6	Technology	E-learning through electronic management within an institution	E-learning and collaboration involving other universities	E-learning driven from the point of view of personal independent learning environments, use of computers and internet	E-learning is totally based on new innovative technology tools, high-speed internet, mobile technology, social media platforms, virtual reality, etc.
7	Location of the institution	Specific building; mortar and brick	Specific building plus online; brick and click	Everywhere in a creative society	Globally networked human body; anytime, anywhere, any device, and any platform

TABLE 4: Education 4.0 framework.

Category	Critical characteristics	Description
Learning content (built-in mechanism for skill adaptation)	Global citizenship skills	Include content that focuses on building awareness about the wider world, sustainability, and playing an active role in the global community
	Innovation and creativity skills	Include content that fosters skills required for innovation, including complex problem-solving, analytical thinking, creativity, and system analysis
	Interpersonal skills	Include content that focuses on interpersonal emotional intelligence, including empathy, cooperation, negotiation, leadership, and social awareness
	Technology skills	Include content that focuses on interpersonal emotional intelligence, including empathy, cooperation, negotiation, leadership, and social awareness
Experiences (leveraging innovative pedagogies)	Personalized and self-paced learning	Move from a system where learning is standardized to the one based on the diverse individual needs of each learner and flexible enough to enable each learner to progress at their own pace
	Accessible and inclusive learning	Move from a system where learning is confined to those with access to school buildings to the one in which everyone has access to learning and is therefore inclusive
	Problem-based and collaborative learning	Move from process-based to project- and problem-based content delivery, requiring peer collaboration and more closely mirroring the future of work
	Lifelong and student-driven learning	Move from a system where learning and skilling decrease over one's lifespan to the one where everyone continuously improves on existing skills and acquires new ones based on their individual needs

a factory, from the shop floor operator to the management level factory [208]. Furthermore, LFs are an effective solution to deal with new technologies, concepts, and methods [209]. Generally, LFs develop a uniform, unambiguous concept of competence that can be applied to production technology in the engineering community [210]. However, the requirements for the planning, implementation, and operation of an academic LF vary depending on the specific area of the respective institution [211]. For instance, the use of LFs differs for education in maintenance, manufacturing, production design, and technology adoption [212]. To this end, several learning factory concepts have been developed including game-based learning or gamification for manufacturing education [213] and Internet of Things laboratory (IoT lab) [214]. Table 5 outlines some examples of the learning factories launched majorly by institutions.

4.2. Energy 4.0

4.2.1. Overview of Energy 4.0. Despite the tremendous improvement in the industrial systems brought about by industry 4.0 in terms of the rudimentary achievements on higher level of operational efficiency, productivity, and automatization, it brought bureaucracy as huge amount of energy and materials is demanded and extremely large amount of solid, liquid, and gaseous wastes or greenhouse gases is generated from these complex industrial systems [237, 238]. Therefore, smart factories need to be sustainable and renewable in terms of energy pattern (electric system industry) [124, 239–241]. Furthermore, the United Nations Industrial Development Organization (UNIDO) has set the relevancy of industry 4.0 and sustainability in the global Sustainable Development Goals (SDG 7 and 9) that digital industrial development should support the growth of industrial sustainable energy [242]. This has pointed towards the evolution of new energy concept known as energy 4.0.

Energy 4.0 is a digital revolution in the energy sector and also known as smart energy or green energy [99]. It presents opportunities for companies to establish new business models and sustainable strategies of producing and delivering energy [99]. Moreover, the idea of energy 4.0 is based on accelerating clean energy through adoption of the industry 4.0 concept in the energy sector [243]. The energy transition from 1.0 to 4.0 can be traced back in a similar manner to that of the web system as illustrated in Figure 3 [99, 101, 102].

4.2.2. The Drivers of Energy 4.0. The concept of energy 4.0 is nascent, and therefore, no clear information on its concept exists so far in the literature [99]. Nevertheless, renewable energy is fundamental to the energy 4.0 epoch. However, the transition to intermittent energy production from renewable energy sources increases the complexity of providing reliable energy supply. This has been handled with the introduction of digital or smart energy systems [244]. The truth is that smart renewable energy ware systems lie at the core of industry 4.0, and a number of recent advanced technologies and approaches play pivotal roles by exploiting innovative technologies and optimization methods [241]. For instance, the

production of crude biofuels obtained from biomass and renewable energy sources is unheard-of. The biomass crude oil generation technology is currently up-to-date in terms of reducing dangerous emissions into the environment [245]. In addition, offshore and onshore wind energy harvesting has become the driving force towards the realization of energy 4.0 in most developed and developing countries [100].

Another key driver of energy 4.0 is how to reduce energy consumption whilst maintaining or increasing profits and productivity. The fact that energy requirements have grown due to automation of industrial systems makes energy optimization central in energy 4.0. Thus, a number of sophisticated energy-efficient mechanisms and software have been developed including real-time embedded systems [246] and computational modeling (e.g., energy efficiency analysis modeling system) [247–249].

Additionally, the advancement in power distribution is another driver of energy 4.0. This is accomplished through the integration of conventional power grid system with industry 4.0 technologies including IoT, big data, and AI. The combination of these technologies and power grid has been cited as smart grid [99].

Furthermore, the advancement in the energy storage system which employed nanotechnology as one of the core technologies for its development is emblematic to energy 4.0. Currently, the next-generation lithium-ion batteries are under rapid development using various nanostructured materials including silicon nanowires and silicon nanotubes which are two promising anode materials due to their high specific capacities [250].

4.3. Agriculture 4.0

4.3.1. Overview of Agriculture 4.0. The disruptive waves of industry 4.0 in agriculture and food systems (agri-food) can be witnessed from the digital transformation of the production infrastructures such as connected farms, new farm equipment, and connected tractors and machines [251, 252]. The driving force behind this is the need to increase efficiency, productivity, and quality in agri-food systems and environmental protection (reduce global warming) [253, 254], that is, the sustainability of agricultural systems which is paramount important for the survival and wellbeing of humans worldwide [255]. In fact, agriculture plays a great role in providing human food security and sustainability in any country [256]. Therefore, to meet this ever-increasing food demand in the epoch of industry 4.0, the new concept “agriculture 4.0” was born [82].

Agriculture 4.0 is known with several names including data-driven and automated agriculture [172, 257], intelligence agriculture [258], smart agriculture [259], digital agriculture [260], digital farming [261], smart farming [262], and farming 4.0 [83]. Agriculture 4.0 emerged when telematics and data management were combined to the already known concept of precision agriculture (improving the accuracy of operations) [172]. Agriculture 4.0 can further be defined as farming in the era of industry 4.0 through digitalization [263]. Moreover, it is the future of farming technology which is based on the emergence of smart

TABLE 5: Examples of learning factories.

S/N	Example	Description	References
1	LEAD Factory	It focuses on lean, energy efficiency, agility, and digitalization and deals with production-relevant process.	[215–220]
2	Schumpeter Laboratory for Innovation (SLFI)	It is an academic makerspace with the focus on product and service development.	[215]
3	Tiphys project	It aims to build an open-networked platform for learning of industry 4.0 themes.	[221]
4	SEPT Learning Factory	W Booth School of Engineering Practice and Technology (SEPT) is an educational unit in the faculty of engineering at McMaster University focusing at developing talents for a workforce that has industry 4.0 foundational education and skills.	[203, 222–224]
5	ELLI project	Excellent Teaching and Learning in Engineering Science (ELLI) aims to develop, introduce, and evaluate several kinds of remote and virtual laboratories into higher engineering education.	[115]
6	Tampere RoboLab	A new learning concept and environment focusing on robotics formal and nonformal education.	[225]
7	Virtual FMS engineering education environment	It focuses on planning, operation, and analysis of flexible manufacturing systems (FMS). The aim is to allow the students to achieve the intended learning outcomes mostly with learning by doing.	[226]
8	Automated class room	This is an industrial cyber-physical system (ICPS) demonstration platform. It is used as a practical testbed, where students from different departments can learn together on how to implement the industry 4.0 concept and technologies.	[227]
9	Industrie 4.0 learning factory	It aims to support “made in China 2025” strategy with necessary qualification of employees in Chinese production companies.	[228]
10	Training Factory Stator Production	It aims at providing small- and medium-sized companies, particularly those affected by change, with the opportunity to train their employees.	[229]
11	MTA SZAKI learning factory	It aims at providing infrastructure, learning content, and opportunities for future production engineers, with a strong emphasis on automation and human-robot collaboration.	[230]
12	Chair of production system (LPS)	It aims at teaching industry 4.0 requirements in application and development.	[231, 232]
13	LogCentre learning factory	It aims at availing a low-cost environment for German Kazakh University in Almaty, Kazakhstan, to learn how state-of-the-art concepts and technologies are applied in logistics systems, e.g., RFID.	[233]
14	Learning Factory advanced Industrial Engineering (LF aIE)	LF aIE is a model factory at the Institute of Industrial Manufacturing and Management (IFF) of University of Stuttgart designed for training on methods of production optimization.	[201, 234]
15	AAU Smart Production Lab	This is the Aalborg University (AAU) learning factory. It has implemented industry 4.0 nine core technologies including collaborative robots, virtual environments, horizontal and vertical system integration, industrial Internet of Things, cyber security, use of cloud service, additive manufacturing, and big data and analytics for training purposes.	[235]
16	TU Wien Pilot Factory Industry 4.0 (TUPF)	It is a pilot, demonstration, and learning factory, aiming to provide companies a fundamental insight into industry 4.0 techniques, applications, and associated challenges through exemplary implementation of a digitized production environment as well as subsequent research, workshops, and presentation.	[236]

technology including smart devices (sensors and actuators) and communication technology [263, 264]. Simply put, agriculture 4.0 is the fourth evolution in the farming technology which is unparalleled to the previous (r)evolutions (Figure 4) [168, 172, 265]. Some authors have argued that it should be called “agriculture 5.0” [171], but it is not yet common among the academic and nonacademic literature.

Similar to industry 4.0, agriculture 4.0 is universally complementary to a number of concepts including vertical farming and food systems, bioeconomy, circular agriculture, and aquaponics [266]. Agriculture 4.0 is composed of

existing or developing technologies such as robotics, nanotechnology, synthetic protein, cellular agriculture, gene editing technology, AI, blockchain, and cloud computing [266].

Importantly, food and farming systems must reconcile the need to produce enough healthy and affordable food with the equally important motive of ensuring that humans do not degrade the ecosystems on which they entirely depend for sustenance [171]. On the one hand, agriculture industry is critical to sustainable development, and agricultural production by smallholders in lower-income

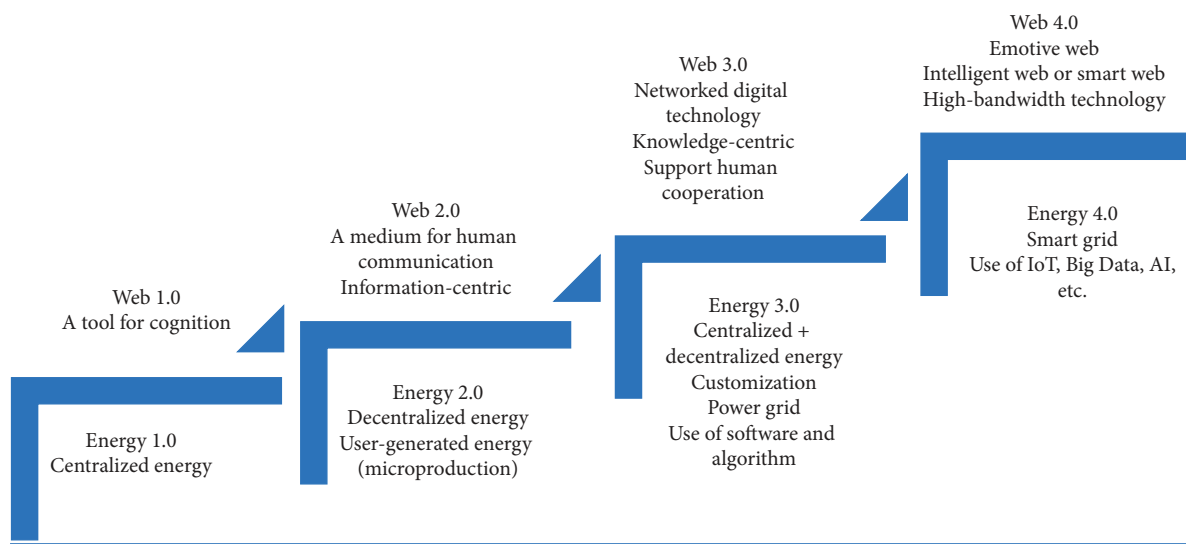


FIGURE 3: The transition in web and energy systems.

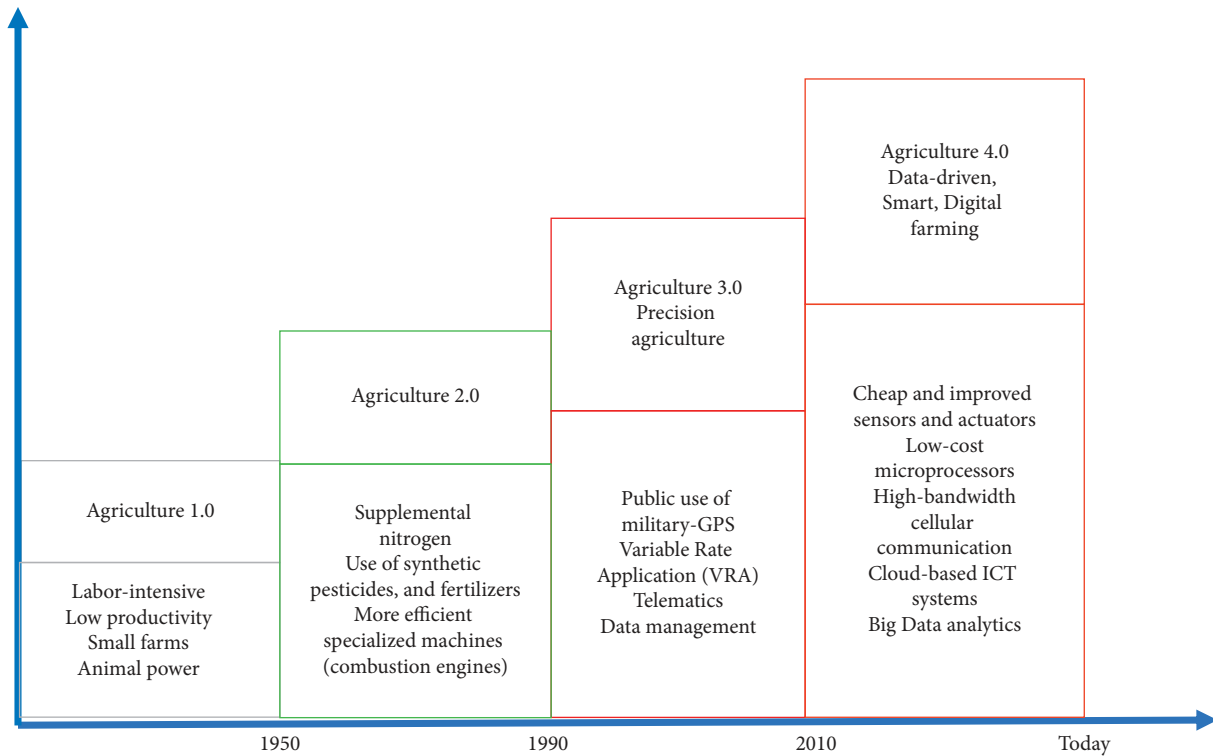


FIGURE 4: Paradigm shifts in agriculture.

countries contributes substantially to the food security of both rural and urban populations [267]. On the other hand, food industry is a key issue in the economic structure due to both weight and position of this industry in the economy and its advantages and potential [268]. In order to harness and control both agriculture and food industries, a complex industry (agri-food) has emerged, better known as “agri-food 4.0,” in the era of the fourth industrial revolution [96, 98, 269]. In fact, the term agri-food 4.0 is an analogy to the term industry 4.0, coming from the concept of

agriculture 4.0 [95]. In this regard, agriculture 4.0 was adopted in this study to cover all the aspects of food and agricultural industries.

4.3.2. *Convergence of Disruptive Technologies in Food and Agriculture.* More like in the manufacturing system, industry 4.0 is disrupting agricultural and food systems through the convergence of its technologies [26]. In order to understand and illustrate this fact, a massive exploratory

literature search was conducted to identify the mentioned use cases or applications of industry 4.0 technologies (disruptive technologies) in the published literature. Disruptive technologies are the technologies that create disruption on the status quo as they produce unique sets of values. In this respect, 12 disruptive technologies were considered [27], and these included 3D printing (3DP), AI, augmented reality (AR), big data, blockchain (BC), cloud computing (cloud), drones, IoT, nanotechnology (nanotech), robotics (robots), simulation (Sim), and synthetic biology (Syn-Bio). The identified applications were categorized into 10 major application areas in agriculture and food systems, namely, food processing and management (FPM), farm equipment and facility maintenance (FEFM), agriculture machinery automation (AMA), general agri-food planning and operation management (GAFPOM), yield prediction and precision farming (YPPF), weather and environment management (WEM), land preparation and planting optimization (LPPO), crop and livestock growth, improvement and protection (CLGIP), food packaging and storage (FPS), and irrigation and water management (IWM) as shown in Table 6. These application areas were derived just from the mentioned applications in the collected relevant publications. So, by mapping the application areas with the disruptive technologies, the convergence of these technologies is clearly visible as illustrated in Figure 5. The quantitative analysis involved counting the converging technologies in each application area and calculating the percentage convergence as shown in Table 7. The result demonstrates that the application areas GAFPOM and YPPF were the dominant with 17% technology convergence followed by WEM and CLGIP with 15% and then LPPO (11%) (Figure 6). However, each application area has totally different sets of technologies in convergence. For instance, the technologies converging in the GAFPOM application area include AI, AR, big data, blockchain, cloud computing, drones, IoT, robotics, and simulation, whilst the technologies converging in YPPF include AI, AR, big data, cloud computing, drones, IoT, nanotechnology, robotics, and synthetic biology. These differences were also observed in the other application areas.

4.4. Healthcare 4.0

4.4.1. Overview of Healthcare 4.0. The disruptive and transformative waves of industry 4.0 which are incredibly retrofitting many industries have also paved its way into the healthcare industry or medical fields including orthopaedics and dentistry. As the result of the tremendous disruption into the healthcare system, a new concept termed as “healthcare 4.0” has evolved [398–401]. Although the implementation of the healthcare 4.0 concept has been characterized as being highly complex and costly and requires a more skilled labor force, a number of hospitals in the advanced countries are already embracing it [402, 403]. The driving force behind this healthcare (r)evolution is the need to deploy industry 4.0 technologies to deliver more effective and efficient healthcare services including high security and privacy on the patients’ data electronic health record while

allowing remote and real-time access and diagnosis by the doctors or healthcare personnel [404–407].

Healthcare 4.0 is also known as hospital 4.0 [123]. It is a term that has egressed recently and derived from industry 4.0. Simply put, healthcare 4.0 is digital health or the use of digital technologies for health. The term digital health is rooted in electronic health (eHealth). eHealth is defined as the use of ICT in support of health and health-related fields, while mobile health (mHealth), which is a subset of eHealth, entails the use of mobile wireless technologies for health. On the contrary, healthcare 4.0 germinated as a broad umbrella term encompassing eHealth (which includes mHealth), as well as emerging areas, such as the use of industry 4.0 technologies including IoT, big data, 5G, AI, computing (cloud, fog, and edge), and blockchain [408–414]. Holistically, the World Health Organization (WHO) [408] reiterated the term healthcare 4.0 as a discrete functionality of digital technology that is applied to achieve health objectives and is implemented within digital health applications and ICT systems, including communication channels such as text messages. In a similar manner to industry 4.0, the healthcare industry has revolutionized from 1.0 to 4.0 as illustrated in Figure 7 [415–417]. Besides the implementation of industry 4.0 technologies in the healthcare system, there are ongoing studies in the development of healthcare services including the Social Cooperation for Integrated Assisted Living (SOCIAL) [418], OpenEHR [419], GraphQL, and HL7 FHIR [420]. This is because healthcare service and management plays an essential role in the human society [421, 422]. These are also contributing a lot to shaping the journey of healthcare 4.0.

One of the factors that is boosting the adoption of healthcare 4.0 is the concept of smart city. Smart healthcare is an essential part of creating a smart city because anyone can go to the hospital for treatment [423]. To this far, some of the major players in healthcare 4.0 include Abbott Laboratories, Philips Healthcare, Life Watch, GE Healthcare, Omron Healthcare, Siemens Healthcare, and Honeywell International Inc. [424]. Nevertheless, the healthcare industry lags behind other industries in protecting its data from cyber attacks [425]. The strength and the benefit of healthcare 4.0 adoption have been witnessed in the fight of the novel coronavirus 2019 (COVID-19) pandemic [426]. Coronavirus is one of the viral respiratory illnesses and can be fatal to some immunocompromised patients [427]. However, combating this pandemic has become a global hurdle. As a lifesaving strategy, a number of healthcare facilities have devoted to using 3D-printed patient respiratory ventilators and breathing equipment to sustain the life of patients [428].

4.4.2. Convergence of Disruptive Technologies in Healthcare.

As with agriculture 4.0, the convergence of industry 4.0 technologies in healthcare has been demonstrated. Here, the analysis was based on 10 application areas which included medical education, research and training (MERT), medical devices and equipment (MDE), pharmaceuticals, drug delivery and discovery (PDDD), detection, diagnosis,

TABLE 6: Industry 4.0 technology applications in the agriculture and food system.

S/N	Technology	Applications	References
1	3D printing	FPM: 3D food printing (sugar, chocolate, pureed food, flat food such as pasta, pizza, and crackers, and snack from waste food)	[270–277]
		FEFM: on-site farm tools and equipment making	[276, 278]
2	AI	AMA: automation of farming and computer vision	[279–281]
		IWM: automated irrigation	[279, 280]
		GAFPOM: digital twin, real-time data analysis, predictive analytics, recommendation systems (decision-making)	[282–285]
		YPPF: crop, soil, and livestock monitoring, yield management FPM: food (supply chain) traceability and safety	[280, 282, 284–287] [282, 283]
3	AR	GAFPOM: optimizing feed and cultivation management, boardroom farm planning, and remote expert assistance (training of farmers)	[288–290]
		YPPF: precision farming and livestock (virtual fencing)	[289]
		WEM: agricultural health and safety (emergency response)	[291]
		LPPO: soil sampling	[292]
4	Big data	YPPF: intelligence agriculture, remote sensing, crop yield prediction, and crop selection	[258, 293–295]
		GAFPOM: crop or farm planning and management, agricultural policy and trade, farm-to-fork traceability, and agri-food by-product supply chain management	[97, 294, 296–299]
		CLGIP: crop disease prediction, weed detection, and plant breeding WEM: weather forecasting	[295, 297, 300, 301] [295, 302]
		LPPO: estimation of soil components, temperature, and soil moisture content	[295]
5	Blockchain	GAFPOM: food and agricultural traceability, smart contract and crop insurance, food trade, land governance and registries, financial services in agriculture, transport and agrolistics, and agricultural supply chain supervision and management (informative)	[303–316]
		FPM: food integrity and food safety	[309, 317]
		WEM: waste reduction and environmental awareness	[317, 318]
6	Cloud computing	GAFPOM: farm management and quality traceability, mobile agriculture services (M-Agric services), agri-info (delivering agriculture as a service), farm documents, and video dissemination	[319–322]
		CLGIP: weed detection (cloud farming)	[323]
		YPPF: smart tunnel farming	[324]
7	Drones	YPPF: supervision or precision agriculture, crop monitoring, harvest prediction or estimation and optimization, yield forecast and management, vegetable index extraction, and variable rate prescriptions in agriculture	[46, 325–335]
		CLGIP: crop spraying or sprinkling (fertilizers, pesticides, and herbicides), efficient scarecrow for birds and insects, disease detection or health assessment and control, pollination, and 3D crop modeling	[325, 326, 328, 330–332, 334, 336–340]
		GAFPOM: planning, production, and disaster management, insurance (agriculture claims management)	[327, 333, 338, 340]
		LPPO: analysis (soil profiles, field, weed presence, nutrient profile, moisture, plant health, fungal abundance, and drainage), ariel planting or seed sowing, field-level phenotyping	[328, 330–334, 339, 340]
		IWM: drones for crop irrigation WEM: frost protection	[330, 332, 333] [337]

TABLE 6: Continued.

S/N	Technology	Applications	References
8	IoT	YPPF: monitoring of crop, soil, irrigation, weather, remote sensing, machinery, farm facilities, and field or environment, livestock, dairy, greenhouse condition and water quality, yield forecasting and prediction, and animal husbandry (smart cow farm and smart chick farm)	[334, 341–348]
		GAFPOM: documentation and traceability, agri-supply chain management and security, and agricultural education	[341–344, 349]
		CLGIP: crop disease and pest management, fertilization, fertigation and chemigation, crop spraying, intrusion detection in agriculture fields	[343, 346, 347, 350, 351]
		AMA: IoT-based agricultural machinery	[342, 352]
		IWM: IoT-based irrigation control systems	[341, 344, 346, 347, 350, 351]
		LPPO: soil sampling and mapping	[346]
		WEM: weather prediction (predicting the rainfall)	[350]
9	Nanotechnology	YPPF: pathogen monitoring, pesticide detection (nanosensors, diagnostic devices, and nanobarcodes), Internet of nano-Things, and nanobiosensors	[353–361]
		CLGIP: plant breeding (plant genetic modification), nanobiotechnology, nanofertilizers, nanobiofertilizers, nanoelements, nanoscale carrier, nanocoating, nanoencapsulation, crop production (plant protection products), nanobionics and photosynthesis, pest, weeds and disease control (nanopesticides, nanoherbicides, antimicrobial nanoparticles, nanoengineered metabolites, nanofungicides, and nanoinsecticides), hydroponics, and nanoparticles from plants for controlling plant virus	[353, 355–369]
		IWM: water purification and pollution remediation (heavy metal removal), irrigation (nanobubbles for biofouling mitigation)	[353, 354, 356, 357, 362, 364, 370]
		LPPO: soil improvement (water/liquid retention), soil remediation (heavy metal removal)	[353, 356, 358]
		FPS: safety and labelling, package material with nanosensors, nanoparticles, smart/intelligence packaging, nanoadditives, control and nutraceutical delivery, nanocoding of plastics and paper materials, nanoencapsulation and target delivery, nanocomposites, nanoplates, nanoclay, nanolaminates, edible film/coating, and pesticide, pathogen, and toxin detection	[355, 359, 361, 363, 365, 366, 371]
		FPM: food security; nanoresearch (nanodevices and nanobiotechnology), nanoscale agroproducts (nanocellulose), nanocomposites, nanofood, color additives, additives or polymer aids, preservatives, flavor carrier, marking fruits and vegetables, anticaking, and nutritional dietary supplements	[354, 361, 364, 368, 371]
		WEM: agrowaste reduction and high-value product (biofuel), biochar nanoparticle	[354, 357, 369]
10	Robotics	CLGIP: weed detection and control, target spraying, pest and disease monitoring and control, pruning, thinning, mowing, pollination, and fertilization	[372–379]
		YPPF: harvesting (picking of fruits), crop status monitoring, counting crops, and classification of plant species	[372, 373, 375, 376, 378, 380, 381]
		LPPO: seeding, sowing, and transplanting, phenotyping, land tilling (plowing, harrowing, rototilling, and cultivating), and soil and field analysis	[373, 378, 379, 381]
		AMA: autonomous navigation (field layout planning, vehicle route, and motion planning), computer vision, and remote-control systems	[375, 378, 379, 381]
		IWM: irrigation robots	[378]
		GAFPOM: livestock management (dairy cattle, pigs, and chickens), milking animals, removing waste from animal cubicle pens, carrying and moving feedstuffs, manipulators, and transportation	[379, 382]
		FPS: labelling and tracking of food products	[382]

TABLE 6: Continued.

S/N	Technology	Applications	References
11	Simulation	CLGIP: development of process-based biophysical models of crops and livestock, crop growth simulation model	[383–386]
		GAFPOM: statistical models based on historical observations and economic optimization, simulation models at household and regional to global scales, simulation of farm machinery operation (optimization of tillage and sowing operations), multiagent modeling and simulation of farmland use	[383, 387, 388]
		WEM: interdisciplinary climate change impact assessment on agriculture, water resources, forestry, and economy through simulations	[389]
12	Synthetic biology	CLGIP: synthetic photorespiratory pathway, modifying and creating new systems, advancing pest control (engineered insects), precise antimicrobials (Eligobiotics), designing crops for fuel production, plant breeding, synthetic genomics, metabolites in microorganisms (vitamins, nutraceuticals, and probiotics), pest and disease control (control of viral, bacterial, and fungal pathogens, parasitic weeds, and insect vectors of plant pathogens. Synthetic chloroplast genome, a synplastome for pest resistance), cellular agriculture (plant cells, animal cells, and microbial cells), and nonfertilization (synthetic nitrogen-fixing bacteria)	[390–396]
		FPM: food processing monitors, biosafety, and biosecurity	[391]
		WEM: bioremediation (waste and pollution control)	[393, 397]
		YPPF: biosensors and molecular circuitry	[393, 396]

FPM: food processing and management, FEFM: farm equipment and facility maintenance, AMA: agriculture machinery automation, GAFPOM: general agri-food planning and operation management, YPPF: yield prediction and precision farming, WEM: weather and environment management, LPPO: land preparation and planting optimization, CLGIP: crop and livestock growth, improvement and protection, FPS: food packaging and storage, and IWM: irrigation and water management.

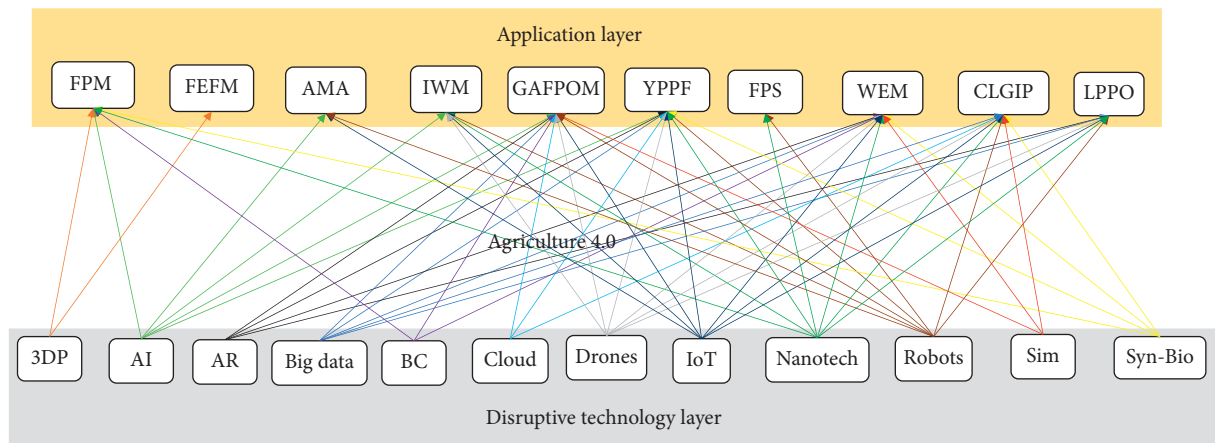


FIGURE 5: The convergence of disruptive technologies in agriculture and food systems.

TABLE 7: Percentage convergence in agriculture and food application areas.

Application area	FPM	FEFM	AMA	IWM	GAFPOM	YPPF	FPS	WEM	CLGIP	LPPO
Number of technologies	4	1	3	4	9	9	2	8	8	6
Convergence (%)	7	2	5	7	17	17	4	15	15	11

prediction, prognosis, prevention and treatment (DDPPPT), telemedicine and medical record (TMR), healthcare facility management and process optimization (HFMPO), surgery, medical imaging, monitoring, and dentistry as shown in Table 8. The convergence of the disruptive technologies in these application areas is illustrated in Figure 8 and

quantified as shown in Table 9. The result depicts that convergence of the disruptive technologies was the highest in both DDPPPT and MERT with 13.5% followed by TMR and monitoring with 12% (Figure 9). The technology convergence in DDPPPT, for example, includes synthetic biology, robotics, IoT, drones, cloud computing, blockchain,

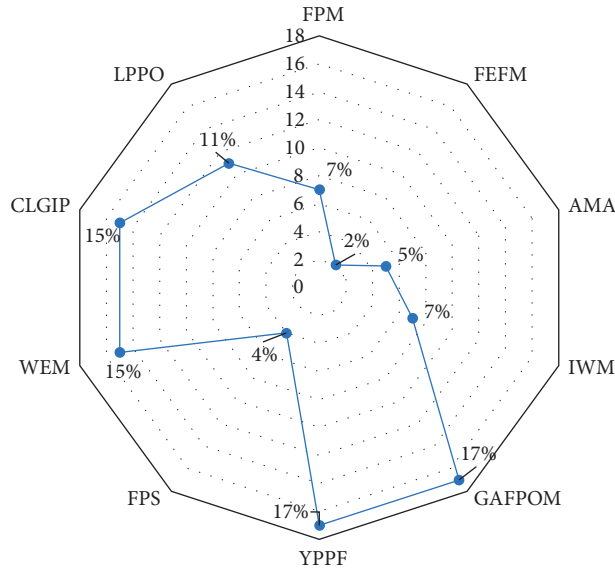


FIGURE 6: Percentage technology convergence in agriculture and food systems.

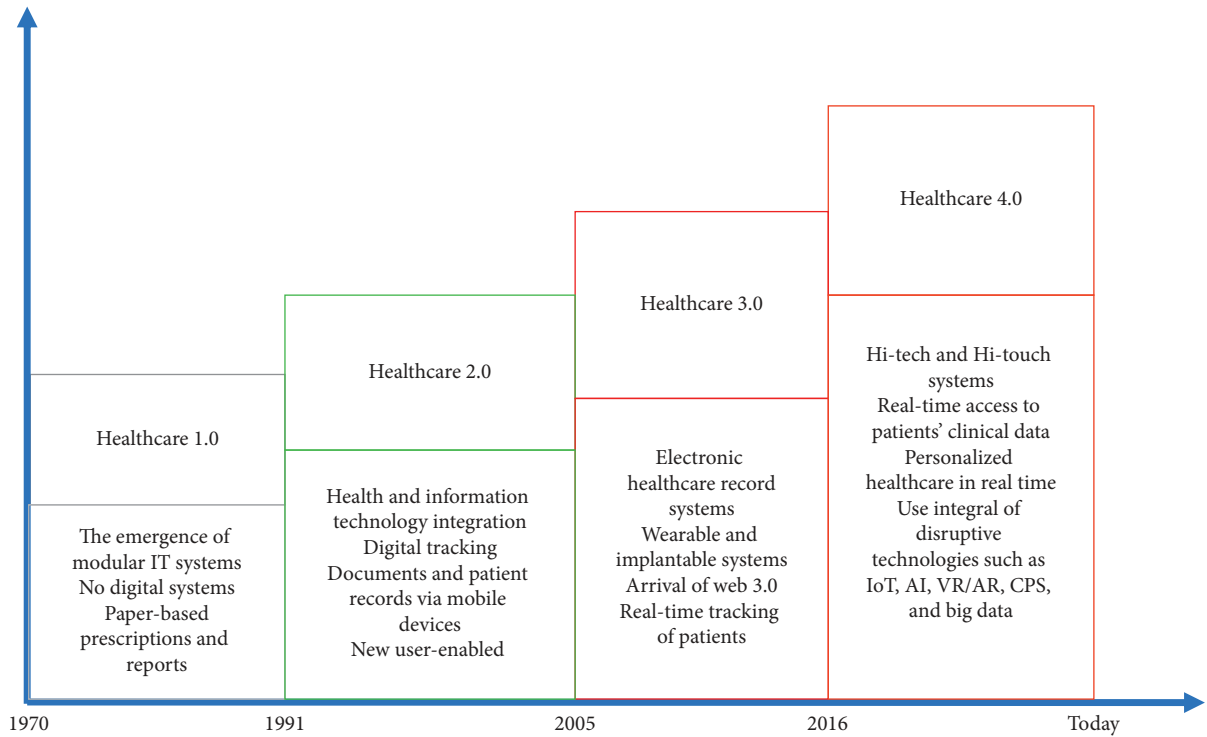


FIGURE 7: Evolution of the healthcare system.

AI, and big data, while for MERT, it includes 3D printing, AI, AR, big data, blockchain, drones, simulation, and robotics. However, dentistry has received only one technology (3D printing). This could be because of limited studies on the technology's application in the field of dentistry.

4.5. Logistics 4.0

4.5.1. Overview of Logistics 4.0. The intricacy of the disruptive and transformative powers of industry 4.0 including

the process of globalization of the world economy is a prerequisite for the successful operation and disruption of logistics which is well-known today as logistics 4.0 [534, 535]. In fact, the formation of logistics 4.0 banks in particular on cutting-edge technologies and the digitalization of business processes [534]. In addition, logistics 4.0 concept emerged purposely to overcome the growing uncertainty and dissatisfaction in implementing industry 4.0, new methods, and tools that specifically address dedicated companies' areas, such as logistics or reverse logistics, supply chain management, and manufacturing processes [536, 537].

TABLE 8: Industry 4.0 technology applications in healthcare.

S/N	Technology	Applications	References
1	3D printing	Surgery: surgical marking guide, implant placement guide, radiation shield, and surgical saw guide	[429–434]
		MERT: patient education	[429, 430, 432, 435]
		MDE: implants (metallic implants, tracheal splint; cranial implants), tissue and organ manufacturing (organ on chips), scaffold manufacturing, respiratory apparatus (ventilators), PPE (face mask and shield), prosthetics and orthotics (e.g., knee replacement; nasal stent; hearing aid cases), and active and wearable devices (wearable sensors, lab on a chip, and microfluidics)	[428–432, 434, 436–440]
		Medical imaging: anatomical modeling, organoids, e.g., 3D-printed model of coronavirus	[428, 430, 431, 433, 434, 437, 439]
		PDDD: construction of oral dosage medications, pills or drug printing, tables, drug-delivery implants, and transdermal delivery	[430–432, 437, 439, 440]
2	AI	Dentistry	[431, 432, 437, 439]
		DDPPPT: prediction and treatment of diseases such as stroke and cancer	[122, 441–446]
		Medical imaging	[442, 443, 447]
		Monitoring: patient care, diabetes care, eye care, and adult care or wellbeing	[442–444, 446, 448]
		Surgery	[442]
3	AR	MERT: virtual assistant for patients	[442, 443, 448]
		MDE: AI-based wearables	[442]
		PDDD: for discovery of a new class of diagnostics and treatment	[442, 443, 445, 446, 448]
		MERT: medical education and training	[449–455]
		Monitoring: wellness (adult care)	[453, 455–458]
4	Big data	DDPPPT: rehabilitation, diagnosis, and prediction	[458, 459]
		TMR: information (telemedicine)	[449–451, 453, 459]
		Surgery: surgical planning, surgical navigation, and surgical rehearsal	[450, 451, 453, 454, 457, 458, 460]
		Medical imaging: anatomical imaging	[451]
		Medical imaging	[461, 462]
5	Blockchain	Monitoring: real-time monitoring	[461–463]
		DDPPPT: treatment (precision medicine)	[122, 461–469]
		TMR: patient care (patient drug history, clinical trials, and medical records) and medical data management	[461, 463–465, 468]
		MERT: clinical research	[465]
		PDDD: drug discovery and design	[463, 464]
6	Cloud computing	HFMPO: fraud detection in healthcare facilities and workflow process optimization	[463, 465]
		DDPPPT: medical data privacy and security, medical fraud detection, diagnosis, and prescription tracking	[470–473]
		TMR: electronic health record (EHR) modification, medical data management (patient-centred), personal health records (PHRs), and medication regimen	[403, 470–480]
		HFMPO: independent medical reviews, claim and billing management, control of contracts for healthcare service, healthcare delivery, drug tracing, tracking and verification, drug supply chain management	[471–473, 478, 481, 482]
		MERT: clinical and neuroscience research, education of medical staff	[471, 478, 481]
6	Cloud computing	Monitoring: blockchain for 5G-enabled IoT	[483]
		TMR: teleconsultation, EHRs, PHRs, patient-centred	[484–487]
		Monitoring: fitness and wellness monitoring	[488]
		HFMPO: patient assignment scheduling, clinical operation, and workflow optimization	[488, 489]
		DDPPPT: treatment of disease (stroke), therapy	[487, 490]
Medical imaging	[487, 488]		

TABLE 8: Continued.

S/N	Technology	Applications	References
7	Drones	HFMPPO: transportation of medical goods (medications, vaccines, biological samples, medical devices, tissue, patient), healthcare delivery and pick-up services, emergency response (transport of blood and plasma), deployment of networks for data harvesting in unconnected areas	[491–496]
		DDPPPT: disease prevention (sterile mosquito release for vector control), public health disaster relief (disaster prediction and management, detection of harmful substances)	[492, 496]
		TMR: telemedicine	[492]
		MERT: health research	[496]
8	IoT	Monitoring: homecare (IoT-based information system), caring and monitoring of patients, Internet of Health Things (IoHT), wearable Internet of things (WIoT)	[422, 424, 497–499]
		MDE: Internet of Medical Things (IoMT) (IoT in implantable and wearable devices)	[422, 500]
		DDPPPT: Internet of nano-Things (IoNT) (IoT in nanomedicine for diagnostics, treatment, preventive health, chronic care disease management, and follow-up care)	[422]
		TMR: Internet of mobile-health Things (m-IoT) (remote monitoring of patients), wearable Internet of Things (WIoT)	[414, 422, 501, 502]
9	Nanotechnology	MDE: biodegradable and bioactive sutures and dressings, drug-eluting stents and scaffolds, cell production, nanobiosensors	[503–505]
		DDPPPT: gene therapy, diagnosis, cancer treatments	[503–506]
		Surgery	[505]
		PDDD: drug delivery, drug coating, and encapsulation	[503]
10	Robotics	TMR: tele-healthcare	[507]
		Surgery	[508–511]
		Monitoring: care and wellness	[511]
		DDPPPT: diagnosis and rehabilitation	[508, 511]
		MERT: training	[511]
11	Simulation	HFMPPO: operation process improvement and optimization, resource planning, emergency room efficiency improvement	[512–517]
		MERT: clinical or midwifery education and training, clinical research	[515, 518–523]
12	Synthetic biology	PDDD: drug development, vaccine, biopolymer vaccines, antimalaria, antibiotics, drug delivery (caveospheres), antimicrobial agents: engineered phages (viruses)	[524–528]
		DDPPPT: gene therapy (bacteria cells), e.g., chromosome-free cell or SimCells, DNA assembly, transplantation, and recombination, genome editing, diagnostics, biologics and biodetection, metabolomics	[524, 527–532]
		MDE: implant (wound care), new biosensors and smart microdevices and nanodevices, re-engineered antibodies and cellular therapeutics for cancer, T-cells, CAR (chimeric antigen receptor) technology, theragnostic cell lines, artificial enzymes, making neurons, regenerative medicine, cybernetic systems	[524, 526–528, 531–533]
		Medical imaging: biomarker	[528, 532]

MERT: medical education, research and training, MDE: medical devices and equipment, PDDD: pharmaceuticals, drug delivery and discovery, DDPPPT: detection, diagnosis, prediction, prognosis, prevention and treatment, TMR: telemedicine and medical record, and HFMPPO: healthcare facility management and process optimization.

For the case of supply chain management, industry 4.0 with its associated technological advances is increasing supply chain resilience or lean supply chain management which is highly linked to the general operation and performance of the logistics industry [538–540].

Generally, logistics 4.0 refers to the combination of using logistics with the innovations and applications added by the cyber-physical system. However, so many related concepts and definitions of logistic 4.0 exist today including smart services and products [541], green logistics [542], smart logistics or intelligent logistics, and smart warehouses

[543–547]. Furthermore, logistics 4.0 reflects logistics innovation [548], digitization in maritime logistics [549], digital supply chain [550, 551], smart ships, smart containers (container 42), and autonomous vessels [130].

Logistics 4.0 is a new paradigm in the logistics industry that focuses on the description of the newest technologies in contemporary supply chain applications [552, 553]. The concept of logistics 4.0 was created as a consequence of industry 4.0 and emergence of new and intelligent technological solutions in logistics including blockchain, IoT, AI, and big data [554–560]. The term logistics 4.0 first appeared

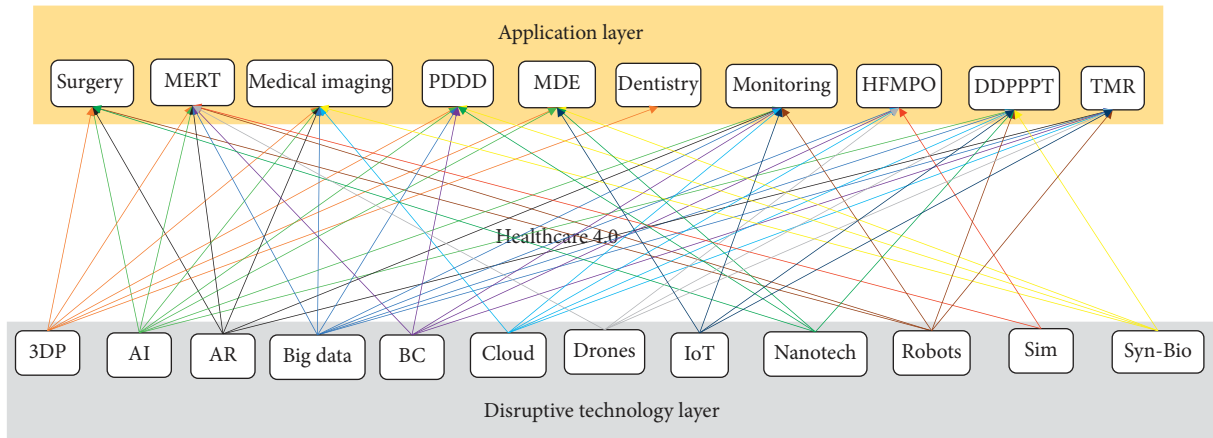


FIGURE 8: The convergence of disruptive technologies in healthcare.

TABLE 9: Percentage convergence in healthcare application areas.

Application areas	Surgery	MERT	Medical imaging	PDDD	MDE	Dentistry	Monitoring	HEMPO	DDPPPT	TMR
Number of technologies	5	8	6	6	5	1	7	5	8	7
Convergence (%)	9	13.5	10	10	9	2	12	9	13.5	12

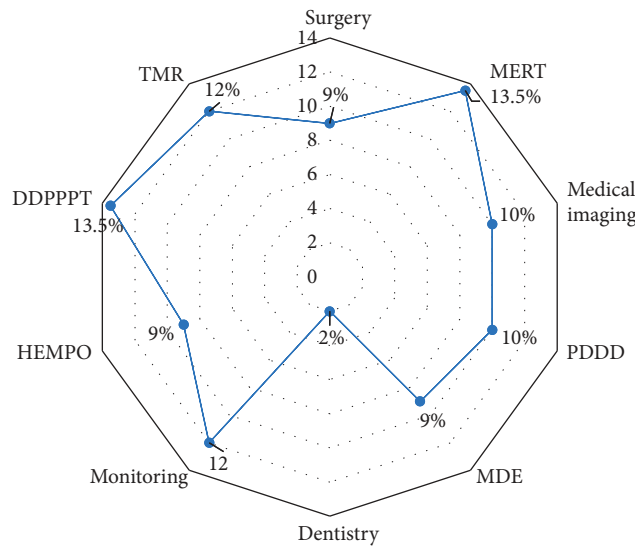


FIGURE 9: Percentage convergence of technologies in the healthcare system.

in 2011 as a response and support to industry 4.0, but today, the terms such as supply chain 4.0, procurement 4.0, marketing 4.0, customer 4.0, consumer 4.0, distribution 4.0, warehousing 4.0, inventory management 4.0, order management 4.0, finance 4.0, maritime 4.0, bank 4.0, globalization 4.0, leadership 4.0, and society 4.0 can be seen. These represent the response of the logistic field to the development and requirements of industry 4.0 [129, 138, 561]. Just as industry 4.0, the generations from 1.0 to 4.0 have been traced for both logistics, supply chain, marketing, and customer as shown in Table 10 [562–568].

Globalization, finance, governance, leadership, and society at large play an astonishing role in enhancement of the general performance and development of the logistics industry as well as economic growth in any country [569–573]. Most importantly, delivering on digitalization for large multinational business, in the contemporary context of global operations and real-time delivery, is a significant opportunity to the logistic industry [574, 575]. In globalization, all the three modes including trade, financial, and technological globalizations are now practiced everywhere in the world as an important and economic reason for

TABLE 10: The generations of logistics, supply chain, marketing, and customer.

Generation	Logistics	Supply chain	Marketing	Customer
Level 1	Logistics 1.0 Mechanization of transport	There is no concept in this level	Marketing 1.0 Product-centric approach User needs	Customer 1.0 Passive consumer A recipient of advertising messages
Level 2	Logistics 2.0 Automation of handling system	Supply chain 2.0 Mainly paper-based	Marketing 2.0 Customer-centric approach User wants	Customer 2.0 Active consumer Expressing own opinion
Level 3	Logistics 3.0 System of logistic management	Supply chain 3.0 Integration between two channels Basic digital components in place	Marketing 3.0 Human-centric approach User anxieties, desires, creativity, values	Customer 3.0 Cocreating consumer Cooperating cocreator
Level 4	Logistics 4.0 Intelligent transportation system Real-time location and tracking system	Supply chain 4.0 Total network integration Leveraging all data available	Marketing 4.0 Content-centric approach: brand integrity, identity, image, and interaction User participates and validates	Customer 4.0 Involved advocate A prosumer promoting the brand

TABLE 11: The transition in globalization, leadership, and society.

Transition	Globalization	Leadership	Society
Level 1	Globalization 1.0 Free country-to-country movement without passports Immigration policy free from governmental limitation Existence of international economic agreements and institutions, e.g., the International Telegraph Union and Universal Postal Union	Leadership 1.0 Charismatic	Society 1.0 Seeker gatherer
Level 2	Globalization 2.0 Modern international economic enabling architecture Multinational corporations, policy liberalization, and improved communications, cross-border integration	Leadership 2.0 Directive	Society 2.0 Peaceful agrarian
Level 3	Globalization 3.0 The advent of the internet, the establishment of the World Trade Organization (WTO) and the formal entry of China into the trading system	Leadership 3.0 Relational	Society 3.0 Modern social order
Level 4	Globalization 4.0 Immigration policy, data privacy, and security, China's Belt and Road Initiative, multispeed European integration	Leadership 4.0 Responsive	Society 4.0 Data social order

company improvement [576–578]. However, globalization in the era of industry 4.0 has taken a quantum leap into a new concept known as “globalization 4.0” which is among the main drivers of logistic 4.0 [579]. One of the key countries behind globalization 4.0 is China. China’s Belt and Road Initiative is an important vector for globalization 4.0 as it helps to bring its enabling infrastructure and technologies to all corners of the globe [580]. Table 11 depicts the transition or (r) evolution from 1.0 to 4.0 for globalization, leadership, and society [581–585].

Similarly, finance sectors in the logistic industry are leapfrogging as disruptive technologies paved their ways into services and financial inclusion. In most organizations today, finance professionals are being asked to learn new skills, often related to such technologies, because work is morphing into more project-oriented opportunities. For instance, the major challenges that chief finance officers of the logistics

industry are facing include handling massively big data, liquidity and cash flow, complicated cash lifecycle finding, and retaining good talent [586]. In order to overcome these hurdles in finance systems for the logistics industry, a new concept of finance called “finance 4.0” was born, which is driven by digital transformation in the finance and banking system [587–589]. Figure 10 elaborates three generations of finance and banking systems from 2.0 to 4.0 [145, 586–588, 590].

4.5.2. Convergence of Disruptive Technologies in Logistics. In this section, 10 application areas in logistics were derived and defined majorly based on the selected studies [591, 592]. These include warehouse capacity optimization and automation (WCOA), logistics assets and facility maintenance (LAFM), delivery and distribution (DD), customer order

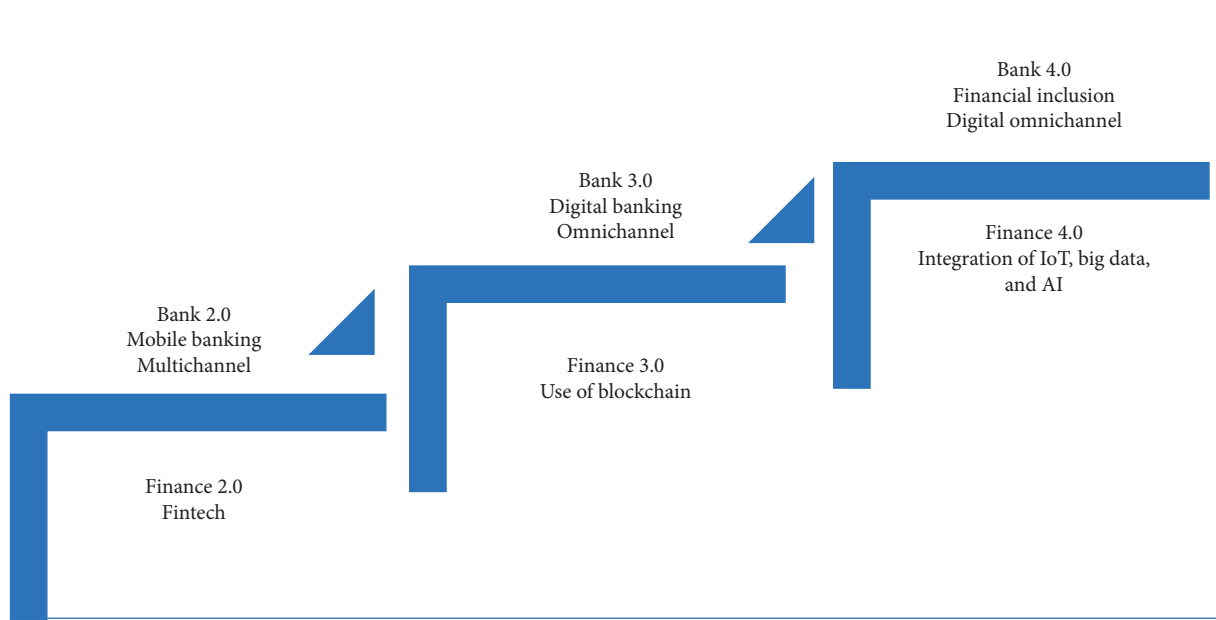


FIGURE 10: Generations of finance and banking systems.

TABLE 12: Industry 4.0 technology applications in logistics.

S/N	Technology	Applications	References
1	3D printing	WCOA: mass customization (individualized direct product manufacturing), localized manufacturing and delivery, mass individualization and personalization, decentralized manufacturing.	[436, 593–599]
		LAFM: on-demand spare parts’ making, end-of-runway service.	[595, 596, 599–601]
		DD: 3D print shops for business and consumers, decentralized production of parts (regional warehouses, delivery depot of logistics service providers).	[595, 602]
2	AI	WCOA: smart warehousing environment, back-office automation, predicting inbound logistics, intelligent logistics assets (seeing, speaking, and thinking logistics assets), and recognition of reverse logistics.	[537, 596, 603–609]
		COP: new customer experience models (seamless, voice-enabled customer interactions). AI-powered customer experience.	[596, 605]
		FPR: simulation and optimization of supply chain operations (eliminating bottleneck), supply chain management decision support, resilience supplier selection, and decision-making.	[606, 608–615]
		LAFM: predictive maintenance to prescriptive maintenance of logistics equipment, trucks, buildings, and machines.	[609, 616]

TABLE 12: Continued.

S/N	Technology	Applications	References
3	AR	WCOA: AR-powered warehouse operations (product routing, picking, packing, labelling, sorting, and even assembling).	[596, 617–619]
		FPR: facility planning (displays task information, reads barcodes, and supports indoor navigation and can be integrated into warehouse management systems for real-time operations).	[596, 619, 620]
		DRO: safer and smarter driving (next generation of navigation and driver-assistance systems).	[596, 618, 620]
		PFM: procurement.	[621]
		DD: intelligent last-mile operations (AR can help in last-meter navigation to correctly locate entrances), freight/container loading (conduct completeness checks of each shipment using object-recognition technology, utilized to virtually highlight inside a vehicle to display the optimal internal loading sequence of each shipment (taking into account route, weight, fragility, etc.)).	[596, 619–621]
		COP: creating a new standard of order picking (picking optimization).	[596, 618–620, 622]
		LAFM: predictive and prescriptive maintenance of warehousing robots, delivery truck, cargo aircraft, and other equipment.	[618, 621]
4	Big data	DRO: dynamic, real-time route optimization, optimization of material and product transportation routing.	[46, 596]
		FPR: smarter forecasting of demand, capacity, and labor. Anticipatory shipping (to predict an order before it occurs), inventory control and logistic planning, supply chain statistics, supply chain simulation, supply chain forecasting, logistics optimization, supply chain network design, learning from customer assessment, decision on the supply chain infrastructure, and product recovery decisions.	[596, 623–629]
		EMM: end-to-end supply chain risk management (detecting, evaluating, and alerting all potential disruptions on key trade lanes, caused by unexpected events such as growing port congestion or high flood risks).	[596]
		PFM: procurement management.	[625]
		LAFM: utility and maintenance aspects.	[628]
		TFDP: fraud detection, smart contracts.	[630]

TABLE 12: Continued.

S/N	Technology	Applications	References
5	Blockchain	MTT: end-to-end status tracking (orders, receipts, invoices, payments, and any other official document), track digital assets (such as warranties, certifications, copyrights, licenses, serial numbers, and bar codes) in a unified way and in parallel with physical assets, and freight tracking.	[596, 631–650]
		TFDP: smart contract for automating commercial processes or supply chain orchestration, immutability (ensures the records' originality and authenticity), anticorruption and humanitarian operations, trust, security, trust and fraud detection, trusting load board.	[596, 630, 634–636, 640, 641, 643, 644, 647, 649–651]
		PFM: finance (remittances and online payments), serve as a base for bitcoin cryptocurrency, invoice and payment management (transaction automatization), smart billing, decentralized transaction, trade finance.	[630, 638, 641, 642, 644–648, 651, 652]
		DD: last-mile delivery by connectivity with drones, fresh food delivery.	[630, 653]
		FPR: demand forecasting, supply chain visibility, supply chain visualization and tokenization.	[644, 645, 648, 650, 651, 653]
6	Cloud computing	MTT: logistics tracking information management system to support whole-ranged and real-time logistics tracking services.	[596, 654, 655]
		FPR: 360-degree management dashboards (coordination and orchestration of logistic information into one integrated view), port logistics service and supply chain optimization, internet-based supply chain forecasting and planning, supplier network logistics planning and manufacturing service composition (configured cloud entropy of logistics and operation suppliers).	[596, 655–661]
		DRO: cloud-powered global supply chains virtualize information and material flows by moving all supply chain processes into the cloud	[596, 656]
		PFM: cloud-based procurement (sourcing and procurement).	[655, 660–662]
7	Drones	WCOA: warehouse inventory checks, fully autonomous indoor cycle counting with drones, inventory counts (audits), and real-time inventory management.	[139, 140, 596, 663, 664]
		DD: intraplant transport and urgent supplier-to-plant spare parts' delivery as well as to ferry products from back rooms to the sales floor, last-mile deliveries, remote delivery and disaster response, deliver small packages between warehouses.	[140, 596, 665–673]
		LAFM: surveillance of infrastructure (check the condition of industrial buildings and inspect trade lines for damage or the need for maintenance work. Additionally, assets can be monitored for theft prevention at warehouses and yards).	[140, 596, 664, 674]
		DRO: analysis of the traffic parameter.	[675]

TABLE 12: Continued.

S/N	Technology	Applications	References
8	IoT	MTT: intelligent identification, monitoring and management of the intelligent network system, cold chain traceability, tracking and remote monitoring of equipment, identifying and locating critical pieces of cargo at each stage in an operation, smart cargo solutions, and asset tracking, tracking and monitoring of stock level.	[92, 596, 676–682]
		DRO: intelligent transportation solutions (in-vehicle telematics)	[596]
		DD: connected consumer and the proliferation of smart homes (e.g., smart locks) (secured in-home delivery services).	[596]
		FPR: IoT-enabled logistics and supply chain management (IoT-based laundry services for real-time scheduling), supply chain (end-to-end) visibility, managing supply chain risk, optimization, and prediction.	[680–688]
		EMM: IoT-enabled smart indoor parking system for industrial hazardous chemical vehicles, IoT-enabled solutions monitor perishable cargo for temperature, humidity, and other environmental factors, and humanitarian assistance disaster response scenario.	[680, 688–690]
		WCOA: warehouse and yard management system (IoT-controlled safe area), inventory management.	[677, 691]
		COP: IoT-based safety interaction mechanisms for storage and picking.	[678, 680]
		LAFM: condition-based maintenance of equipment (fleet management).	[680]
		TFDP: theft prevention, after-sale service, and warranty validation.	[692]
9	Nanotechnology	MTT: nanochip RFID labels for tracking.	[693, 694]
		LAFM: nano-based coatings to handle biofouling and corrosion, nano-based materials for the enhancement of strength of marine vehicles, and efficient and durable nano-based tires for trucks.	[54]
10	Robotics	WCOA: flexible automation in warehousing and fulfillment (picking, packing, palletizing, and sorting), stationary-mobile piece-picking robots, receiving, replenishment, shipping, robots for autonomously supply workstations, keep control over inventory.	[46, 596, 695–702]
		DD: transportation and loading tasks, autonomous kitting, trailer and container unloading robots (equipped with powerful sensors and grippers to locate single parcels, analyze their size and shape, and determine the optimal unloading sequence), assistance robots for local or home delivery (follow delivery personnel to transport heavy items, presort shipments inside delivery vehicles, and autonomously deliver shipments to dedicated collection points), last-mile delivery, and distribution centres.	[596, 697, 699, 702]
		LAFM: perform maintenance.	[699]
		COP: innovation in order fulfillment with human-robot collaboration.	[596]

TABLE 12: Continued.

S/N	Technology	Applications	References
11	Simulation	DRO: evaluation and assessment of road transport.	[703]
		FPR: analysis of supply chain activities, supply chain management optimization and logistics cost control, design and implementation of reverse logistics networks, planning and monitoring of fourth-party logistic (4PL) process.	[598, 704–710]
		DD: define an optimal distribution cost for products shipped to wholesale customers.	[711, 712]
		WCOA: flow- oriented models of inventory control systems.	[713]
12	Synthetic biology	DD: biofuels for trucks and ships' vessel.	[714, 715]
		MTT: biosensors, biosafety, and biosecurity.	[716, 717]

WCOA: warehouse capacity optimization and automation, LAFM: logistics assets and facility maintenance, DD: delivery and distribution, COP: customer order picking, FPR: forecasting, planning and reporting, DRO: dynamic route optimization, PFM: procurement and financial management, TFDP: threat and fraud detection and prevention, MTT: monitoring, tracking and traceability, EMM: environment monitoring and management, and RFID: radio frequency identification.

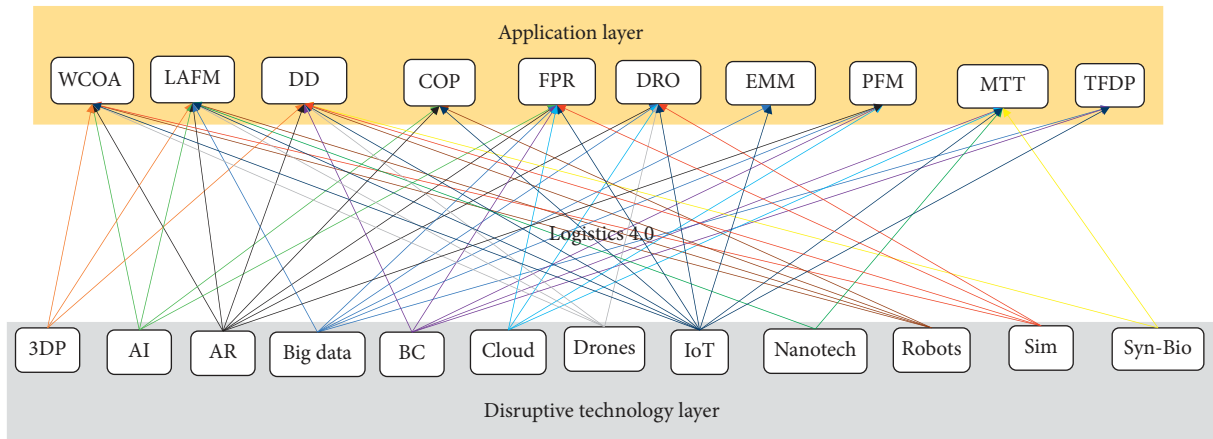


FIGURE 11: The convergence of disruptive technologies in logistics.

TABLE 13: Percentage convergence in logistics application areas.

Application area	WCOA	LAFM	DD	COP	FPR	DRO	EMM	PFM	MTT	TFDP
Number of technologies	7	8	8	4	7	6	2	4	5	3
Convergence (%)	13	15	15	7	13	11	4	7	9	6

picking (COP), forecasting, planning and reporting (FPR), dynamic route optimization (DRO), procurement and financial management (PFM), threat and fraud detection and prevention (TFDP), monitoring, tracking and traceability (MTT), and environment monitoring and management (EMM) as shown in Table 12. The mapping of the technologies in these application areas was conducted as demonstrated in Figure 11. The technology convergence in the application areas was calculated as presented in Table 13. The result shows LAFM and DD were the dominant with 15%

convergence followed by WCOA and FPR with 13% as illustrated in Figure 12. The technologies converging in LAFM include 3D printing, AI, AR, big data, drones, IoT, nanotechnology, and robotics, while for DD, they include 3D printing, AR, blockchain, drones, IoT, robotics, simulation, and synthetic biology. In WCOA, the converging disruptive technologies are 3D printing, AI, AR, drones, IoT, robotics, and simulation. In the same way, the technologies converging in FPR and the rest of application areas were elaborated.

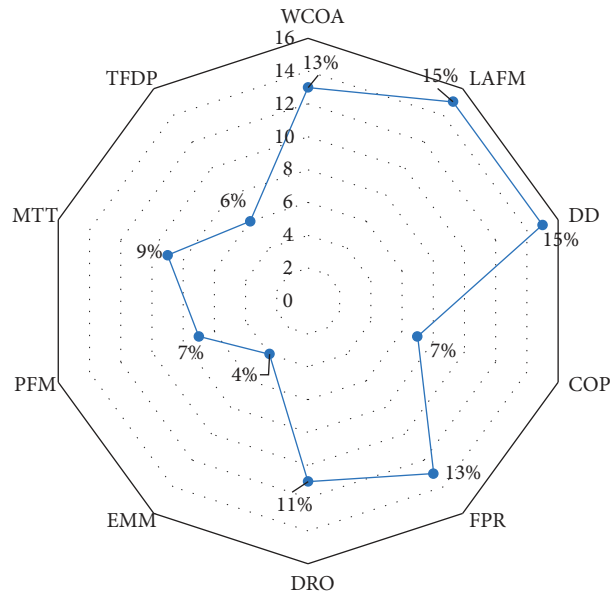


FIGURE 12: Percentage convergence of technologies in logistics.

5. Conclusions

Just like the light set-up in the morning, the disruptive landscape of industry 4.0 in the industrial sectors is unlimited. This can be evidenced from the explosive use of neologism “4.0” among the academic and business communities. The convergence of disruptive technologies is incredible, and this is the remarkable power of industry 4.0 disruption in any industrial sector. Adoption of education 4.0 through implementation of the learning factory is paramount important for building the requisite skills into the workforce for industry 4.0. The concept of energy 4.0 is still nascent, and thus, much research is required to ensure its success because the amount of energy requirement has reached unprecedented level due to the automation of the industrial plants to make them industry 4.0-compliant. The present study demonstrated the convergence of disruptive technologies in agriculture, healthcare, and logistics industries. This might not depict the real-life situation because the study was solely based on the published literature and therefore limited by the availability of information. Nonetheless, it provides an insight into the convergence of industry 4.0 technologies in the industrial sectors. A number of disruptive technologies, however, have received very few applications in these selected industries. This points out the need for more research to increase the application areas of these technologies. More especially, application of synthetic biology in logistics needs to be investigated. Additionally, application of disruptive technologies in the field of dentistry should be expanded. The convergence of disruptive technologies in education and energy sectors should also be investigated.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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References

- [1] C.-C. Kuo, J. Z. Shyu, and K. Ding, “Industrial revitalization via industry 4.0—a comparative policy analysis among China, Germany and the USA,” *Global Transitions*, vol. 1, pp. 3–14, 2019.
- [2] M. Sony and S. Naik, “Industry 4.0 integration with socio-technical systems theory: a systematic review and proposed theoretical model,” *Technology in Society*, vol. 1, 2020.
- [3] T. Lins and R. A. R. Oliveira, “Cyber-physical production systems retrofitting in context of industry 4.0,” *Computers & Industrial Engineering*, vol. 139, pp. 1–13, 2020.
- [4] F. Galati and B. Bigliardi, “Industry 4.0: emerging themes and future research avenues using a text mining approach,” *Computers in Industry*, vol. 109, pp. 100–113, 2019.
- [5] T. Ruppert, S. Jaskó, T. Holczinger, and J. Abonyi, “Enabling technologies for operator 4.0: a survey,” *Applied Sciences*, vol. 8, no. 1650, p. 1, 2018.
- [6] I. Zolotová, P. Papcun, E. Kajáti, M. Miškuf, and J. Mocnej, “Smart and cognitive solutions for operator 4.0: laboratory H-CPPS case studies,” *Computers & Industrial Engineering*, vol. 8, 2018.
- [7] D. Romero, J. Stahre, and M. Taisch, “The Operator 4.0: towards socially sustainable factories of the future,” *Computers & Industrial Engineering*, vol. 139, pp. 1–5, 2019.
- [8] M. Jasiulewicz and A. Gola, “Maintenance 4.0 technologies for sustainable manufacturing—an overview,” *IFAC-Papers-onLine*, vol. 52, no. 10, pp. 91–96, 2019.

- [9] M. Haarman, M. Mulders, and C. Vassiliadis, "Predictive maintenance 4.0: predict the unpredictable," 2017.
- [10] H. Ç. Erkan and Ç. Erkan, "Industry 4.0 and competitiveness," *Procedia Computer Science*, vol. 158, pp. 625–631, 2019.
- [11] G. Beier, A. Ullrich, S. Niehoff, M. Reißig, and M. Habich, "Industry 4.0: how it is defined from a sociotechnical perspective and how much sustainability it includes—a literature review," *Journal of Cleaner Production*, vol. 259, pp. 1–12, 2020.
- [12] B. Eynard and Z. Cherfi, "Digital and organizational transformation of industrial systems," *Computers & Industrial Engineering*, vol. 139, no. 1, 2020.
- [13] U. Meyer, "The emergence of an envisioned future. Sense-making in the case of "Industrie 4.0" in Germany," *Futures*, vol. 109, pp. 130–141, 2019.
- [14] W. Bauer, S. Schuler, T. Hornung, and J. Decker, "Development of a procedure model for human-centered industry 4.0 projects," *Procedia Manufacturing*, vol. 39, pp. 877–885, 2019.
- [15] O. Bongomin, E. O. Nganyi, M. R. Abswaidi, E. Hitiyise, and G. Tumusiime, "Sustainable and dynamic competitiveness towards technological leadership of industry 4.0: implications for East african community," *Journal of Engineering*, vol. 2020, pp. 1–22, 2020.
- [16] A. Rainnie and M. Dean, "Industry 4.0 and the future of quality work in the global digital economy," *Labour & Industry: A Journal of the Social and Economic Relations of Work*, vol. 30, no. 1, pp. 16–33, 2020.
- [17] M. Ghobakhloo, "Industry 4.0, digitization, and opportunities for sustainability," *Journal of Cleaner Production*, vol. 30, 2019.
- [18] T. Yıldız, "Examining the concept of industry 4.0 studies using text mining and scientific mapping method," *Procedia Computer Science*, vol. 158, pp. 498–507, 2019.
- [19] C. O. Klingenberg, M. Antônio, and V. Borges, "Industry 4.0 as a data-driven paradigm: a systematic literature review on technologies," *Journal of Manufacturing Technology Management*, vol. 30, 2019.
- [20] G. Büchi, M. Cugno, and R. Castagnoli, "Smart factory performance and Industry 4.0," *Technological Forecasting & Social Change*, vol. 150, pp. 1–10, 2020.
- [21] F. Rosin, P. Forget, S. Lamouri, and R. Pellerin, "Impacts of industry 4.0 technologies on lean principles," *International Journal of Production Research*, vol. 58, no. 6, pp. 1644–1661, 2020.
- [22] S. Luthra, A. Kumar, E. K. Zavadskas, S. K. Mangla, and J. A. Garza-reyes, "Industry 4.0 as an enabler of sustainability diffusion in supply chain: an analysis of influential strength of drivers in an emerging economy," *International Journal of Production Research*, vol. 58, no. 5, pp. 1505–1521, 2020.
- [23] C. G. Machado and E. H. D. Ribeiro da Silva, "Sustainable manufacturing in Industry 4.0: an emerging research agenda," *International Journal of Production Research*, vol. 58, no. 5, pp. 1462–1484, 2020.
- [24] B. Winroth, B. Bettayeb, M. H. Sahnoun, and F. Duval, "Towards predicting system disruption in industry 4.0: machine learning-based approach," *Procedia Computer Science*, vol. 151, pp. 667–674, 2019.
- [25] D. Mourtzis, S. Fotia, N. Boli, and E. Vlachou, "Modelling and quantification of industry 4.0 manufacturing complexity based on information theory: a robotics case study," *International Journal of Production Research*, vol. 57, no. 22, pp. 6908–6921, 2019.
- [26] A. G. Frank, L. S. Dalenogare, and N. F. Ayala, "Industry 4.0 technologies: implementation patterns in manufacturing companies," *International Journal of Production Economics*, vol. 210, pp. 15–26, 2019.
- [27] O. Bongomin, G. Gilibrays Ocen, E. Oyondi Nganyi, A. Musinguzi, and T. Omara, "Exponential disruptive technologies and the required skills of industry 4.0," *Journal of Engineering*, vol. 2020, pp. 1–17, 2020.
- [28] N. Dragicevic, A. Ullrich, E. Tsui, and N. Gronau, "A conceptual model of knowledge dynamics in the industry 4.0 smart grid scenario," *Knowledge Management Research & Practice*, vol. 20, pp. 1–15, 2019.
- [29] M. M. Queiroz, S. C. F. Pereira, and M. C. Machado, "Industry 4.0 and digital supply chain capabilities A framework for understanding digitalisation challenges and opportunities," *Benchmarking: An International Journal*, vol. 20, 2019.
- [30] M. Mariani and M. Borghi, "Industry 4.0: a bibliometric review of its managerial intellectual structure and potential evolution in the service industries," *Technological Forecasting & Social Change*, vol. 149, pp. 1–24, 2019.
- [31] M. Asif, "Are qm models aligned with industry 4.0? A perspective on current practices," *Journal of Cleaner Production*, vol. 20, pp. 1–26, 2020.
- [32] A. Bruzzone, M. Massei, and K. Sinelshnikov, "Enabling strategic decisions for the industry of tomorrow," *Procedia Manufacturing*, vol. 42, pp. 548–553, 2020.
- [33] A. Primi and M. Toselli, "A global perspective on industry 4.0 and development: new gaps or opportunities to leapfrog?" *Journal of Economic Policy Reform*, vol. 20, pp. 1–19, 2020.
- [34] G. Culot, G. Nassimbeni, G. Orzes, M. Sartor, and M. Sartor, "The future of manufacturing: a delphi-based scenario analysis on industry 4.0," *Technological Forecasting & Social Change*, vol. 20, 2020.
- [35] J. Weking, M. Stocker, M. Kowalkiewicz, M. Bohm, and H. Krcmar, "Leveraging industry 4.0—a business model pattern framework," *International Journal of Production Economics*, vol. 225, pp. 1–17, 2020.
- [36] A. G. Frank, G. H. S. Mendes, N. F. Ayala, and A. Ghezzi, "Servitization and Industry 4.0 convergence in the digital transformation of product firms: a business model innovation perspective," *Technological Forecasting and Social Change*, vol. 141, pp. 341–351, 2019.
- [37] M.-L. Martín-Peña, J.-M. Sánchez-Lopez, and E. Díaz-Garrido, "Servitization and digitalization in manufacturing: the influence on firm performance," *Journal of Business & Industrial Marketing*, vol. 35, no. 3, pp. 564–574, 2020.
- [38] F. R. P. M. Vianna, A. R. Graeml, and J. Peinado, "The role of crowdsourcing in industry 4.0: a systematic literature review," *International Journal of Computer Integrated Manufacturing*, vol. 33, no. 4, pp. 411–427, 2020.
- [39] S. Rajput and S. P. Singh, "Connecting circular economy and industry 4.0," *International Journal of Information Management*, vol. 49, pp. 98–113, 2019.
- [40] G. Piscitelli, A. Ferazzoli, A. Petrillo, R. Cioffi, A. Parmentola, and M. Travaglioni, "Circular economy models in the industry 4.0 era: a review of the last decade," *Procedia Manufacturing*, vol. 42, pp. 227–234, 2020.
- [41] G. Yadav, S. Luthra, S. Jakhar, S. K. Mangla, and D. P. Rai, "A framework to overcome sustainable supply chain challenges through solution measures of industry 4.0 and circular economy: an automotive case," *Journal of Cleaner Production*, vol. 20, 2020.
- [42] C. J. C. Jabbour, "First-mover firms in the transition towards the sharing economy in metallic natural resource-intensive

- industries: implications for the circular economy and emerging industry 4.0 technologies,” *Resources Policy*, vol. 66, pp. 1–13, 2020.
- [43] N. K. Dev, R. Shankar, and F. H. Qaiser, “Industry 4.0 and circular economy: operational excellence for sustainable reverse supply chain performance,” *Resources, Conservation & Recycling*, vol. 153, pp. 1–15, 2020.
- [44] C. Chauhan, A. Sharma, and A. Singh, “A SAP-LAP linkages framework for integrating Industry 4.0 and circular economy,” *Benchmarking: An International Journal*, vol. 15, 2019.
- [45] J. Ordieres-meré, T. P. Remón, and J. Rubio, “Digitalization: an opportunity for contributing to sustainability from knowledge creation,” *Sustainability*, vol. 12, no. 1460, p. 1, 2020.
- [46] B. Bigliardi, E. Bottani, and G. Casella, “Enabling technologies, application areas and impact of industry 4.0: a bibliographic analysis,” *Procedia Manufacturing*, vol. 42, pp. 322–326, 2020.
- [47] L. Fratini, I. Ragai, and L. Wang, “New trends in manufacturing systems research 2020,” *Journal of Manufacturing Systems*, vol. 15, pp. 1–3, 2020.
- [48] S. Aheleroff, “IoT-enabled smart appliances under industry 4.0: a case study,” *Advanced Engineering Informatics*, vol. 43, pp. 1–14, 2020.
- [49] K. Lee, F. Malerba, and A. Primi, “The fourth industrial revolution, changing global value chains and industrial upgrading in emerging economies,” *Journal of Economic Policy Reform*, vol. 15, pp. 1–12, 2020.
- [50] M. D. Anuşlu and S. Ü. Firat, “Clustering analysis application on Industry 4.0-driven global indexes,” *Procedia Computer Science*, vol. 158, pp. 145–152, 2019.
- [51] G. Culot, “Behind the definition of industry 4.0: analysis and open questions,” *International Journal of Production Economics*, vol. 15, pp. 1–47, 2020.
- [52] F. Chiarello, L. Trivelli, A. Bonaccorsi, and G. Fantoni, “Extracting and mapping industry 4.0 technologies using wikipedia,” *Computers in Industry*, vol. 100, pp. 244–257, 2018.
- [53] D. Ø. Madsen, “The emergence and rise of industry 4.0 viewed through the lens of management fashion theory,” *Administrative Science*, vol. 9, no. 71, p. 1, 2019.
- [54] M. Shafique and X. Luo, “Nanotechnology in transportation vehicles: an overview of its applications, environmental, health and safety concerns,” *Materials*, vol. 12, no. 2493, p. 1, 2019.
- [55] S. H. Moon, “Industry 4.0 for advanced manufacturing and its implementation,” *Eurasian Journal of Analytical Chemistry*, vol. 13, no. 6, pp. 491–497, 2018.
- [56] V. Alcácer and V. Cruz-machado, “Scanning the industry 4.0: a literature review on technologies for manufacturing systems,” *Engineering Science and Technology, an International Journal*, vol. 22, no. 3, pp. 899–919, 2019.
- [57] J. Franke, A. Mayr, F. Shepherd, and C. Zeiselmaier, “Six Sigma 4.0: data mining as supporting technology in zero error management,” *Economic Factory Journal*, vol. 114, no. 3, pp. 140–144, 2019.
- [58] F. Koenig, P. A. Found, and M. Kumar, “Innovative airport 4.0 condition-based maintenance system for baggage handling DCV systems,” *International Journal of Productivity and Performance Management*, vol. 68, no. 3, pp. 561–577, 2019.
- [59] T. Paschou, F. Adrodegari, M. Rapaccini, N. Saccani, and M. Perona, “Towards service 4.0: a new framework and research priorities,” *Procedia CIRP*, vol. 68, pp. 1–7, 2018.
- [60] A. M. Carvalho, P. Sampaio, E. Rebentisch, and P. Saraiva, “35 years of excellence, and perspectives ahead for excellence 4.0,” *Total Quality Management*, vol. 6, pp. 1–34, 2019.
- [61] M. Golan, Y. Cohen, and G. Singer, “A framework for operator-workstation interaction in Industry 4.0,” *International Journal of Production Research*, vol. 58, no. 8, pp. 2421–2432, 2020.
- [62] Á. Segura, “Visual computing technologies to support the Operator 4.0,” *Computers & Industrial Engineering*, vol. 139, pp. 1–8, 2020.
- [63] L. Gazzaneo, A. Padovano, and S. Umbrello, “Designing smart operator 4.0 for human values: a value sensitive design approach,” *Procedia Manufacturing*, vol. 42, pp. 219–226, 2020.
- [64] C. Liu and X. Xu, “Cyber-physical machine tool-the Era of machine tool 4.0,” *Procedia CIRP*, vol. 63, pp. 70–75, 2017.
- [65] R. Kurth and T. Päßler, “Forming 4.0: smart machine components applied as a hybrid plain bearing and a tool clamping system,” *Procedia Manufacturing*, vol. 27, pp. 65–71, 2019.
- [66] Z. Tehel, T. Wanyama, I. Singh, A. Gadhri, and R. Schmidt, “From industry 4.0 to robotics 4.0-a conceptual framework for collaborative and intelligent robotic systems,” *Procedia Manufacturing*, vol. 46, pp. 591–599, 2020.
- [67] A. Mayr and A. Kühl, “Lean 4.0-a conceptual conjunction of lean management and Industry 4.0,” *Procedia CIRP*, vol. 72, pp. 622–628, 2018.
- [68] M. Weigelt, M. Hofbauer, and B. Mandl, “Integration of IT into a lean basic training: target group-specific insights and recommendations,” *Procedia Manufacturing*, vol. 31, pp. 52–59, 2019.
- [69] A. Zonnenshain, R. S. Kenett, A. Zonnenshain, and R. S. Kenett, “Quality 4.0-the challenging future of quality engineering,” *Quality Engineering*, vol. 31, pp. 1–13, 2020.
- [70] S. Arsovski, “Social oriented quality: from quality 4.0 towards quality 5.0,” in *Proceedings of the 13th International Quality Conference*, pp. 397–404, New York, NY, USA, 2019.
- [71] D. Mourtzis, N. Milas, and N. Athinaios, “Towards machine shop 4.0: a general machine model for CNC machine-tools through OPC-UA,” *Procedia CIRP*, vol. 78, pp. 301–306, 2018.
- [72] L. Hartmann, T. Meudt, S. Seifermann, and J. Metternich, “Value stream method 4.0: holistic method to analyse and design value streams in the digital age,” *Procedia CIRP*, vol. 78, pp. 249–254, 2018.
- [73] Y. Cohen, M. Faccio, and A. Elaluf, “Hierarchy of smart awareness in assembly 4.0 systems,” *IFAC-PapersOnLine*, vol. 52, no. 13, pp. 1508–1512, 2019.
- [74] D. Guo, R. Y. Zhong, S. Ling, Y. Rong, and G. Q. Huang, “A roadmap for Assembly 4.0: self-configuration of fixed-position assembly islands under Graduation Intelligent Manufacturing System,” *International Journal of Production Research*, vol. 5, pp. 1–16, 2020.
- [75] R. Jose and S. Ramakrishna, “Materials 4.0: materials big data enabled materials discovery,” *Applied Materials Today*, vol. 10, pp. 127–132, 2018.
- [76] S. Bysko, J. Krystek, and S. Bysko, “Automotive paint shop 4.0,” *Computers & Industrial Engineering*, vol. 10, pp. 1–13, 2018.
- [77] E. Lima, E. Gorski, E. F. R. Loures, E. A. P. Santos, and F. Deschamps, “Applying machine learning to AHP multicriteria decision making method to assets prioritization in the context of industrial maintenance 4.0,” *IFAC-Papers OnLine*, vol. 52, no. 13, pp. 2152–2157, 2019.

- [78] P. Bertola and J. Teunissen, "Fashion 4.0. Innovating fashion industry through digital transformation," *Research Journal of Textile and Apparel*, vol. 22, no. 4, pp. 352–369, 2018.
- [79] O. Behr, "Fashion 4.0-digital innovation in the fashion industry," *Journal of Technology and Innovation Management*, vol. 2, no. 1, pp. 1–9, 2018.
- [80] V. Luiz, J. L. Kovaleski, and R. N. Pagani, "Technology transfer in the supply chain oriented to industry 4.0: a literature review," *Technology Analysis & Strategic Management*, vol. 31, no. 5, pp. 546–562, 2019.
- [81] M. A. Rapela, *Fostering Innovation for Agriculture 4.0: A Comprehensive Plant Germplasm System*, Springer Nature Switzerland AG, Cham, Switzerland, 2019.
- [82] A.-T. Braun, E. Colangelo, and T. Steckel, "Farming in the era of industrie 4.0," *Procedia CIRP*, vol. 72, pp. 979–984, 2018.
- [83] R. Berger, *Farming 4.0: How Precision Agriculture Might Save the World: Precision Farming Improves Farmer Livelihoods and Ensures Sustainable Food Production*, Springer, Munich, Germany, 2019.
- [84] I. C. Reinhardt, C. O. Jorge, and D. T. Ring, "Current perspectives on the development of industry 4.0 in the pharmaceutical sector," *Journal of Industrial Information Integration*, vol. 72, 2020.
- [85] W. S. Alaloul, M. S. Liew, N. A. W. A. Zawawi, I. B. Kennedy, and I. B. Kennedy, "Industrial Revolution 4.0 in the construction industry: challenges and opportunities for stakeholders," *Ain Shams Engineering Journal*, vol. 11, no. 1, pp. 225–230, 2020.
- [86] R. M. Ellahi, M. U. Ali Khan, and A. Shah, "Redesigning curriculum in line with industry 4.0," *Procedia Computer Science*, vol. 151, pp. 699–708, 2019.
- [87] R. Butt, H. Siddiqui, R. A. Soomro, and M. M. Asad, "Integration of industrial revolution 4.0 and iots in academia: a state-of-the-art review on the concept of education 4.0 in pakistan," *Interactive Technology and Smart Education*, vol. 11, 2020.
- [88] B. K. M. Wong and S. A. S. Hazley, "The future of health tourism in the industrial revolution 4.0 era," *Journal of Tourism Futures*, vol. 11, 2020.
- [89] A. Hussain, "Industrial revolution 4.0: implication to libraries and librarians," *Library Hi Tech News*, vol. 37, no. 1, p. 1, 2020.
- [90] E. Gökalp, M. O. Gökalp, and P. E. Eren, "Industry 4.0 revolution in clothing and apparel factories: apparel 4.0," *Industry 4.0 From The Management Information Systems Perspectives*, vol. 37, pp. 169–184, 2018.
- [91] M. C. Annosi, F. Brunetta, A. Monti, and F. Nati, "Is the trend your friend? An analysis of technology 4.0 investment decisions in agricultural SMEs," *Computers in Industry*, vol. 109, pp. 59–71, 2019.
- [92] M. Romer and S. Meißner, "Data-based services for smart load carriers: functional design and requirements analysis for internet of things technologies," *IFAC-PapersOnLine*, vol. 52, no. 13, pp. 2098–2103, 2019.
- [93] B. G. De Soto, I. Agustí-juan, S. Joss, and J. Hunhevcz, "Implications of Construction 4.0 to the workforce and organizational structures," *International Journal of Construction Management*, vol. 5, pp. 1–13, 2019.
- [94] H. Lu, L. Guo, M. Azimi, and K. Huang, "Oil and Gas 4.0 era: a systematic review and outlook," *Computers in Industry*, vol. 111, pp. 68–90, 2019.
- [95] M. Lezoche, J. E. Hernandez, M. D. M. E. A. Diaz, H. Panetto, and J. Kacprzyk, "Agri-food 4.0: a survey of the supply chains and technologies for the future agriculture," *Computers in Industry*, vol. 117, pp. 1–13, 2020.
- [96] H. Panetto, M. Lezoche, J. E. H. Hormazabal, M. D. M. E. A. Diaz, and J. Kacprzyk, "Special issue on Agri-Food 4.0 and digitalization in agriculture supply chains-new directions, challenges and applications," *Computers in Industry*, vol. 116, pp. 4–6, 2020.
- [97] J.-P. Belaud, N. Prioux, C. Vialle, and C. Sablayrolles, "Big data for agri-food 4.0: application to sustainability management for by-products supply chain," *Computers in Industry*, vol. 111, pp. 41–50, 2019.
- [98] J. Miranda, P. Ponce, A. Molina, and P. Wright, "Sensing, smart and sustainable technologies for Agri-Food 4.0," *Computers in Industry*, vol. 108, pp. 21–36, 2019.
- [99] B. Satuyeva, C. Sauranbayev, I. A. Ukaegbu, and H. S. V. S. K. Nunna, "Energy 4.0: towards IoT applications in Kazakhstan," *Procedia Computer Science*, vol. 151, pp. 909–915, 2019.
- [100] M. Seixas, R. Melicio, and V. Mendes, "Comparison of offshore and onshore wind systems with MPC five-level converter under energy 4.0," *Electric Power Components and Systems*, vol. 46, no. 13, pp. 1399–1415, 2018.
- [101] H. Kurgun, O. A. Kurgun, and E. Aktaş, "What does web 4.0 promise for tourism ecosystem? A qualitative research on tourism ecosystem stakeholders' awareness," *Journal of Tourism and Hospitality Management*, vol. 6, no. 1, pp. 55–65, 2018.
- [102] Guidehouse, *Energy Cloud 4.0: Capturing Business Value through Disruptive Energy Platforms*, Guidehouse, Washington, DC, USA, 2020.
- [103] P. Vingerhoets, M. Chebbo, and N. Hatzirygiouri, "The digital energy system 4.0," 2016.
- [104] Development Dimensions International, "A leader's guide to manufacturing 4.0: four talent strategies to transform your organization for the future," 2017.
- [105] T. J. Lopez-Garcia, J. A. Alvarez-Cedillo, T. A. Sanchez, and C. M. Vicario-Solorzano, "Review of trends in the educational model of distance education in Mexico, towards an education 4.0," *Computer Reviews Journal*, vol. 3, pp. 111–121, 2019.
- [106] D. Mourtzis, E. Vlachou, G. Dimitrakopoulos, and V. Zogopoulos, "Cyber-physical systems and education 4.0-the teaching factory 4.0 concept," *Procedia Manufacturing*, vol. 23, pp. 129–134, 2018.
- [107] L. Farrell, T. Newman, and C. Corbel, "Literacy and the workplace revolution: a social view of literate work practices in Industry 4.0," *Discourse: Studies in the Cultural Politics of Education*, vol. 1–15, 2020.
- [108] D. Janssen, C. Tummel, A. Richert, and I. Isenhardt, "Virtual environments in higher education-immersion as a key construct for learning 4.0," *International Journal of Advanced Corporate Learning*, vol. 23, pp. 1–7, 2016.
- [109] M. Bartelt, J. Stecken, and B. Kuhlentötter, "Automated production of individualized products for teaching I4.0 concepts," *Procedia Manufacturing*, vol. 45, pp. 337–342, 2020.
- [110] L. Angrisani, P. Arpaia, F. Bonavolontá, and N. Moccaldi, "A learning small enterprise networked with a FabLab: an academic course 4.0 in instrumentation and measurement," *Measurement*, vol. 150, pp. 1–8, 2020.
- [111] A. V. Lapteva and V. S. Efimov, "New generation of universities," *Journal of Siberian Federal University*, vol. 11, no. 9, pp. 2681–2696, 2016.

- [112] K. Vodenko, "Science and education in the form 4.0: public policy and organization based on human and artificial intellectual capital," *Journal of Intellectual Capital*, vol. 15, 2020.
- [113] S. Sathya, "ECLECTIC 4.0: the new learning model for business schools," *Higher Education, Skills and Work-Based Learning*, vol. 10, no. 3, pp. 581–590, 2020.
- [114] E. Flores, X. Xu, and Y. Lu, "Human Capital 4.0: a workforce competence typology for Industry 4.0," *Journal of Manufacturing Technology Management*, vol. 31, no. 4, pp. 687–703, 2020.
- [115] J. Grodotzki, T. R. Ortelt, and A. E. Tekkaya, "Remote and virtual labs for engineering education 4.0," *Procedia Manufacturing*, vol. 26, pp. 1349–1360, 2018.
- [116] L. Moldovan, "State-of-the-art analysis on the knowledge and skills gaps on the topic of industry 4.0 and the requirements for work-based learning," *Procedia Manufacturing*, vol. 32, pp. 294–301, 2019.
- [117] K. Jordon, P. Dossou, and J. C. Junior, "Using lean manufacturing and machine learning for improving medicines procurement and dispatching in a hospital," *Procedia Manufacturing*, vol. 38, pp. 1034–1041, 2020.
- [118] J. C. Pinheiro, P.-E. Dossou, and J. C. Junior, "Methods and concepts for elaborating a decision aided tool for optimizing healthcare medicines dispatching flows," *Procedia Manufacturing*, vol. 38, pp. 209–216, 2020.
- [119] S. Winkelhaus and E. H. Grosse, "Logistics 4.0: a systematic review towards a new logistics system," *International Journal of Production Research*, vol. 58, no. 1, pp. 18–43, 2020.
- [120] G. L. Tortorella, F. S. Fogliatto, A. M. C. Vergara, R. Vassolo, and R. Sawhney, "Healthcare 4.0: trends, challenges and research directions," *Production Planning & Control*, vol. 38, pp. 1–16, 2019.
- [121] A. C. B. Monteiro, R. P. França, V. V. Estrela, Y. Iano, A. Khelassi, and N. Razmjoo, "Health 4.0: applications, management, technologies and review," *Medical Technologies Journal*, vol. 2, no. 4, pp. 262–276, 2019.
- [122] J. Lopes, T. Guimarães, and M. F. Santos, "Predictive and prescriptive analytics in healthcare: a survey," *Procedia Computer Science*, vol. 170, pp. 1029–1034, 2020.
- [123] A. Moreira and M. F. Santos, "Multichannel interaction for healthcare intelligent decision support," *Procedia Computer Science*, vol. 170, pp. 1053–1058, 2020.
- [124] L. B. Liboni, L. H. B. Liboni, and L. O. Cezarino, "Electric utility 4.0: trends and challenges towards process safety and environmental protection," *Process Safety and Environmental Protection*, vol. 117, pp. 593–605, 2018.
- [125] V. Yavas and Y. D. Ozkan-ozen, "Logistics centers in the new industrial era: a proposed framework for logistics center 4.0," *Transportation Research Part E*, vol. 135, pp. 1–18, 2020.
- [126] D. Mourtzis, V. Siatras, J. Angelopoulos, and N. Panopoulos, "An augmented reality collaborative product design cloud-based platform in the context of learning factory," *Procedia Manufacturing*, vol. 45, pp. 546–551, 2020.
- [127] W. Wereda and J. Woźniak, "Building relationships with customer 4.0 in the era of marketing 4.0: the case study of innovative enterprises in Poland," *Social Sciences*, vol. 8, no. 177, p. 1, 2019.
- [128] A. U. Rahayu, I. Herawaty, N. R. S. A. S. Prafitriyani, A. P. Afini, and A. P. Kautsar, "Marketing 4.0: a digital transformation in pharmaceutical industry to reach customer brand experience," *Farmaka*, vol. 16, no. 1, p. 80, 2018.
- [129] B. P. Sullivan, S. Desai, J. Sole, M. Rossi, L. Ramundo, and S. Terzi, "Maritime 4.0-opportunities in digitalization and advanced manufacturing for vessel development," *Procedia Manufacturing*, vol. 42, pp. 246–253, 2020.
- [130] G. Aiello, A. Giallanza, and G. Mascarella, "Towards Shipping 4.0. A preliminary gap analysis," *Procedia Manufacturing*, vol. 42, pp. 24–29, 2020.
- [131] J. Wullbrandt, J. Pontevedra, and S. Fochler, "Center of excellence for lean enterprise 4.0," *Procedia Manufacturing*, vol. 31, pp. 66–71, 2019.
- [132] P.-E. Dossou, "Impact of Sustainability on the supply chain 4.0 performance," *Procedia Manufacturing*, vol. 17, pp. 452–459, 2018.
- [133] D. Makris, Z. N. L. Hansen, and O. Khan, "Adapting to supply chain 4.0: an explorative study of multinational companies," *Supply Chain Forum: An International Journal*, vol. 20, no. 2, pp. 116–131, 2019.
- [134] C. Chute and T. French, "Introducing care 4.0: an integrated care paradigm built on industry 4.0 capabilities," *International Journal of Environmental Research and Public Health*, vol. 16, no. 2247, p. 1, 2019.
- [135] S. A. Gawankar, A. Gunasekaran, and S. Kamble, "A study on investments in the big data-driven supply chain, performance measures and organisational performance in Indian retail 4.0 context," *International Journal of Production Research*, vol. 58, no. 5, pp. 1574–1593, 2020.
- [136] C. K. H. Lee, "A GA-based optimisation model for big data analytics supporting anticipatory shipping in Retail 4.0," *International Journal of Production Research*, vol. 55, no. 2, pp. 593–605, 2017.
- [137] O. Kunze, "Replicators, ground drones and crowd logistics a vision of urban logistics in the year 2030," *Transportation Research Procedia*, vol. 19, pp. 286–299, 2016.
- [138] N. Karunarathna, R. Wickramarachchi, and K. Vidanagamachchi, "A study of the implications of logistics 4.0 in future warehousing: a Sri Lankan perspective," in *Proceedings of the International Conference on Industrial Engineering and Operations Management*, pp. 1024–1035, New York, NY, USA, 2019.
- [139] FlytBase, "Drone automation for warehouse 4.0," 2019.
- [140] L. Wawrla, O. Maghazei, and T. Netland, "Applications of drones in warehouse operations," 2019.
- [141] B. Asdecker and V. Felch, "Development of an Industry 4.0 maturity model for the delivery process in supply chains," *Journal of Modelling in Management*, vol. 13, no. 4, pp. 840–883, 2018.
- [142] S. Bag, L. C. Wood, S. K. Mangla, and S. Luthra, "Procurement 4.0 and its implications on business process performance in a circular economy," *Resources, Conservation & Recycling*, vol. 152, pp. 1–2, 2020.
- [143] J. J. Blazquez-resino, S. Gutiérrez-broncano, and P. Ruiz-palomino, "Dealing with human resources in the age of consumer 4.0: aiming to improve service delivery," *Frontiers in Psychology*, vol. 0, no. 3058, 2020.
- [144] B. Nicoletti, "Fintech and procurement finance 4.0," *Palgrave Studies in Financial Services Technology*, vol. 1, pp. 155–248, 2018.
- [145] B. King, *Bank 4.0: Banking Everywhere, Never at a Bank*, Marshall Cavendish Business, Singapore, 2018.
- [146] B. Sivathanu and R. Pillai, *Smart HR 4.0-How Industry 4.0 Is Disrupting HR*, Human Resource Management International Digest, Singapore, 2018.
- [147] F. Ansari, "Knowledge management 4.0: theoretical and practical considerations in cyber physical production systems," *IFAC-PapersOnLine*, vol. 52, no. 13, pp. 1597–1602, 2019.

- [148] E. Tom, G. Neumann, and J. Majewska, *Theory and Applications in the Knowledge Economy*, Marshall Cavendish Business, Poznan, Poland, 2018.
- [149] R. Kelly, *Constructing Leadership 4.0: Swarm Leadership and the Fourth Industrial Revolution*, Springer Nature Switzerland AG, Kent, UK, 2019.
- [150] S. Helming, F. Ungermann, N. Hierath, N. Stricker, and G. Lanza, "Development of a training concept for leadership 4.0 in production environments," *Procedia Manufacturing*, vol. 31, pp. 38–44, 2019.
- [151] D. Rogers, "Building management 4.0: smart technology and the great American retrofit," *Construction Research and Innovation*, vol. 9, no. 1, pp. 21–25, 2018.
- [152] A. Cooper and N. Sebake, "Neighbourhood 4.0: a response to urban futures," in *Proceedings of the Out-of-the Box 2018 Conference*, New York, NY, USA, 2019.
- [153] G. Reischauer, "Industry 4.0 as policy-driven discourse to institutionalize innovation systems in manufacturing," *Technological Forecasting & Social Change*, vol. 23, pp. 1–8, 2018.
- [154] H. Fischer, M. Engler, and S. Sauer, "A human-centered perspective on software quality: acceptance criteria for work 4.0," *Lecture Notes in Computer Science*, vol. 2017, 2017.
- [155] World Economic Forum, *HR 4.0: Shaping People Strategies in the Fourth Industrial Revolution*, Cologny, Geneva, Switzerland, 2019.
- [156] L. B. Liboni, L. O. Cezarino, C. J. C. Jabbour, B. G. Oliveira, and N. O. Stefanelli, "Smart industry and the pathways to HRM 4.0: implications for SCM," *Supply Chain Management: An International Journal*, vol. 24, no. 1, pp. 124–146, 2019.
- [157] U. Schäffer and J. Weber, "Controlling 4.0," *Controlling & Management Review*, vol. 60, no. 6, p. 3, 2016.
- [158] World Economic Forum, *Globalization 4.0: Shaping a New Global Architecture in the Age of the Fourth Industrial Revolution*, Cologny, Geneva, Switzerland, 2019.
- [159] M. E. Gladden, "Who will Be the members of society 5.0? Towards an anthropology of technologically posthumanized future societies," *Social Sciences*, vol. 8, no. 148, p. 1, 2019.
- [160] E. M. Frazzon, C. M. T. Rodriguez, M. M. Pereira, M. C. Pires, and I. Uhlmann, "Towards supply chain management 4.0," *Brazilian Journal of Operations & Production Management*, vol. 16, no. 2, pp. 180–191, 2019.
- [161] W. Cho and E. M. Berman, "E-government 4.0 in Thailand: the role of central agencies," *Information Polity*, vol. 23, pp. 343–353, 2018.
- [162] The United Nations Development Programme, "Development 4.0: opportunities and challenges for accelerating progress towards the sustainable development goals in asia and the pacific," 2018.
- [163] Skills Development Scotland, "Skills 4.0: a skills model to drive scotland's future," 2018.
- [164] J. I. T. Goena, Á. L. de Nalda, E. V. Díez, and J. S. García, "Professional competences 4.0," 2018.
- [165] P. Buasuwan, "Rethinking Thai higher education for Thailand 4.0," *Asian Education and Development Studies*, vol. 7, no. 2, pp. 157–173, 2018.
- [166] P. Chiengkul, "Uneven development, inequality and concentration of power: a critique of Thailand 4.0," *Third World Quarterly*, vol. 40, no. 9, pp. 1689–1707, 2019.
- [167] D. Mourtzis, J. Angelopoulos, G. Dimitrakopoulos, and J. Angelopoulos, "Design and development of a flexible manufacturing cell in the concept of learning factory paradigm for the education of generation 4.0 engineers," *Procedia Manufacturing*, vol. 45, pp. 361–366, 2020.
- [168] I. Zambon, M. Cecchini, G. Egidi, M. G. Saporito, and A. Colantoni, "Revolution 4.0: industry vs agriculture in a future development for SMEs," *Processes*, vol. 7, no. 36, p. 1, 2019.
- [169] O. Onday, "Japan's society 5.0: going beyond industry 4.0," *Business and Economics Journal*, vol. 10, no. 2, pp. 2–7, 2019.
- [170] T. Salimova, N. Guskova, I. Krakovskaya, and E. Sirota, "From industry 4.0 to Society 5.0: challenges for sustainable competitiveness of Russian industry," *IOP Conference Series: Materials Science and Engineering*, vol. 497, 2019.
- [171] E. D. G. Fraser and M. Campbell, "Agriculture 5.0: reconciling production with planetary health," *One Earth*, vol. 1, no. 3, pp. 278–280, 2019.
- [172] V. Saiz-rubio, "From smart farming towards agriculture 5.0: a review on crop data management," *Agronomy*, vol. 10, 2020.
- [173] K. A. Demir, G. Döven, and B. Sezen, "Industry 5.0 and human-robot Co-working," *Procedia Computer Science*, vol. 158, pp. 688–695, 2019.
- [174] F. Aslam, W. Aimin, M. Li, and K. U. Rehman, "Innovation in the era of IoT and industry 5.0: absolute innovation management (AIM) framework," *Information*, vol. 11, no. 124, 2020.
- [175] S. Nahavandi, "Industry 5.0-a human-centric solution," *Sustainability*, vol. 11, no. 4371, 2019.
- [176] G. F. Mukwawaya and B. Emwanu, "Assessing the readiness of South Africa for Industry 4.0-analysis of government policy, skills and education," in *Proceedings of the International Conference on Industrial Engineering and Operations Management*, pp. 1587–1604, New York, NY, USA, 2018.
- [177] A. A. Hussin, "Education 4.0 made Simple: ideas for teaching," *International Journal of Education & Literacy Studies*, vol. 6, no. 3, pp. 92–98, 2018.
- [178] B. Andrea and T. Jiří, "Requirements for education and qualification of people in industry 4.0," *Procedia Manufacturing*, vol. 11, pp. 2195–2202, 2017.
- [179] C. Selim, K. Yasanur, and G. Eray, "Adapting engineering education to industry 4.0 vision," *Technologies*, vol. 10, no. 7, pp. 1–13, 2019.
- [180] D. Mourtzis, D. Tsakalos, F. Xanthi, and V. Zogopoulos, "Optimization of highly automated production line: an advanced engineering educational approach," *Procedia Manufacturing*, vol. 31, pp. 45–51, 2019.
- [181] A. A. Shahroom and N. Hussin, "Industrial revolution 4.0 and education," *International Journal of Academic Research in Business and Social Sciences*, vol. 8, no. 9, pp. 314–319, 2018.
- [182] C. C. Chea, J. Tan, and J. Huan, "Higher education 4.0: the possibilities and challenges," *Journal of Social Sciences and Humanities*, vol. 5, no. 2, pp. 81–85, 2019.
- [183] M. A. Peters, "Technological unemployment: educating for the fourth industrial revolution," *Educational Philosophy and Theory*, vol. 49, no. 1, pp. 1–6, 2017.
- [184] R. Jamaludin, G. Town, and E. Mckay, "Are we ready for Education 4.0 within ASEAN higher education institutions? Thriving for knowledge, industry and humanity in a dynamic higher education ecosystem?" *Journal of Applied Research in Higher Education*, vol. 49, pp. 1–13, 2019.
- [185] OECD, "OCED future of education and skills 2030: project background," 2019.
- [186] T. Molla and D. Cuthbert, "Calibrating the PhD for Industry 4.0: global concerns, national agendas and Australian

- institutional responses,” *Policy Reviews in Higher Education*, vol. 3, no. 2, pp. 167–188, 2019.
- [187] A. Cropley, “Creativity-focused technology education in the age of industry 4.0,” *Creativity Research Journal*, vol. 49, pp. 1–8, 2020.
- [188] S. EMokhtar, J. A. Q. Alshboul, and G. O. A. Shahin, “Towards data-driven education with learning analytics for educator 4.0,” *Journal of Physics: Conference Series*, vol. 1339, 2019.
- [189] A. Hariharasudan and S. Kot, “A scoping review on digital english and education 4.0 for industry 4.0,” *Social Sciences*, vol. 7, p. 227, 2018.
- [190] M. Ciolacu, P. M. Svasta, W. Berg, and H. Popp, “Education 4.0 for tall thin engineer in a data driven society,” in *Proceedings of the 2017 IEEE 23rd International Symposium for Design and Technology in Electronic Packaging*, London, UK, 2018.
- [191] S. H. Halili, “Technological advancements in education 4.0,” *The Online Journal of Distance Education and E-Learning*, vol. 7, no. 1, pp. 63–69, 2019.
- [192] H. K. Pangandaman, N. D. Ali, J. H. C. Lambayong, and M. L. G. Ergas, “Philippine higher education vis-à-vis education 4.0: a scoping review,” *International Journal of Advanced Research and Publications ISSN*, vol. 3, no. 3, pp. 65–69, 2019.
- [193] M. Maria, F. Shahbodin, and N. C. Pee, “Malaysian higher education system towards industry 4.0-current trends overview,” in *Proceedings of the 3rd International Conference on Applied Science and Technology (ICAST'18)*, London, UK, 2018.
- [194] FICCI-EY, *Leapfrogging to Education 4.0: Student at the Core*, Springer, New Delhi, India, 2017.
- [195] N. Songkram, S. Chootongchai, J. Khlaisang, and P. Koraneeki, “Education 3.0 system to enhance twenty-first century skills for higher education learners in thailand,” *Interactive Learning Environments*, vol. 3, pp. 1–17, 2019.
- [196] S. Fareri, G. Fantoni, F. Chiarello, E. Coli, and A. Binda, “Computers in Industry Estimating Industry 4.0 impact on job profiles and skills using text mining,” *Computers in Industry*, vol. 118, pp. 1–19, 2020.
- [197] C. Catal and B. Tekinerdogan, “Aligning education for the life sciences domain to support digitalization and industry 4.0,” *Procedia Computer Science*, vol. 158, pp. 99–106, 2019.
- [198] World Economic Forum, *Schools of the Future: Defining New Models of Education for the Fourth Industrial Revolution*, Cologny, Geneva, Switzerland, 2020.
- [199] D. Mourtzis and G. Chryssolouris, “Editorial,” *Procedia Manufacturing*, vol. 23, pp. 7–8, 2018.
- [200] E. Rauch, F. Morandell, and D. T. Matt, “AD design guidelines for implementing I4.0 learning factories,” *Procedia Manufacturing*, vol. 31, pp. 239–244, 2019.
- [201] T. Rossmeißl, E. Groß, M. Tzempetionidou, and J. Siegert, “Living learning environments,” *Procedia Manufacturing*, vol. 31, pp. 20–25, 2019.
- [202] F. Baena, A. Guarin, J. Mora, J. Souza, and S. Retat, “Learning factory: the path to industry 4.0,” *Procedia Manufacturing*, vol. 9, pp. 73–80, 2017.
- [203] E. Mo, D. Centea, I. Singh, and T. Wanyama, “SEPT learning factory for industry 4.0 education and applied research,” *Procedia Manufacturing*, vol. 23, pp. 249–254, 2018.
- [204] B. Salah, M. H. Abidi, S. H. Mian, M. Krid, H. Alkhalefeh, and A. Abdo, “Virtual reality-based engineering education to enhance manufacturing sustainability in industry 4.0,” *Sustainability*, vol. 11, p. 1477, 2019.
- [205] L. Büth, S. Blume, G. Posselt, and C. Herrmann, “Training concept for and with digitalization in learning factories: an energy efficiency training case,” *Procedia Manufacturing*, vol. 23, pp. 171–176, 2018.
- [206] S. Imran, E. Szczerbicki, and C. Sanin, “Proposition of the methodology for data acquisition, analysis and visualization in support of industry 4.0,” *Procedia Computer Science*, vol. 159, p. 1976, 2019.
- [207] I. Daniyan, K. Mpofu, M. Oyesola, B. Ramatsetse, and A. Adeodu, “Artificial intelligence for predictive maintenance in the railcar learning factories,” *Procedia Manufacturing*, vol. 45, pp. 13–18, 2020.
- [208] F. Sieckmann, N. Petrusch, and H. Kohl, “Effectivity of Learning Factories to convey problem solving competencies,” *Procedia Manufacturing*, vol. 45, pp. 228–233, 2020.
- [209] L. F. C. S. Durão, M. O. Guimarães, M. S. Salerno, and E. Zancul, “Uncertainty management in advanced manufacturing implementation: the case for learning factories,” *Procedia Manufacturing*, vol. 31, pp. 213–218, 2019.
- [210] J. Siegert, T. Schlegel, and T. Bauernhansl, “Verifiable competencies for production technology,” *Procedia Manufacturing*, vol. 45, pp. 466–472, 2020.
- [211] B. J. Ralph, A. Schwarz, and M. Stockinger, “An implementation approach for an academic learning factory for the metal forming industry with special focus on digital twins and finite elements analysis,” *Procedia Manufacturing*, vol. 45, pp. 253–258, 2020.
- [212] J. L. Jooste and K. Leipzig, “Teaching maintenance plan development in a learning factory environment,” *Procedia Manufacturing*, vol. 45, pp. 379–385, 2020.
- [213] E. Louw, O. C. Chaim, D. Braatz, B. Muschard, and H. Rozenfeld, “Exploring gamification to support manufacturing education on industry 4.0 as an enabler for innovation and sustainability,” *Procedia Manufacturing*, vol. 21, pp. 438–445, 2018.
- [214] K. Lensing and J. Friedhoff, “Designing a curriculum for the Internet-of-Things-Laboratory to foster creativity and a maker mindset within varying target groups,” *Procedia Manufacturing*, vol. 23, pp. 231–236, 2018.
- [215] P. Herstätter, T. Wildbolz, M. Hulla, and C. Ramsauer, “Data acquisition to enable research, education and training in learning factories and makerspaces,” *Procedia Manufacturing*, vol. 45, pp. 289–294, 2020.
- [216] E. A. Sadaj, M. Hulla, and C. Ramsauer, “Design approach for a learning factory to train services,” *Procedia Manufacturing*, vol. 45, pp. 60–65, 2020.
- [217] A. Kohlweiss, E. Auberger, A. Ketenci, and C. Ramsauer, “Integration of a teardown approach at graz university of Technology’s LEAD factory,” *Procedia Manufacturing*, vol. 45, pp. 240–245, 2020.
- [218] M. Eder, A. Ketenci, E. Auberger, M. Gotthard, and C. Ramsauer, “Integration of low-cost digital energy meters in learning factory assembly lines,” *Procedia Manufacturing*, vol. 45, pp. 202–207, 2020.
- [219] A. Santana, P. Afonso, A. Zanin, and R. Wernke, “Learn how to cope with volatility in operations at Graz University of Technology’s LEAD Factory,” *Procedia Manufacturing*, vol. 23, pp. 15–20, 2018.
- [220] M. Wolf, P. Herstätter, and C. Ramsauer, “Using the IIM LEAD factory to identify countermeasures for the demographic challenge,” *Procedia Manufacturing*, vol. 31, pp. 123–128, 2019.

- [221] D. Antonelli, "Tiphys: an open networked platform for higher education on industry 4.0," *Procedia CIRP*, vol. 79, pp. 706–711, 2018.
- [222] D. Centea, I. Singh, T. Wanyama, M. Magolon, J. Boer, and M. Elbestawi, "Using the SEPT learning factory for the implementation of industry 4.0: case of SMEs," *Procedia Manufacturing*, vol. 45, pp. 102–107, 2020.
- [223] D. Centea, I. Singh, M. Yakout, J. Boer, and M. Elbestawi, "Opportunities and challenges in integrating additive manufacturing in the SEPT learning factory," *Procedia Manufacturing*, vol. 45, pp. 108–113, 2020.
- [224] D. Centea, I. Singh, and M. Elbestawi, "SEPT approaches for education and training using a learning factory," *Procedia Manufacturing*, vol. 31, pp. 109–115, 2019.
- [225] M. Lanz, R. Pieters, and R. Ghabcheloo, "Learning environment for robotics education and industry-academia collaboration," *Procedia Manufacturing*, vol. 31, pp. 79–84, 2019.
- [226] H. Nylund, V. Valjus, V. Toivonen, M. Lanz, and H. Nieminen, "The virtual FMS-an engineering education environment," *Procedia Manufacturing*, vol. 31, pp. 251–257, 2019.
- [227] J. Wermann, A. W. Colombo, A. Pechmann, and M. Zarte, "Using an interdisciplinary demonstration platform for teaching Industry 4.0," *Procedia Manufacturing*, vol. 31, pp. 302–308, 2019.
- [228] J.-A. Scholz, F. Sieckmann, and H. Kohl, "Implementation with agile project management approaches: case study of an industrie 4.0 learning factory in China," *Procedia Manufacturing*, vol. 45, pp. 234–239, 2020.
- [229] L. Hausmann, F. Wirth, M. O. Flammer, J. Hofmann, and J. Fleischer, "Aligning vocational training to the electromobile transformation by establishing the "Training Factory Stator Production"-a methodical deficit analysis with derivation of measures," *Procedia Manufacturing*, vol. 45, pp. 448–453, 2020.
- [230] Z. Kemény, R. Beregi, J. Nacsá, C. Kardos, and D. Horváth, "Example of a problem-to-course life cycle in layout and process planning at the MTA SZTAKI learning factories," *Procedia Manufacturing*, vol. 31, pp. 206–212, 2019.
- [231] C. Block, D. Kreimeier, and B. Kuhlenkötter, "Holistic approach for teaching IT skills in a production environment," *Procedia Manufacturing*, vol. 23, pp. 57–62, 2018.
- [232] A. Conrad, H. Oberc, and M. Wannöffel, "Co-determination-an interdisciplinary concept to train PhD students from different disciplines," *Procedia Manufacturing*, vol. 31, pp. 129–135, 2019.
- [233] V. D. Kuhlenkötter, S. Lang, and T. Reggelen, "Integration of LiFi technology in an industry 4.0 learning factory," *Procedia Manufacturing*, vol. 31, pp. 232–238, 2019.
- [234] J. Siegert, L. Zarco, T. Schlegel, and T. Bauernhansl, "Software control system requirements for ultra-flexible learning factories," *Procedia Manufacturing*, vol. 45, pp. 442–447, 2020.
- [235] S. T. Mortensen, K. K. Nygaard, and O. Madsen, "Outline of an industry 4.0 awareness game," *Procedia Manufacturing*, vol. 31, pp. 309–315, 2019.
- [236] M. Hennig, G. Reisinger, T. Trautner, P. Hold, D. Gerhard, and A. Mazak, "TU wien pilot factory industry 4.0," *Procedia Manufacturing*, vol. 31, pp. 200–205, 2019.
- [237] L. Zhao-hui, Z. Wei-min, X. Zhong-yue, S. Jia-bin, and L. Dongdong, "Research on extended carbon emissions accounting method and its application in sustainable manufacturing," *Procedia Manufacturing*, vol. 43, pp. 175–182, 2020.
- [238] T. Zaimovic, "Setting speed-limit on Industry 4.0-an outlook of power-mix and grid capacity challenge," *Procedia Computer Science*, vol. 158, pp. 107–115, 2019.
- [239] Z. Huang, H. Yu, Z. Peng, and Y. Feng, "Planning community energy system in the industry 4.0 era: achievements, challenges and a potential solution," *Renewable and Sustainable Energy Reviews*, vol. 78, pp. 710–721, 2017.
- [240] F. Schafer, C. Andr, C. David, P. Crovato, and R. Righi, "Looking at energy through the lens of industry 4.0: a systematic literature review of concerns and challenges," *Computers & Industrial Engineering*, vol. 78, pp. 1–57, 2020.
- [241] R. Ferrero, M. Collotta, M. V. Bueno-delgado, and H. Chen, "Smart management energy systems in industry 4.0," *Energies*, vol. 13, no. 382, 2020.
- [242] A. Hidayatno, A. R. Destyanto, and C. A. Hulu, "Industry 4.0 technology implementation impact to industrial sustainable energy in Indonesia: a model conceptualization," *Energy Procedia*, vol. 156, pp. 227–233, 2019.
- [243] UNIDO, *Accelerating Clean Energy through Industry 4.0 Manufacturing the Next Revolution*, Springer, Vienna, Austria, 2017.
- [244] S. Scharl and A. Praktijnjo, "The role of a digital industry 4.0 in a renewable energy system," *International Journal of Energy Research*, vol. 43, no. 8, pp. 3891–3904, 2019.
- [245] C. Koyunoğlu and H. Karaca, "Application of Industry 4.0 on biomass liquefaction study: a case study," *Procedia Computer Science*, vol. 158, pp. 401–406, 2019.
- [246] A. K. Shukla, R. Nath, P. K. Muhuri, and Q. M. D. Lohani, "Energy efficient multi-objective scheduling of tasks with interval type-2 fuzzy timing constraints in an Industry 4.0 ecosystem," *Engineering Applications of Artificial Intelligence*, vol. 87, pp. 1–18, 2020.
- [247] V. J. Mawson and B. R. Hughes, "The development of modelling tools to improve energy efficiency in manufacturing processes and systems," *Journal of Manufacturing Systems*, vol. 51, pp. 95–105, 2019.
- [248] R. Rentsch and B. Karpuschewski, "Energy and Resource efficiency analysis of manufacturing chains by modular process models and simulation," *Procedia Manufacturing*, vol. 43, pp. 159–166, 2020.
- [249] G. Thiele, O. Heimann, K. Grabowski, and J. Krüger, "Framework for energy efficiency optimization of industrial systems based on the Control Layer Model," *Procedia Manufacturing*, vol. 33, pp. 414–421, 2019.
- [250] F. Wang, L. Ma, and C. Yuan, "Experimental methods to study environmental sustainability of silicon-based lithium ion battery manufacturing," *Procedia Manufacturing*, vol. 33, pp. 501–507, 2019.
- [251] S. Fielke, B. Taylor, and E. Jakku, "Digitalisation of agricultural knowledge and advice networks: a state-of-the-art review," *Agricultural Systems*, vol. 180, pp. 1–11, 2020.
- [252] L. Klerkx, "Advisory services and transformation, plurality and disruption of agriculture and food systems: towards a new research agenda for agricultural education and extension studies," *The Journal of Agricultural Education and Extension*, vol. 26, no. 2, pp. 131–140, 2020.
- [253] V. Bonneau, B. Copigneaux, L. Probst, and B. Pedersen, "Industry 4.0 in agriculture: focus on iot aspects," 2017.
- [254] N. M. Trendov, S. Varas, and M. Zeng, *Digital Technologies in Agriculture and Rural Areas*, Briefing Paper, Rome, 2019.
- [255] B. Talukder, A. Blay-palmer, W. Gary, and K. W. Hipel, "Towards complexity of agricultural sustainability

- assessment: main issues and concerns," *Environmental and Sustainability Indicators*, vol. 26, pp. 1–11, 2020.
- [256] M. Anshari, M. N. Almunawar, M. Masri, and M. Hamdan, "Digital marketplace and FinTech to support agriculture sustainability," *Energy Procedia*, vol. 156, pp. 234–238, 2019.
- [257] I. Charania and X. Li, "Smart farming: agriculture's shift from a labor intensive to technology native industry," *Internet of Things*, vol. 1–22, 2019.
- [258] J. Huang and L. Zhang, "The big data processing platform for intelligent agriculture," *AIP Conference Proceedings*, vol. 1864, 2017.
- [259] F. Bu and X. Wang, "A smart agriculture IoT system based on deep reinforcement learning," *Future Generation Computer Systems*, vol. 99, pp. 500–507, 2019.
- [260] J. M. S. Garcia and D. P. Jerez, "Agro-food projects: analysis of procedures within digital revolution projects," *International Journal of Managing Projects in Business*, vol. 9, 2019.
- [261] L. Klerkx, E. Jakku, and P. Labarthe, "A review of social science on digital agriculture, smart farming and agriculture 4.0: new contributions and a future research agenda," *NJAS-Wageningen Journal of Life Sciences*, vol. 90, 2019.
- [262] P. O. Skobelev, E. V. Simonova, S. V. Smirnov, D. S. Budaeva, G. Y. Voshchuk, and A. L. Morokovd, "Development of a knowledge base in the smart farming system for agricultural enterprise management," *Procedia Computer Science*, vol. 150, pp. 154–161, 2019.
- [263] I. Kovács and I. Husty, "The role of digitalization in the agricultural 4.0-how to connect the industry 4.0 to agriculture?" *Hungarian Agricultural Engineering*, vol. 7410, no. 33, pp. 38–42, 2018.
- [264] M. De Clercq, A. Vats, and A. Biel, "Agriculture 4.0: the future of farming technology," 2018.
- [265] Z. Zhai, J. F. Martínez, V. Beltran, and N. L. Martínez, "Decision support systems for agriculture 4.0: survey and challenges," *Computers and Electronics in Agriculture*, vol. 170, pp. 1–16, 2020.
- [266] L. Klerkx and D. Rose, "Dealing with the game-changing technologies of Agriculture 4.0: how do we manage diversity and responsibility in food system transition pathways?" *Global Food Security*, vol. 24, pp. 1–7, 2020.
- [267] P. K. Thornton, P. Kristjanson, W. Förch, C. Barahona, L. Cramer, and S. Pradhan, "Is agricultural adaptation to global change in lower-income countries on track to meet the future food production challenge?" *Global Environmental Change*, vol. 52, pp. 37–48, 2018.
- [268] A. Luque, M. E. Peralta, A. de las Heras, and A. Córdoba, "State of the industry 4.0 in the andalusian food sector," *Procedia Manufacturing*, vol. 13, pp. 1199–1205, 2017.
- [269] S. Saetta and V. Caldarelli, "How to increase the sustainability of the agri-food supply chain through innovations in 4.0 perspective: a first case study analysis," *Procedia Manufacturing*, vol. 42, pp. 333–336, 2020.
- [270] N. Shahrubudina, T. C. Leea, and R. Ramlana, "An overview on 3D printing technology: technological, materials, and technology: applications," *Procedia Manufacturing*, vol. 35, pp. 1286–1296, 2019.
- [271] C. He, M. Zhang, and Z. Fang, "3D printing of food: pre-treatment and post-treatment of materials," *Critical Reviews in Food Science and Nutrition*, vol. 35, pp. 1–14, 2019.
- [272] J. L. Tran, "3D-Printed food," *Minnesota Journal of Law, Science & Technology*, vol. 17, no. 2, pp. 1–27, 2016.
- [273] Rural Industries Research & Development Corporation, "3D printing: a fact sheet series on new and emerging transformative technologies in australian agriculture," 2016.
- [274] DeltaHedron, *The Impact of Emerging Technologies on Agriculture: Recent Trends*, Hull HU1 1UU, London, UK, 2019.
- [275] F. C. Godoi, S. Prakash, and P. B. R. Bhandari, "3d printing technologies applied for food design: status and prospects," *Journal of Food Engineering*, vol. 17, pp. 1–27, 2016.
- [276] M. Javaid and A. Haleem, "Using additive manufacturing applications for design and development of food and agricultural equipments," *International Journal of Materials and Product Technology*, vol. 58, no. 2/3, pp. 225–238, 2019.
- [277] P. Phupattanasilp and S. Tong, "Augmented reality in the integrative internet of things (AR-IoT): application for precision farming," *Sustainability*, vol. 11, no. 2658, 2019.
- [278] J. M. Pearce, "Applications of open source 3-D printing on small farms," *Organic Farming*, vol. 1, no. 1, pp. 19–35, 2015.
- [279] K. Jha, A. Doshi, P. Patel, and M. Shah, "A comprehensive review on automation in agriculture using artificial intelligence," *Artificial Intelligence in Agriculture*, vol. 2, pp. 1–12, 2019.
- [280] Deloitte, "Transforming agriculture through digital technologies," 2020.
- [281] H. Tian, T. Wang, Y. Liu, X. Qiao, and Y. Li, "Computer vision technology in agricultural automation-a review," *Information Processing in Agriculture*, vol. 7, no. 1, pp. 1–19, 2020.
- [282] AI Forum of New Zealand and AsureQuality, "Artificial intelligence for agriculture in New Zealand," 2019.
- [283] M. J. Smith, "Getting value from artificial intelligence in agriculture," *Animal Production Science*, vol. 60, no. 1, pp. 46–54, 2020.
- [284] OECD, *Artificial Intelligence in Society*, Springer, Paris, France, 2019.
- [285] A. Gurumurthy and D. Bharthur, *Taking Stock of Artificial Intelligence in Indian Agriculture*, Springer, New Delhi, India, 2019.
- [286] S. G. Salcedo, *Artificial Intelligence in Digital Agriculture Towards in Field Grapevine Monitoring Using Non-invasive Sensors*, University of La Rioja, New Delhi, India, 2019.
- [287] V. Dharmaraj and C. Vijayanand, "Artificial intelligence (AI) in agriculture," *International Journal of Current Microbiology and Applied Sciences*, vol. 7, no. 12, pp. 2122–2128, 2018.
- [288] M. Xi, M. Adcock, and O. McCulloch, "Future agriculture farm management using augmented reality," in *Proceedings of the IEEE Workshop On Virtual And Augmented Realities For Good*, pp. 1–3, New York, NY, USA, 2018.
- [289] M. Caria, G. Sara, G. Todde, M. Polese, and A. Pazzona, "Exploring smart glasses for augmented reality: a valuable and integrative tool in precision livestock farming," *Animals*, vol. 9, 2019.
- [290] A. Katsaros, E. Keramopoulos, and M. Salampasis, "A prototype Application for cultivation optimization using augmented reality," in *Proceedings of the 8th International Conference on Information and Communication Technologies in Agriculture*, pp. 805–811, London, UK, 2017.
- [291] B. Weichelt, A. Yoder, C. Bendixsen, M. Pilz, G. Minor, and M. Keifer, "Augmented reality farm MAPPER development: lessons learned from an app designed to improve rural emergency response," *Journal of Agromedicine*, vol. 23, no. 3, pp. 284–296, 2018.
- [292] J. Huuskonen and T. Oksanen, "Soil sampling with drones and augmented reality in precision agriculture," *Computers and Electronics in Agriculture*, vol. 154, pp. 25–35, 2018.
- [293] Y. Huang, Z.-X. Chen, T. Yu, X.-Z. Huang, and X.-F. Gu, "Agricultural remote sensing big data: management and

- applications,” *Journal of Integrative Agriculture*, vol. 17, no. 9, pp. 1915–1931, 2018.
- [294] K. Prasad, “Big data in the bigger world of agriculture today,” *IEEE India Info*, vol. 14, no. 3, pp. 154–157, 2019.
- [295] N. Tantalaki, S. Souravlas, and M. Roumeliotis, “Data-Driven decision making in precision agriculture: the rise of big data in agricultural systems data-driven decision making in precision Agriculture,” *Journal of Agricultural & Food Information*, vol. 14, pp. 1–37, 2019.
- [296] C. C. Sekhar, J. U. Kumar, B. K. Kumar, and C. Sekhar, “Effective use of big data analytics in crop planning to increase agriculture production in India,” *International Journal of Advanced Science and Technology*, vol. 113, pp. 31–40, 2018.
- [297] T. Guo and Y. Wang, “Big data application issues in the agricultural modernization of China,” *Ekoloji*, vol. 28, no. 107, pp. 3677–3688, 2019.
- [298] J. A. Delgado, D. P. Roberts, and B. Vandenberg, “Big data analysis for sustainable agriculture on a geospatial cloud framework,” *Frontiers in Sustainable Food Systems*, vol. 3, no. 54, pp. 1–13, 2019.
- [299] K. H. Coble, A. K. Mishra, and S. Ferrell, “Big data in agriculture: a challenge for the future,” *Applied Economic Perspectives and Policy*, vol. 40, no. 1, pp. 79–96, 2018.
- [300] FAO and ITU, *E-Agriculture in Action: Big Data for Agriculture*, Springer, Bangkok, Thailand, 2019.
- [301] N. Griffin, D. Northrup, S. Murray, and T. C. Mockler, “Big data driven agriculture: big data analytics in plant breeding, genomics, and the use of remote sensing technologies to advance crop productivity,” *The Plant Phenome Journal*, vol. 2, 2019.
- [302] C. Zhang and Z. Liu, “Application of big data technology in agricultural Internet of Things,” *International Journal of Distributed Sensor Networks*, vol. 15, no. 10, pp. 1–11, 2019.
- [303] V. S. Yadav and A. R. Singh, “A systematic literature review of blockchain technology in agriculture,” in *Proceedings of the International Conference on Industrial Engineering and Operations Management*, pp. 973–981, New York, NY, USA, 2019.
- [304] V. S. Yadav and A. R. Singh, “Use of blockchain to solve select issues of Indian farmers,” *AIP Conference Proceedings*, vol. 2148, 2019.
- [305] H. Xiong, T. Dalhaus, P. Wang, and J. Huang, “Blockchain technology for agriculture: applications and rationale,” *Frontiers in Blockchain*, vol. 3, no. 7, 2020.
- [306] A. D. Nazarov, V. V. Shvedov, and V. V. S. Ural, “Blockchain technology and smart contracts in the agro-industrial complex of Russia Blockchain technology and smart contracts in the agro- industrial complex of Russia,” *IOP Conference Series: Earth and Environmental Science*, vol. 315, 2019.
- [307] M. Mattern, “Exploring blockchain applications to agricultural finance,” 2018.
- [308] G. Sylvester, “E-agriculture in Action: Blockchain for Agriculture, Opportunities and Challenges,” 2019.
- [309] T. Surasak, N. Wattanavichean, C. Preuksakarn, and S. C. Huang, “Thai agriculture products traceability system using blockchain and internet of things,” *International Journal of Advanced Computer Science and Applications*, vol. 10, no. 9, pp. 578–583, 2019.
- [310] J. Lin, A. Zhang, Z. Shen, and Y. Chai, “Blockchain and IoT based food traceability for smart agriculture,” in *Proceedings of the 3rd International Conference on Crowd Science And Engineering*, pp. 1–6, Singapore, 2018.
- [311] G. Mirabelli and V. Solina, “Blockchain and agricultural supply chains traceability: research trends and future challenges,” *Procedia Manufacturing*, vol. 42, pp. 414–421, 2020.
- [312] S. S. Kamble, A. Gunasekaran, and R. Sharma, “Modeling the blockchain enabled traceability in agriculture supply chain,” *International Journal of Information Management*, vol. 42, pp. 1–16, 2019.
- [313] C. Addison, I. Boto, T. Heinen, and K. Lohento, “Opportunities of blockchain for agriculture of blockchain for agriculture,” 2019.
- [314] M. Tripoli and J. Schmidhuber, “Emerging opportunities for the application of blockchain in the agri-food industry,” 2018.
- [315] D. Mao, Z. Hao, F. Wang, and H. Li, “Innovative blockchain-based approach for sustainable and credible environment in food trade: a case study in shandong province, China,” *Sustainability*, vol. 10, p. 3149, 2018.
- [316] V. Micalé and H. Van Caenegem, “Blockchain climate risk crop insurance,” 2019.
- [317] A. Kamilaris, A. Fonts, and F. X. Prenafeta-Bold , “The rise of blockchain technology in agriculture and food supply chains,” *Trends in Food Science & Technology*, vol. 91, pp. 640–652, 2019.
- [318] D. Zhang, “Application of blockchain technology in incentivizing efficient use of rural wastes: a case study on yitong system,” *Energy Procedia*, vol. 158, pp. 6707–6714, 2019.
- [319] F. Yang, K. Wang, Y. Han, and Z. Qiao, “A cloud-based digital farm management system for vegetable production process management and quality traceability,” *Sustainability*, vol. 10, 2018.
- [320] E. M. Emeana, L. Trenchard, and K. Dehnen-schmutz, “The revolution of mobile phone-enabled services for agricultural development (m-Agri services) in Africa: the challenges for sustainability,” *Sustainability*, vol. 12, no. 485, 2020.
- [321] S. Singh, I. Chana, and R. Buyya, “Agri-info: cloud based autonomic system for delivering agriculture as a service,” *Internet of Things*, vol. 1–18, 2019.
- [322] V. Anandhi and J. P. Venkatapirabu, “Cloud computing-an innovative initiative for technology transfer,” *International Journal of Current Microbiology and Applied Sciences*, vol. 9, no. 3, pp. 645–647, 2020.
- [323] J. Joshi, “Machine learning based cloud integrated farming,” *ICMLSC '17*, vol. 13–16, 2017.
- [324] S. M. Alam, A. Hasssan, A. Bashir, and M. Iqbal, “Smart tunnel farming model: an inculcation of cloud computing with cortex for reliable agricultural production,” *International Journal of Sensor Networks and Data Communications*, vol. 7, no. 4, pp. 1–11, 2018.
- [325] U. R. Mogili and B. B. V. L. Deepak, “Review on application of drone systems in precision agriculture,” *Procedia Computer Science*, vol. 133, pp. 502–509, 2018.
- [326] P. Diamantoulakis, “Internet of things (IoT) and agricultural unmanned aerial vehicles (UAVS) in smart farming: a comprehensive review,” *Internet of Things*, vol. 1–43, 2020.
- [327] J. V. N. Nakshmi, K. S. Hemanth, and J. Bharath, “Optimizing quality and outputs by improving variable rate prescriptions in agriculture using UAVs,” *Procedia Computer Science*, vol. 167, pp. 1981–1990, 2020.
- [328] PwC Belgium and Agoria, “A drone’s eye view: overview of the belgian uav ecosystem & the development of commercial drone application in Belgium,” 2018.
- [329] A. Brown, “Agri-drones in China: market status and growth potential,” 2017.

- [330] PwC, "Clarity from above: PwC global report on the commercial applications of drone technology," 2016.
- [331] P. Daponte, "A review on the use of drones for precision agriculture A review on the use of drones for precision agriculture," *IOP Conference Series: Earth and Environmental Science*, vol. 275, 2019.
- [332] L. Probst, B. Pedersen, and L. Dakkak-Arnoux, "Digital transformation monitor: drones in agriculture," 2018.
- [333] D. C. Tsouros, S. Bibi, and P. G. Sarigiannidis, "A review on UAV-based applications for precision agriculture," *Information*, vol. 10, no. 349, 2019.
- [334] S. Ahirwar, R. Swarnkar, S. Bhukya, and G. Namwade, "Application of drone in agriculture," *International Journal of Current Microbiology and Applied Sciences*, vol. 8, no. 1, pp. 2500–2505, 2019.
- [335] K. R. Krishna, *Agricultural Drones: A Peaceful Pursuit*, Apple Academic Press, Oakville, OA, USA, 2018.
- [336] I. A. Joiner, "Drones : agriculture's new best friend!" *Modern Concepts & Developments in Agronomy*, vol. 1, no. 4, pp. 62-63, 2018.
- [337] P. Frankelius, C. Norrman, and K. Johansen, "Agricultural innovation and the role of institutions: lessons from the game of drones," *Journal of Agricultural and Environmental Ethics*, vol. 1, pp. 1–27, 2017.
- [338] D. K. Giles and R. C. Billing, "Deployment and performance of a UAV for crop spraying," *Chemical Engineering Transactions*, vol. 44, pp. 307–312, 2015.
- [339] S. Kanase, S. Patwegar, P. Patil, A. Pore, and Y. Kadam, "Agriculture drone sprayer," *International Journal of Recent Trends in Engineering & Research*, vol. 4, no. 3, pp. 181–185, 2018.
- [340] G. Sylvester, "E-agriculture in action: drones for agriculture," 2018.
- [341] A. Villa-Henriksen, G. T. C. Edwards, L. A. Pesonen, and O. Green, "Internet of Things in arable farming: implementation, applications, challenges and potential," *Bio-systems Engineering*, vol. 191, pp. 60–84, 2020.
- [342] O. Sørensen, T. A. Rahman, I. Orikumhi, C. Y. Leow, and M. H. D. N. Hindia, "An overview of internet of things (IoT) and data analytics in agriculture: benefits and challenges," *IEEE Internet of Things Journal*, vol. 5, no. 5, pp. 3758–3773, 2018.
- [343] P. P. Ray, "Internet of things for smart agriculture: technologies, practices and future direction," *Journal of Ambient Intelligence and Smart Environments*, vol. 9, no. 4, pp. 395–420, 2017.
- [344] A. Srilakshmi, J. Rakkini, K. R. Sekar, and R. Manikandan, "A comparative study on internet of things (IoT) and its applications in smart agriculture," *Pharmacognosy Journal*, vol. 10, no. 2, pp. 260–264, 2018.
- [345] A. Pathak, M. Amazuddin, M. J. Abedin, K. Andersson, R. Mustafa, and M. S. Hossain, "IoT based smart system to support agricultural parameters: a case study," *Procedia Computer Science*, vol. 155, pp. 648–653, 2019.
- [346] M. Ayaz, S. Member, and M. A. S. Member, "Internet-of-Things (IoT) based smart Agriculture: towards making the fields talk," *IEEE Access Date*, vol. xx, pp. 1–34, 2019.
- [347] L. Zhang and I. K. Dabipi, "Internet of Things Applications for Agriculture," John Wiley & Sons, London, UK, 2018.
- [348] R. Dhall and H. Agrawal, "An improved energy efficient duty cycling algorithm for IoT based precision agriculture," *Procedia Computer Science*, vol. 141, pp. 135–142, 2018.
- [349] K. Gunasekera, A. N. Borrero, F. Vasuian, and K. P. Bryceson, "Experiences in building an IoT infrastructure for agriculture education," *Procedia Computer Science*, vol. 135, pp. 155–162, 2018.
- [350] S. K. Roy and D. De, "Genetic algorithm based internet of precision agricultural things (IoPAT) for agriculture 4.0," *Internet of Things*, vol. 1–19, 2020.
- [351] D. Thakur, Y. Kumar, and S. Vijendra, "Smart irrigation and intrusions detection in agricultural field using IoT," *Procedia Computer Science*, vol. 167, pp. 154–162, 2020.
- [352] R. Zhang, F. Hao, and X. Sun, "The design of agricultural machinery service management system based on internet of things," *Procedia Computer Science*, vol. 107, pp. 53–57, 2017.
- [353] C. Parisi, M. Vigani, and E. Rodríguez-Cerezo, "Agricultural Nanotechnologies: what are the current possibilities?" *Nano Today*, vol. 10, no. 2, pp. 124–127, 2015.
- [354] H. N. Cheng, K. T. Klasson, T. Asakura, and Q. Wu, "Nanotechnology in Agriculture," American Chemical Society, Washington, DC, USA, 2016.
- [355] R. Prasad, A. Bhattacharyya, and Q. D. Nguyen, "Nanotechnology in sustainable agriculture: recent developments, challenges, and perspectives," *Frontiers in Microbiology*, vol. 8, no. 1014, 2017.
- [356] A. Elizabeth, M. Babychan, A. M. Mathew, and G. M. Syriac, "Application of nanotechnology in agriculture," *International Journal of Pure & Applied Bioscience*, vol. 7, no. 2, pp. 131–139, 2019.
- [357] D.-Y. Kim, A. Kadam, S. Shinde, R. G. Saratale, and J. Patra, "Recent developments in nanotechnology transforming the agricultural sector: a transition replete with opportunities," *Journal of the Science of Food and Agriculture*, vol. 98, no. 3, pp. 849–864, 2018.
- [358] Y. Ghodake, K. Hasan, G. J. Ahammed, M. Li, and H. Yin, "Applications of nanotechnology in plant growth and crop protection: a review," *Molecules*, vol. 24, no. 2558, 2019.
- [359] N. Ndlovu, T. Mayaya, C. Muitire, and N. Munyengwa, "Nanotechnology applications in crop production and food systems," *International Journal of Plant Breeding and Crop Science*, vol. 7, no. 1, pp. 624–634, 2020.
- [360] L. Marchiol, "Nanotechnology in agriculture: new opportunities and perspectives," IntechOpen, London, UK, 2018.
- [361] X. He, H. Deng, and H. Hwang, "The current application of nanotechnology in food and agriculture," *Journal of Food and Drug Analysis*, vol. 27, pp. 1–21, 2018.
- [362] R. A. Taha, "Nanotechnology and its application in agriculture," *Advances in Plants & Agriculture Research*, vol. 3, no. 2, p. 15406, 2016.
- [363] S. Thakur, S. Thakur, and R. Kumar, "Bio-nanotechnology and its role in agriculture and food industry," *Journal of Molecular and Genetic Medicine*, vol. 12, no. 1, pp. 1–5, 2018.
- [364] I. Iavicoli, V. Leso, D. H. Beezhold, and A. A. Shvedova, "Nanotechnology in agriculture: opportunities, toxicological implications, and occupational risks," *Toxicol Appl Pharmacol*, vol. 329, pp. 96–111, 2019.
- [365] H. Joshi, P. Choudhary, and S. L. Mundra, "Future prospects of nanotechnology in agriculture," *International Journal of Chemical Studies*, vol. 7, no. 2, pp. 957–963, 2019.
- [366] A. Y. Ghidan and T. M. Al Antary, "Applications of nanotechnology in agriculture," IntechOpen, London, UK, 2019.
- [367] S. Mishra, C. Keswani, P. C. Abhilash, L. F. Fraceto, and H. B. Singh, "Integrated approach of agri-nanotechnology: challenges and future trends," *Frontiers in Plant Science*, vol. 8, no. 471, 2017.

- [368] D. G. Panpatte, *Nanotechnology for Agriculture: Crop Production & Protection*, Springer Nature Singapore Pte Ltd, Singapore, 2019.
- [369] S. Ali, O. Shafique, T. Mahmood, M. A. Hanif, I. Ahmed, and B. A. Khan, "A review about perspectives of nanotechnology in agriculture," *Pakistan Journal of Agricultural Research*, vol. 30, no. 2, pp. 116–121, 2018.
- [370] Y. Xiao, S. C. Jiang, X. Wang, T. Muhammad, P. Song, and B. Zhou, "Mitigation of biofouling in agricultural water distribution systems with nanobubbles," *Environment International*, vol. 141, pp. 1–12, 2020.
- [371] I. Chung, G. Rajakumar, T. Gomathi, S. Kim, and M. Thiruvengadam, "Nanotechnology for human food: advances and perspective," *Frontiers in Life Science*, vol. 3769, no. 10, pp. 63–72, 2017.
- [372] R. R. Shamshiri, "Research and development in agricultural robotics: a perspective of digital farming," *International Journal of Agricultural and Biological Engineering*, vol. 11, no. 4, pp. 1–14, 2018.
- [373] K. R. Aravind, P. Raja, and M. Pérez-ruiz, "Task-based agricultural mobile robots in arable farming: a review," *Spanish Journal of Agricultural Research*, vol. 15, no. 1, pp. 1–16, 2017.
- [374] D. Zhang, "Robotics and mechatronics for agriculture," CRC Press Taylor & Francis Group, Boca Raton, MA, USA, 2018.
- [375] S. G. Vougioukas, "Agricultural robotics," *Annual Review of Control, Robotics, and Autonomous Systems*, vol. 2, no. 1, pp. 365–392, 2019.
- [376] M. Mitra, "Robotic farmers in agriculture *Advances in Robotics & Mechanical Engineering*, vol. 1, no. 5, pp. 91–93, 2019.
- [377] B. L. Steward, J. Gai, and L. Tang, "The use of agricultural robots in weed management and control," *Robotics and automation for improving agriculture*, vol. 44, pp. 1–25, 2019.
- [378] D. Albiero, "Agricultural robotics: a promising challenge," *Current Agriculture Research Journal*, vol. 7, no. 1, 2019.
- [379] A. Bechar and C. Vigneault, "Agricultural robots for field operations: concepts and components," *Biosystems Engineering*, vol. 149, pp. 94–111, 2016.
- [380] M. G. Lampridi, "A case-based economic assessment of robotics employment in precision arable farming," *Agronomy*, vol. 9, no. 175, 2019.
- [381] A. Proskokov, M. Momot, and D. N. Nesteruk, "Prospects and features of robotics in Russian crop farming," *Journal of Physics: Conference Series*, vol. 803, 2017.
- [382] UK-RAS Network, "Agricultural robotics: the future of robotic agriculture," 2018.
- [383] J. W. Jones, "Brief history of agricultural systems modeling," *Agricultural Systems*, vol. 155, pp. 240–254, 2016.
- [384] K. O. Rauff and R. Bello, "A review of crop growth simulation models as tools for agricultural meteorology," *Agricultural Sciences*, vol. 6, no. 9, pp. 1098–1105, 2015.
- [385] M. I. Khan and D. Walker, "Application of crop growth simulation models in agriculture with special reference to water management planning," *International Journal Of Core Engineering & Management*, vol. 2, no. 5, pp. 113–130, 2015.
- [386] J. Van Wart, P. Grassini, H. Yang, L. Claessens, A. Jarvis, and K. G. Cassman, "Creating long-term weather data from thin air for crop simulation modeling," *Agricultural and Forest Meteorology*, vol. 209–210, pp. 49–58, 2015.
- [387] A. K. Moghaddam, H. Sadrnia, H. Aghel, and M. Bannayan, "Optimization of tillage and sowing operations using discrete event simulation," *Research in Agricultural Engineering*, vol. 64, no. 4, pp. 187–194, 2018.
- [388] X. Bai, H. Yan, L. Pan, and H. Huang, "Multi-agent modeling and simulation of farmland use change in a farming-pastoral zone: a case study of qianjingou town in inner Mongolia, China," *Sustainability*, vol. 7, no. 11, pp. 14802–14833, 2015.
- [389] FAO, "A modelling system for the assessment of the agricultural impacts of climate change," 2015.
- [390] E. T. Wurtzel, "Revolutionizing agriculture with synthetic biology," *Nature Plants*, vol. 7, pp. 1–15, 2019.
- [391] Rural Industries Research & Development Corporation, *Synthetic Biology: Transformative Technologies*, Wagga Wagga NSW, New York, NY, USA, 2016.
- [392] E. W. Welch, M. Bagley, and T. Kuiken, "Potential implications of new synthetic biology and genomic research trajectories on the international treaty for plant genetic resources for food and agriculture (ITPGRFA or treaty)," 2017.
- [393] L. J. Frewer, D. Coles, A. M. Dijkstra, S. Kuznesof, H. Kendall, and G. Kaptan, "Synthetic biology applied in the agrifood sector: societal priorities and pitfalls," *Applied Studies in Agribusiness and Commerce*, vol. 10, no. 2-3, pp. 89–95, 2016.
- [394] K. V. Pixley and K. E. Giller, "Genome editing, gene drives, and synthetic biology: will they contribute to disease-resistant crops, and who will benefit?" *Annual Review of Phytopathology*, vol. 57, no. 1, pp. 165–188, 2019.
- [395] H. Falck-Zepeda, G. R. Szilvay, and K.-M. Oksman-Caldentey, "Cellular agriculture-industrial biotechnology for food and materials," *Current Opinion in Biotechnology*, vol. 61, pp. 128–134, 2020.
- [396] H. D. Goold, P. Wright, and D. Hailstones, "Emerging opportunities for synthetic biology in agriculture," *Genes*, vol. 341, no. 9, pp. 1–17, 2018.
- [397] V. De Lorenzo, "The power of synthetic biology for biotechnology on a global scale," *EMBO Reports*, vol. 19, 2018.
- [398] M. U. Rehman, A. E. Andargoli, and H. Pousti, "Healthcare 4.0: Trends, Challenges and Benefits," *Australasian Conference on Information Systems*, vol. 19, pp. 556–564, 2019.
- [399] X. Larrucea, M. Moff, S. Asaf, and I. Santamaria, "Towards a GDPR compliant way to secure European cross border Healthcare," *Computer Standards & Interfaces*, vol. 69, pp. 1–7, 2020.
- [400] M. Javaid and A. Haleem, "Industry 4.0 applications in medical field: a brief review," *Current Medicine Research and Practice*, vol. 9, no. 3, pp. 102–109, 2019.
- [401] M. Javaid and A. Haleem, "Impact of industry 4.0 to create advancements in orthopaedics," *Journal of Clinical Orthopaedics and Trauma*, vol. 19, pp. 1–8, 2020.
- [402] G. L. Tortorella, "Effects of contingencies on healthcare 4.0 technologies adoption and barriers in emerging economies," *Technological Forecasting & Social Change*, vol. 156, pp. 1–11, 2020.
- [403] S. Tanwar, K. Parekh, and R. Evans, "Blockchain-based electronic healthcare record system for healthcare 4.0 applications," *Journal of Information Security and Applications*, vol. 50, pp. 1–13, 2020.
- [404] P. P. Jayaraman, A. R. M. Forkan, A. Morshed, P. D. Haghghi, and Y.-B. Kang, "Healthcare 4.0: A Review of Frontiers in Digital Health," *WIREs Data Mining Knowledge Discovery*, vol. 19, 2019.
- [405] J. J. Hathaliya, S. Tanwar, S. Tyagi, and N. Kumar, "Securing electronics healthcare records in Healthcare 4.0: a biometric-based approach," *Computers & Electrical Engineering*, vol. 76, pp. 398–410, 2019.

- [406] I. Albarki, M. Rasslan, A. M. Bahaa-eldin, and M. Sobh, "Robust hybrid-security protocol for HealthCare systems," *Procedia Computer Science*, vol. 160, pp. 843–848, 2019.
- [407] M. Haddara and A. Staaby, "RFID applications and adoptions in healthcare: a review on patient safety," *Procedia Computer Science*, vol. 138, pp. 80–88, 2018.
- [408] World Health Organization, "WHO Guideline: Recommendations for Health System Interventions on Digital Strengthening," 2019.
- [409] A. Mavrogiorgou, A. Kiourtis, K. Perakis, D. Miltiadou, S. Pitsios, and D. Kyriazis, "Computer Methods and Programs in Biomedicine," *Computer Methods and Programs in Biomedicine*, vol. 19, pp. 1–10, 2019.
- [410] A. Abugabah, N. Nizamuddin, and A. Abuqabbeh, "A review of challenges and barriers implementing RFID technology in the Healthcare sector," *Procedia Computer Science*, vol. 170, pp. 1003–1010, 2020.
- [411] K. Tiwari, S. Kumar, and R. K. Tiwari, "FOG assisted healthcare architecture for pre-operative support to reduce latency," *Procedia Computer Science*, vol. 167, pp. 1312–1324, 2020.
- [412] A. A. Mutlag, M. Khanapi, A. Ghani, N. Arunkumar, and M. A. Mohamed, "Enabling Technologies for Fog Computing in Healthcare IoT Systems," *Future Generation Computer Systems*, vol. 19, pp. 1–38, 2018.
- [413] P. P. Ray, D. Dash, and D. De, "Edge computing for Internet of Things: a survey, e-healthcare case study and future direction," *Journal of Network and Computer Applications*, vol. 140, pp. 1–22, 2019.
- [414] T. Aladwani, "Scheduling IoT healthcare tasks in fog computing based on their importance," *Procedia Computer Science*, vol. 163, pp. 560–569, 2019.
- [415] J. J. Hathaliya and S. Tanwar, "An exhaustive survey on security and privacy issues in Healthcare 4.0," *Computer Communications*, vol. 153, pp. 311–335, 2020.
- [416] A. Kumari, S. Tanwar, S. Tyagi, and N. Kumar, "Fog computing for Healthcare 4.0 environment: opportunities and challenges," *Computers & Electrical Engineering*, vol. 72, pp. 1–13, 2018.
- [417] C. Chen, E. Loh, K. N. Kuo, and K. Tam, "The times they are a-changin' -healthcare 4.0 is coming!" *Journal of Medical Systems*, vol. 44, no. 40, 2020.
- [418] M. Rosa, C. Faria, A. M. Barbosa, H. Caravau, A. F. Rosa, and N. P. Rocha, "A fast healthcare interoperability resources (FHIR) implementation integrating complex security mechanisms," *Procedia Computer Science*, vol. 164, pp. 524–531, 2019.
- [419] F. Hak, D. Oliveira, N. Abreu, P. Leuschner, A. Abelha, and M. Santos, "An OpenEHR adoption in a Portuguese healthcare facility," *Procedia Computer Science*, vol. 170, pp. 1047–1052, 2020.
- [420] S. K. Mukhiya, F. Rabbi, V. K. I Pun, A. Rutle, and Y. Lamo, "A GraphQL approach to healthcare information exchange with HL7 FHIR," *Procedia Computer Science*, vol. 160, pp. 338–345, 2019.
- [421] J. Wu, Y. Wang, L. Tao, and J. Peng, "Stakeholders in the healthcare service ecosystem," *Procedia CIRP*, vol. 83, pp. 375–379, 2019.
- [422] G. Aceto, V. Persico, and A. Pescap, "Industry 4.0 and health: internet of things, big data, and cloud computing for healthcare 4.0," *Journal of Industrial Information Integration*, vol. 19, pp. 1–14, 2020.
- [423] B. Feng, P. He, P. Li, H. Yao, Y. Ji, and J. He, "Developing a smart healthcare framework with an Aboriginal lens," *Procedia Computer Science*, vol. 162, pp. 347–354, 2019.
- [424] A. Papa, M. Mital, P. Pisano, and M. Del Giudice, "E-health and wellbeing monitoring using smart healthcare devices: an empirical investigation," *Technological Forecasting & Social Change*, vol. 19, pp. 1–10, 2018.
- [425] M. Barad, "Linking cyber security improvement actions in healthcare systems to their strategic improvement needs," *Procedia Manufacturing*, vol. 39, pp. 279–286, 2019.
- [426] N. W. S. Chew, "A multinational, multicentre study on the psychological outcomes and associated physical symptoms amongst healthcare workers during COVID-19 outbreak," *Brain Behavior and Immunity*, vol. 19, pp. 1–7, 2020.
- [427] S. Buckrell and S. A. McNeil, "Sources of viral respiratory infections in Canadian acute care hospital healthcare personnel," *Journal of Hospital Infection*, vol. 104, no. 4, pp. 513–521, 2020.
- [428] R. Coleman, "COVID-19 and the role of 3D printing in medicine," *3D Printing in Medicine*, vol. 6, no. 11, pp. 1–8, 2020.
- [429] Q. Yan and J. Su, "A review of 3D printing technology for medical applications," *Engineering*, vol. 4, no. 5, pp. 729–742, 2018.
- [430] E. J. Dong, "3D printing in healthcare: emerging applications," *Journal of Hospital Librarianship*, vol. 16, no. 3, pp. 255–267, 2016.
- [431] Medical Manufacturing Innovations, "Medical Additive Manufacturing/3D Printing: Annual Report," 2018.
- [432] H. Dodziuk, "Applications of 3D printing in healthcare," *Polish Journal of Cardio-Thoracic Surgery*, vol. 3, no. 3, pp. 283–293, 2016.
- [433] A. Christensen and F. J. Rybicki, "Maintaining safety and efficacy for 3D printing in medicine," *3D Printing in Medicine*, vol. 3, no. 1, pp. 1–10, 2017.
- [434] L. E. Diment, M. S. Thompson, and J. H. M. Bergmann, "Clinical efficacy and effectiveness of 3D printing: a systematic review," *BMJ Open*, vol. 7, 2017.
- [435] A. Aimar, A. Palermo, and B. Innocenti, "The role of 3D printing in medical applications: a state of the art," *Journal of Healthcare Engineering*, vol. 2019, 2019.
- [436] World Economic Forum, *3D Printing: A Guide for Decision-Makers*, Cologny, Geneva, Switzerland, 2020.
- [437] P. Ahangar, M. E. Cooke, M. H. Weber, and D. H. Rosenzweig, "Current biomedical applications of 3D printing and additive manufacturing," *Applied Sciences*, vol. 9, 2019.
- [438] S. Sharma and S. A. Goel, "Three-dimensional printing and its future in medical world," *Journal of Medical Research and Innovation*, vol. 3, no. 1, pp. 1–8, 2019.
- [439] S. J. Trenfield, "Shaping the future: recent advances of 3D printing in drug delivery and healthcare," *Expert Opinion on Drug Delivery*, vol. 3, pp. 1–14, 2019.
- [440] P. Ravi, "Understanding the relationship between slicing and measured fill density in material extrusion 3D printing towards precision porosity constructs for biomedical and pharmaceutical applications," *3D Printing in Medicine*, vol. 6, no. 10, pp. 1–10, 2020.
- [441] F. Jiang, H. Zhi et al., "Artificial intelligence in healthcare: past, present and future," *Stroke and Vascular Neurology*, vol. 2, no. 4, pp. 230–243, 2017.
- [442] F. Jiang, "Artificial Intelligence in Healthcare Table of Contents Abbreviations," 2018.

- [443] A. J. Mason, A. Morrison, and S. Visintini, *An Overview of Clinical Applications of Artificial Intelligence*, CADTH, Ottawa, OA, USA, 2018.
- [444] T. Davenport and R. Kalakota, "The potential for artificial intelligence in healthcare," *Future Healthcare Journal*, vol. 6, no. 2, pp. 94–98, 2019.
- [445] N. Noorbakhsh-sabet, R. Zand, Y. Zhang, and V. Abedi, "Artificial intelligence transforms the future of health care," *The American Journal of Medicine*, vol. 132, no. 7, pp. 795–801, 2019.
- [446] N. Deloitte, "The future of artificial intelligence in health care: how ai will impact patients, clinicians, and the pharmaceutical industry," 2019.
- [447] Pure Storage, "AI in Healthcare: Building the Foundation," 2019.
- [448] Academy of Medical Royal Colleges, "Artificial Intelligence in Healthcare," 2019.
- [449] M. Bonham, "Augmented reality simulation toward improving therapeutic healthcare communication techniques," in *Proceedings of the 24th International Conference on Intelligent User Interfaces (IUI' 19 Companion)*, pp. 19–20, Marina del Rey, CA, USA, 2019.
- [450] J. Gerup, C. B. Soerensen, and P. Dieckmann, "Augmented reality and mixed reality for healthcare education beyond surgery: an integrative review," *International Journal of Medical Education*, vol. 11, no. 1, pp. 1–18, 2020.
- [451] D. S. Lopes and J. A. Jorge, "Extending medical interfaces towards virtual reality and augmented reality," *Annals of Medicine*, vol. 51, no. 1, p. 29, 2019.
- [452] J. Herron, "Augmented reality in medical education and training," *Journal of Electronic Resources in Medical Libraries*, vol. 13, no. 2, pp. 51–55, 2016.
- [453] M. Eckert, J. S. Volmerg, C. M. Friedrich, and C. M. Friedrich, "Augmented reality in medicine: systematic and bibliographic review," *JMIR Mhealth Uhealth*, vol. 7, no. 4, pp. 1–17, 2019.
- [454] N. Wake, "Patient-specific 3D printed and augmented reality kidney and prostate cancer models: impact on patient education," *3D Printing in Medicine*, vol. 5, no. 4, pp. 1–8, 2019.
- [455] P. Katkin, K. H. Onkka, T. Moyer, and D. P. Goel, "Virtual and augmented reality best practices for healthcare," 2018.
- [456] L. N. Lee, M. J. Kim, and W. J. Hwang, "Potential of augmented reality and virtual reality technologies to promote wellbeing in older adults," *Applied Sciences*, vol. 9, no. 3556, pp. 1–17, 2019.
- [457] V. Ferrari, G. Klinker, and F. Cutolo, "Augmented reality in healthcare," *Journal of Healthcare Engineering*, vol. 2019, 2019.
- [458] CAICT, *Virtual Reality/Augmented Reality White Paper*, Huawei Technologies Co., Ltd, China, 2017.
- [459] R. H. Brown, *Augmenting the Reality of Everything Everything*, Teaneck, London, UK, 2017.
- [460] F. Salehahmadi and F. Hajjaliasgari, "Grand adventure of augmented reality in landscape of surgery," *World Journal of Plastic Surgery*, vol. 8, no. 2, pp. 135–145, 2019.
- [461] P. Kaur, M. Sharma, and M. Mittal, "Big data and machine learning based secure healthcare framework," *Procedia Computer Science*, vol. 132, pp. 1049–1059, 2018.
- [462] L. Hong, M. Luo, R. Wang, P. Lu, W. Lu, and L. Lu, "Big data in health care: what is so different about was ist so anders am neuroenhancement?" *Data and Information Management*, vol. 1, no. 2, pp. 122–135, 2018.
- [463] P. K. D. Pramanik, S. Pal, and M. Mukhopadhyay, "Healthcare Big Data: A Comprehensive Overview," *IGI Global*, vol. 1, pp. 72–100, 2018.
- [464] S. Sa, B. K. Rai, A. A. Meshram, A. Gunasekaran, and S. Chandrakumarmangalam, "Big data in healthcare management: a review of literature," *American Journal of Theoretical and Applied Business*, vol. 4, no. 2, pp. 57–69, 2018.
- [465] Big Data Value Association, "Big data technologies in healthcare: needs, opportunities and challenges," 2016.
- [466] R. Pastorino, "Benefits and challenges of Big Data in healthcare: an overview of the European initiatives," *European Journal of Public Health*, vol. 29, no. 3, pp. 23–27, 2019.
- [467] R. M. Visconti and D. Morea, "Big data for the sustainability of healthcare project financing," *Sustainability*, vol. 11, no. 3748, 2019.
- [468] Q. K. Fatt and A. Ramadas, "The usefulness and challenges of big data in healthcare," *Journal of Healthcare Communications*, vol. 3, no. 2, pp. 1–4, 2018.
- [469] H. Khaloufi, K. Abouelmehdi, A. Beni-hssane, and M. Saadi, "Security model for big healthcare data lifecycle," *Procedia Computer Science*, vol. 141, pp. 294–301, 2018.
- [470] M. Prokofieva and S. J. Miah, "Blockchain in healthcare Blockchain in healthcare," *Australasian Journal of Information Systems*, vol. 23, pp. 1–22, 2019.
- [471] A. A. Siyal, A. Z. Junejo, M. Zawish, K. Ahmed, A. Khalil, and G. Soursou, "Applications of blockchain technology in medicine and healthcare: challenges and future perspectives," *Cryptography*, vol. 3, no. 3, pp. 1–16, 2019.
- [472] Advanced Medical Reviews, "Blockchain in healthcare: how it could transform ehers, drug safety and medical reviews," 2017.
- [473] P. Zhang, D. C. Schmidt, J. White, and G. Lenz, *Blockchain Technology use Cases in Healthcare*, Elsevier, Berlin, Germany, 2018.
- [474] S. Demarinis, "US Health Care Companies Exploring Blockchain Technologies," 2018.
- [475] S. Dash, A. Majumdar, and P. Gunjekar, "Blockchain : A Healthcare Industry View," 2017.
- [476] H. S. Chen, J. T. Jarrell, K. A. Carpenter, D. S. Cohen, and X. Huang, "Blockchain in healthcare: a patient-centered model," *Biomedical Journal of Scientific & Technical Research*, vol. 20, no. 3, pp. 15017–15022, 2019.
- [477] S. Khezr, M. Moniruzzaman, A. Yassine, and R. Benlamri, "Blockchain Technology in Healthcare: A Comprehensive Review and Directions for Future Research," *Applied Sciences*, vol. 9, 2019.
- [478] C. C. Agbo, Q. H. Mahmoud, and J. M. Eklund, "Blockchain technology in healthcare: a systematic review," *Healthcare*, vol. 7, no. 56, pp. 1–30, 2019.
- [479] T. Mackey, H. Bekki, T. Matsuzaki, and H. Mizushima, "Examining the potential of blockchain technology to meet the needs of 21st-century Japanese health care: viewpoint on use cases and policy," *Journal of Medical Internet Research*, vol. 22, no. 1, pp. 1–12, 2020.
- [480] S. Badr, I. Goma, and E. Abd-elrahman, "Multi-tier blockchain framework for IoT-EHRs systems," *Procedia Computer Science*, vol. 141, pp. 159–166, 2018.
- [481] K. A. Koshechkin, G. S. Klimenko, I. V. Ryabkov, and P. B. Kozhin, "Scope for the application of blockchain in the public healthcare of the Russian federation," *Procedia Computer Science*, vol. 126, pp. 1323–1328, 2018.
- [482] W. Chien, "The last mile: DSCSA solution through blockchain technology: drug tracking, tracing, and verification at the last mile of the pharmaceutical supply chain with

- BRUINchain,” *Blockchain in healthcare TodayTM*, vol. 12, pp. 1–28, 2020.
- [483] I. Mistry, S. Tanwar, S. Tyagi, and N. Kumar, “Blockchain for 5G-enabled IoT for industrial automation: a systematic review, solutions, and challenges,” *Mechanical Systems and Signal Processing*, vol. 135, pp. 1–20, 2020.
- [484] I. Mistry, “Cloud computing and healthcare services,” *Journal of Biosensors & Bioelectronics*, vol. 7, no. 3, pp. 1–4, 2017.
- [485] Cloud Standards Customer Council, “Impact of Cloud Computing on Healthcare: Version 2.0,” 2017.
- [486] R. Ganiga, R. M. Pai, and M. Pai, “Private cloud solution for securing and managing patient data in rural healthcare system,” *Procedia Computer Science*, vol. 135, pp. 688–699, 2018.
- [487] L. Griebel, “A scoping review of cloud computing in healthcare,” *BMC Medical Informatics and Decision Making*, vol. 15, no. 17, pp. 1–16, 2015.
- [488] L. M. Dang, J. Piran, D. Han, K. Min, and H. Moon, “A survey on internet of things and cloud computing for healthcare,” *Electronics*, vol. 8, no. 768, 2019.
- [489] Y. Li, H. Wang, Y. Li, and L. Li, “Patient assignment scheduling in a cloud healthcare system based on petri net and greedy-based heuristic,” *Enterprise Information Systems*, vol. 13, no. 4, pp. 515–533, 2019.
- [490] Y. Karaca, M. Moonis, Y. Zhang, and C. Gezgez, “Mobile cloud computing based stroke healthcare system,” *International Journal of Information Management*, vol. 13, pp. 1–12, 2018.
- [491] M. Eichleay, E. Evens, K. Stankevitz, and C. Parker, “Using the unmanned aerial vehicle delivery decision tool to consider transporting medical supplies via drone,” *Global Health: Science and Practice*, vol. 7, no. 4, pp. 500–506, 2019.
- [492] J. C. Rosser, V. Vignesh, B. A. Terwilliger, and B. C. Parker, “Surgical and medical applications of drones: a comprehensive review,” *JSLs*, vol. 22, no. 3, pp. 1–9, 2018.
- [493] M. Balasingam, “Drones in medicine—the rise of the machines,” *The International Journal of Clinical Practice*, vol. 71, 2017.
- [494] S. J. Kim, G. J. Lim, J. Cho, and M. J. Cote, “Drone-Aided healthcare services for patients with chronic diseases in rural areas,” *Journal of Intelligent Robotic System*, vol. 3, pp. 1–18, 2017.
- [495] M. S. Y. Hii, P. Courtney, and P. G. Royall, “An evaluation of the delivery of medicines using drones,” *Drones*, vol. 3, no. 52, pp. 1–20, 2019.
- [496] A. M. Knoblauch, “Bi-directional drones to strengthen healthcare provision: experiences and lessons from Madagascar, Malawi and Senegal,” *BMJ Global Health*, vol. 4, 2019.
- [497] D. Dziak, B. Jachimczyk, and W. J. Kulesza, “IoT-based information system for healthcare application: design methodology approach,” *Applied Sciences*, vol. 7, no. 596, pp. 1–26, 2017.
- [498] P. A. Laplante, M. Kassab, N. L. Laplante, and J. M. Voas, “Building caring healthcare systems in the internet of things,” *IEEE System Journal*, vol. 12, no. 3, pp. 1–19, 2018.
- [499] N. Mani, A. Singh, and S. L. Nimmagadda, “An IoT guided healthcare monitoring system for managing real-time notifications by fog computing services,” *Procedia Computer Science*, vol. 167, pp. 850–859, 2020.
- [500] H. Zakaria, N. A. Abu Bakar, N. H. Hassan, and S. Yaacob, “IoT security risk management model for secured practice in healthcare environment,” *Procedia Computer Science*, vol. 161, pp. 1241–1248, 2019.
- [501] Z. Lou, L. Wang, K. Jiang, Z. Wei, and G. Shen, “Reviews of wearable healthcare systems: materials, devices and system integration,” *Materials Science & Engineering R*, vol. 140, pp. 1–43, 2020.
- [502] J.-C. Ni, C.-S. Yang, J.-K. Huang, and L. C. Shiu, “Combining non-invasive wearable device and intelligent terminal in HealthCare IoT,” *Procedia Computer Science*, vol. 154, pp. 161–166, 2019.
- [503] A. Mohammad, A. Moshed, M. Khairul, I. Sarkar, and A. Khaleque, “The application of nanotechnology in medical Sciences: new horizon of treatment,” *American Journal of Biomedical Sciences*, vol. 9, no. 1, pp. 1–14, 2017.
- [504] V. Bhardwaj and A. Kaushik, “Biomedical applications of nanotechnology and nanomaterials,” *Micromachines*, vol. 8, no. 298, 2017.
- [505] F. A. Radwan, “Nanotechnology and medicine,” *Material Science and Nanotechnology*, vol. 2, no. 2, pp. 7–8, 2018.
- [506] P. Fletcher and A. Holian, “Nanotechnology: the risks and benefits for medical diagnosis and treatment,” *Journal of Nanomedicine & Nanotechnology*, vol. 7, no. 4, pp. 1–2, 2016.
- [507] A. Joseph, B. Christian, A. A. Abiodun, and F. Oyawale, “A review on humanoid robotics in healthcare,” *MATEC Web of Conferences*, vol. 153, 2018.
- [508] E. D. Oña, J. M. Garcia-haro, A. Jardón, and C. Balaguer, “Robotics in Health Care: Perspectives of Robot-Aided Interventions in Clinical Practice for Rehabilitation of Upper Limbs,” *Applied Sciences*, vol. 9, no. 2586, 2019.
- [509] R. Wason, V. Jain, G. S. Narula, A. Balyan, and M. Kaur, “Smart Robotics for Smart Healthcare,” *Advances In Robotics & Mechanical Engineering*, vol. 1, no. 5, pp. 73–74, 2019.
- [510] M. Vatandsoost and S. Litkouhi, “The future of healthcare facilities: how technology and medical advances may shape hospitals of the future,” *Hospital Practices and Research*, vol. 4, no. 1, pp. 1–11, 2019.
- [511] Z. Dolic, R. Castro, and A. Moarcas, “Robots in Healthcare: A Solution or a Problem,” 2019.
- [512] M. K. Traoré, G. Zacharewicz, R. Duboz, and B. Zeigler, “Modeling and simulation framework for value-based healthcare systems,” *Simulation*, vol. 95, no. 6, pp. 481–497, 2019.
- [513] K. Steins, *Towards Increased Use of Discrete-Event Simulation for Hospital Resource Planning*, Linköping University, London, UK, 2017.
- [514] S. N. Roy, “Healthcare Resource Planning: A Simulation Approach,” *Indian Institute of Management*, vol. 13, 2018.
- [515] N. Harder, “The value of simulation in health care: the obvious, the tangential, and the obscure,” *Clinical Simulation in Nursing*, vol. 15, pp. 73–74, 2018.
- [516] A. Atalan and C. C. Donmez, “Employment of emergency advanced nurses of Turkey: a discrete-event simulation application,” *Processes*, vol. 7, no. 48, pp. 1–18, 2019.
- [517] Z. Liu, “Modeling and simulation for healthcare operations management using high performance computing and agent-based model,” *Universitat Autònoma de Barcelona*, vol. 13, 2016.
- [518] H. Y. So, P. P. Chen, G. K. C. Wong, and T. T. N. Chan, “Simulation in medical education,” *Journal of the Royal College of Physicians of Edinburgh*, vol. 49, no. 1, pp. 52–57, 2019.
- [519] D. S. Dirzu, “Medical simulation—a costly but essential teaching tool,” *Romanian Journal of Anaesthesia and Intensive Care*, vol. 24, no. 1, pp. 5–6, 2017.
- [520] J. C. A. Martins, R. C. N. Baptista, V. R. D. Coutinho, M. I. D. Fernandes, and A. M. Fernandes, *Simulation in*

- Nursing and Midwifery Education Simulation*, WHO regional office, Copenhagen, Denmark, 2018.
- [521] A. Pavlovic, N. Kalezić, S. Trpkovic, N. Videnovic, and L. Sulovic, "The application of simulation in medical education-our experience from improvisation to simulation," *Srpski Arhiv Za Celokupno Lekarstvo*, vol. 146, no. 5-6, pp. 338-344, 2018.
- [522] L. F. N. D. Carramate, "Simulation of image-guided intervention in medical imaging education," *Journal of Medical Imaging and Radiation Sciences*, vol. 13, pp. 1-6, 2019.
- [523] E. J. Yeuna and M. Y. Chona, "Perceptions of video-facilitated debriefing in simulation education among nursing students: findings from a Q-methodology study," *Journal of Professional Nursing*, vol. 13, pp. 1-8, 2019.
- [524] V. Raper, "Synthetic biology seizes new ground in healthcare," *Genetic Engineering & Biotechnology News*, vol. 39, no. 11, pp. 40-43, 2019.
- [525] L. Clarke and R. Kitney, "Developing synthetic biology for industrial biotechnology applications," *Biochemical Society Transactions*, vol. 48, no. 1, pp. 113-122, 2020.
- [526] V. B. Reddy, "Current synthetic and systems biology synthetic biology: a good choice for medicinal advances," *Current Synthetic and Systems Biology*, vol. 3, no. 2, pp. 2-3, 2015.
- [527] H. Van Mierlo, *Tackling Antimicrobial Resistance: The Role of Synthetic Biology*, University of Groningen, Melbourne Victoria, Australia, 2016.
- [528] P. Gray, "Synthetic biology in australia: an outlook to 2030," 2018.
- [529] C. Fan and R. Habgood, "Chromosome-free bacterial cells are safe and programmable platforms for synthetic biology," *Proceedings of the National Academy of Sciences*, vol. 117, no. 12, pp. 6752-6761, 2020.
- [530] T. A. D. O. Davison, F. Castiglione, P. Tieri, and L. Felicori, "Systems and Synthetic Biology Applied to Health," *Current Developments in Biotechnology and Bioengineering: Human and Animal Health Applications*, vol. 11, pp. 183-213, 2017.
- [531] B. J. Kinder and M. Robbins, "The Present and Future State of Synthetic Biology in Canada," 2018.
- [532] M. El Karoui, M. Hoyos-flight, and L. Fletcher, "Future trends in synthetic biology-a report," *Frontiers in Bioengineering and Biotechnology*, vol. 7, 2019.
- [533] UNCTAD, "Synthetic Biology and its Potential Implications for Biotrade and Access and Benefit-Sharing," 2019.
- [534] M. Igor, B. Sergiy, S. Tatyana, and G. Larissa, "Logistics and transport in industry 4.0: perspective for Ukraine," *SHS Web of Conferences*, vol. 67, 2019.
- [535] A. Galkin, L. Obolentseva, I. Balandina, E. Kush, V. Karpenko, and P. Bajdor, "Last-Mile delivery for consumer driven logistics," *Transportation Research Procedia*, vol. 39, pp. 74-83, 2019.
- [536] L. Ranieri, A. Urbinati, F. Facchini, and J. Ole, "A maturity model for logistics 4.0: an empirical analysis and a roadmap for future research," *Sustainability*, vol. 12, no. 86, pp. 1-18, 2019.
- [537] C. Briese, M. Schlüter, J. Lehr, K. Maurer, and J. Krüger, "Towards deep learning in industrial applications taking advantage of service-oriented architectures," *Procedia Manufacturing*, vol. 43, pp. 503-510, 2020.
- [538] P. Ralston and J. Blackhurst, "Industry 4.0 and resilience in the supply chain: a driver of capability enhancement or capability loss," *International Journal of Production Research*, vol. 11, pp. 1-14, 2020.
- [539] M. Núñez-merino, J. M. Maqueira-marín, J. Moyano-fuentes, and P. J. Martínez-jurado, "Information and digital technologies of Industry 4.0 and Lean supply chain management: a systematic literature review," *International Journal of Production Research*, vol. 11, pp. 1-27, 2020.
- [540] H. Fatorachian and H. Kazemi, "The Management of Operations Impact of Industry 4.0 on Supply Chain Performance," *Production Planning & Control*, vol. 11, pp. 1-19, 2020.
- [541] L. Barreto, A. Amaral, and T. Pereira, "Industry 4.0 implications in logistics: an overview," *Procedia Manufacturing*, vol. 13, pp. 1245-1252, 2017.
- [542] O. Seroka-stolka and A. Ociepa-kubicka, "Green logistics and circular economy," *Transportation Research Procedia*, vol. 39, pp. 471-479, 2019.
- [543] J. Korczak and K. Kijewska, "Smart Logistics in the development of Smart Cities," *Transportation Research Procedia*, vol. 39, pp. 201-211, 2019.
- [544] C. Cimini, A. Lagorio, F. Pirola, and R. Pinto, "Exploring human factors in Logistics 4.0: empirical evidence from a case study," *IFAC-PapersOnLine*, vol. 52, no. 13, pp. 2183-2188, 2019.
- [545] C. K. M. Lee, Y. Lv, K. K. H. Ng, W. Ho, and K. L. Choy, "Design and application of Internet of things-based warehouse management system for smart logistics," *International Journal of Production Research*, vol. 56, no. 8, pp. 2753-2768, 2018.
- [546] A. J. C. Trappey, C. V. Trappey, C.-Y. Fan, A. P. T. Hsu, X.-K. Li, and I. J. Y. Lee, "IoT patent roadmap for smart logistic service provision in the context of Industry 4.0," *Journal of the Chinese Institute of Engineers*, vol. 40, no. 7, pp. 593-602, 2017.
- [547] W. Liu, J. Zhang, S. Wei, and D. Wang, "Factors influencing organisational efficiency in a smart-logistics ecological chain under e-commerce platform leadership," *International Journal of Logistics Research and Applications*, vol. 11, pp. 1-28, 2020.
- [548] M. Wang, S. Asian, L. C. Wood, and B. Wang, "Logistics innovation capability and its impacts on the supply chain risks in the Industry 4.0 era," *Modern Supply Chain Research and Applications*, vol. 2, no. 2, pp. 83-98, 2020.
- [549] M. Fruth and F. Teuteberg, "Digitization in maritime logistics-what is there and what is missing," *Cogent Business & Management*, vol. 17, no. 1, pp. 1-40, 2017.
- [550] S. Gupta, S. Modgil, A. Gunasekaran, and S. Bag, "Dynamic capabilities and institutional theories for Industry 4.0 and digital supply chain," *Supply Chain Forum: An International Journal*, vol. 11, 2020.
- [551] C. L. Garay-rondero, J. L. Martinez-flores, S. O. C. Morales, N. R. Smith, and A. Aldrette-malacara, "Digital Supply Chain Model in Industry 4.0," *Journal of Manufacturing Technology Management*, vol. 11, pp. 1-47, 2019.
- [552] O. Szymańska, M. Adamczak, and P. Cyplik, "Logistics 4.0-a new paradigm or set of known solutions," *Research in Logistics & Production*, vol. 7, no. 4, pp. 299-310, 2017.
- [553] M. Kostrzewski, M. Kosacka-Olejnik, and K. Werner-Lewandowska, "Assessment of innovativeness level for chosen solutions related to Logistics 4.0," *Procedia Manufacturing*, vol. 38, pp. 621-628, 2019.
- [554] W. Kersten and T. Blecker, "digitalization in supply chain management and logistics: smart and digital solutions for an industry 4.0 environment," 2017.
- [555] G. Radivojević and L. Milosavljević, "The Concept of Logistics 4.0," 2019.

- [556] P.-E. Dossou, "Using industry 4.0 concepts and theory of systems for improving company supply chain: the example of a joinery," *Procedia Manufacturing*, vol. 38, pp. 1750–1757, 2019.
- [557] M. Kosacka-olejnik and K. Werner-lewandowska, "Logistics 4.0 Maturing in Service Industry: Empirical Research Results," *Procedia Manufacturing*, vol. 38, pp. 1058–1065, 2019.
- [558] W. Torbacki and K. Kijewska, "Identifying Key Performance Indicators to be used Logistics 4.0 and Industry 4.0 for the needs of sustainable municipal logistics by means of the DEMATEL method," *Transportation Research Procedia*, vol. 39, pp. 534–543, 2019.
- [559] S. Kauf, "Smart logistics as a basis for the development of the smart city," *Transportation Research Procedia*, vol. 39, pp. 143–149, 2019.
- [560] G. Li, H. Wang, and W. Hardjawana, "New advancement in information technologies for industry 4.0," *Enterprise Information Systems*, vol. 14, no. 4, pp. 402–405, 2020.
- [561] T.-M. Choi, "Facing market disruptions: values of elastic logistics in service supply chains," *International Journal of Production Research*, vol. 14, pp. 1–15, 2020.
- [562] M. Szymczak, "Digital Smart Logistics. Managing Supply Chain 4.0: Concepts, Components and Strategic Perspective," 2019.
- [563] V. Bamberger, F. Nansé, B. Schreiber, and M. Zintel, "Logistics 4.0-Facing Digitalization-Driven Disruption," 2017.
- [564] M. J. Ferrantino and E. E. Koten, "Understanding Supply Chain 4.0 and its Potential Impact on Global Value Chains," *World Bank Group*, vol. 14, pp. 103–119, 2019.
- [565] G. F. Frederico, J. A. Garza-reyes, and A. Anosike, "Supply Chain 4.0: concepts, maturity and research agenda," *Supply Chain Management: An International Journal*, vol. 25, no. 2, pp. 262–282, 2020.
- [566] R. Fioravanti, S. Kraiselburd, and L. M. Laporte, "Monitoring and Assessing the Impact of Supply Chain 4.0," 2019.
- [567] World Economic Forum, *Impact of the Fourth Industrial Revolution on Supply Chains*, Cologny, Geneva, Switzerland, 2017.
- [568] K. Alicke, J. Rachor, and A. Seyfert, *Supply Chain 4.0-the Next-Generation Digital Supply Chain*, McKinsey & Company, Geneva, Switzerland, 2016.
- [569] A. Benešová, M. Hirman, F. Steiner, and J. Tupa, "Determination of changes in process management within industry 4.0," *Procedia Manufacturing*, vol. 38, pp. 1691–1696, 2020.
- [570] A. Ancarani, C. Di Mauro, and F. Mascali, "Backshoring strategy and the adoption of industry 4.0: evidence from Europe," *Journal of World Business*, vol. 54, no. 4, pp. 360–371, 2019.
- [571] J. Zheng and C. Shen, "Domestic demand-based economic globalization and inclusive growth," *China Political Economy*, vol. 2, no. 1, pp. 136–156, 2019.
- [572] S. A. Asongu, U. Efobi, and V. S. Tchamyu, "Globalisation and governance in Africa: a critical contribution to the empirics," *International Journal of Development Issues*, vol. 17, no. 1, pp. 2–27, 2018.
- [573] W. O. Shittu, H. A. Yusuf, A. E. M. El Houssein, and S. Hassan, "The impacts of foreign direct investment and globalisation on economic growth in West Africa: examining the role of political governance," *Journal of Economic Studies*, vol. 2, pp. 1–23, 2020.
- [574] A. Telukdarie, E. A. Buhulaiga, S. Bag, S. Gupta, and Z. Luo, "Industry 4.0 Implementation for Multinationals," *Process Safety and Environmental Protection*, vol. 2, pp. 1–40, 2018.
- [575] P. Gimenez-escalante and S. Rahimifard, "Metrics for identifying the most suitable strategy for distributed localised food manufacturing," *Procedia Manufacturing*, vol. 33, pp. 586–593, 2019.
- [576] N. P. Petersson, S. Tenold, and N. J. White, *Shipping and Globalization in the Post-War Era: Contexts, Companies, Connections*, Palgrave Studies in Maritime Economics, Cham, Switzerland, 2019.
- [577] K. Munir and M. Bukhari, "Impact of globalization on income inequality in Asian emerging economies," *International Journal of Sociology and Social Policy*, vol. 40, no. 1/2, pp. 44–57, 2020.
- [578] W. Khlif, S. El Omari, and H. Hammami, "Challenging the meaning of globalisation in Tunisian context," *Society and Business Review*, vol. 14, no. 4, pp. 320–337, 2019.
- [579] A. Daribay, A. Serikova, and I. A. Ukaegbu, "Industry 4.0: kazakhstan industrialization needs a global perspective," *Procedia Computer Science*, vol. 151, pp. 903–908, 2019.
- [580] H. Wang, "China and globalization: 40 years of Reform and Opening-up and globalization 4.0," *Journal of Chinese Economic and Business Studies*, vol. 17, no. 3, pp. 215–220, 2019.
- [581] M. J. Sousa, V. Santos, A. Sacavém, I. Pinto, and M. C. Sampaio, "4.0 leadership skills in hospitality sector," *Journal of Reviews on Global Economics*, vol. 7, pp. 1–13, 2018.
- [582] K. A. Prince, "Industrie 4.0 and leadership," 2017.
- [583] C. Promsri, "Training program analysis for leadership 4.0 in fourth industrial revolution," *East African Scholars Journal of Economics, Business and Management*, vol. 2, no. 9, pp. 591–595, 2019.
- [584] F. Herder-Wynne, R. Amato, and F. Uit de Weerd, *Leadership 4.0: A Review of the Thinking*, Oxford Leadership, Oxford, UK, 2017.
- [585] C. Deloitte, "Success personified in the fourth industrial revolution: four leadership personas for an era of change and uncertainty," 2019.
- [586] Axiom Groupe, "Finance 4.0: bringing financial functions into 4th Revolution," 2019.
- [587] Siemens Financial Services, "The finance factor: the role of integrated finance in enabling digital transformation for manufacturers and technology providers," 2019.
- [588] UniCredit, "Trade Finance 4.0: a world of new opportunities," 2015.
- [589] T. Lynn, J. G. Mooney, P. Rosati, and M. Cummins, "Disrupting Finance: FinTech and Strategy In the 21st Century," 2019.
- [590] M. M. Dapp, S. Klauser, and M. Ballandies, "Finance 4.0 Concept-Technical Report-WP3 Interim Report (M12) for futurICT2 Project," 2018.
- [591] M. Lacey, H. Lisachuk, A. Giannopoulos, and A. Ogura, "Shipping Smarter: IoT Opportunities in Transport and Logistics," 2015.
- [592] J. Fitzgerald and E. Quasney, "Using Autonomous Robots to Drive Supply Chain Innovation: A Series Exploring Industry 4.0 Technologies and Their Potential Impact for Enabling Digital Supply Networks in Manufacturing," 2017.
- [593] H. K. Chan, J. Griffin, J. J. Lim, F. Zeng, and A. S. F. Chiu, "The impact of 3D Printing Technology on the supply chain: manufacturing and legal perspectives," *International Journal of Production Economics*, vol. 205, pp. 156–162, 2018.
- [594] A. Wiczorek, "Impact of 3D printing on logistics," *Research in Logistics and Production*, vol. 7, no. 5, pp. 443–450, 2017.

- [595] DHL, *3D Printing and the Future of Supply Chains: A DHL Perspective on the State of 3D Printing and Implications for Logistics*, Troisdorf, Germany, 2016.
- [596] G. Chung, B. Gesing, K. Chaturvedi, and P. Bodenbenner, *Logistics Trend Radar: Delivering Insight Today, Creating Value Tomorrow*, Troisdorf, Germany, 2018.
- [597] W. Boon and B. Van Wee, "Influence of 3D printing on transport: a theory and experts judgment based conceptual model," *Transport Reviews*, vol. 38, no. 5, pp. 556–575, 2018.
- [598] E. Özceylan, C. Çetinkaya, N. Demirel, and O. Sabırlıoğlu, "Impacts of additive manufacturing on," *Supply Chain Flow: A Simulation Approach in Healthcare Industry*, vol. 2, no. 1, pp. 1–20, 2018.
- [599] L. Kubáč and O. Kodym, "The Impact of 3D Printing Technology on Supply Chain," *MATEC Web of Conferences*, vol. 134, 2017.
- [600] N. Vasileios, *The Impact of 3D Printing on the Traditional Supply Chain: A Quantitative Analysis*, Aristotle University of Thessaloniki, London, UK, 2018.
- [601] R. Geissbauer, J. Wunderlin, and J. Lehr, "The Future of Spare Parts Is 3D: A Look at the Challenges and Opportunities of 3D Printing," 2017.
- [602] J. R. Daduna, "Disruptive effects on logistics processes by additive manufacturing," *IFAC-PapersOnLine*, vol. 52, no. 13, pp. 2770–2775, 2019.
- [603] D. A. P. Pandian, "Artificial intelligence application in smart warehousing environment for automated logistics," *IFAC-PapersOnLine*, vol. 2019, no. 2, pp. 63–72, 2019.
- [604] Big Innovation Centre, *Future Supply Chains with Artificial Intelligence: Achieving AI Success-Building Capacity & Understanding Complexities*, Innovate UK, London, UK, 2018.
- [605] B. Gesing, S. J. Peterson, and D. Michelsen, *Artificial Intelligence in Logistics: A Collaborative Report by DHL and IBM on Implications and Use Cases for the Logistics Industry*, Troisdorf, Germany, 2018.
- [606] C. Zhou, A. Stephen, X. Cao, and S. Wang, "A data-driven business intelligence system for large-scale semi-automated logistics facilities," *International Journal of Production Research*, vol. 5, pp. 1–19, 2020.
- [607] D. Knoll, M. Prüglmeier, and G. Reinhart, "Predicting future inbound logistics processes using machine learning," *Procedia CIRP*, vol. 52, pp. 145–150, 2016.
- [608] S. Soleimani, "A perfect triangle with: artificial intelligence," *Supply Chain Management, and Financial Technology*, vol. 6, no. 11, pp. 85–94, 2018.
- [609] SSI Schafer IT Solutions GmbH, *Artificial Intelligence in Logistics: Terms, Applications and Perspectives*, Friesach, Germany, 2018.
- [610] M. M. Hasan, D. Jiang, A. M. M. S. Ullah, and M. Noor-E-Alam, "Resilient supplier selection in logistics 4.0 with heterogeneous information," *Expert Systems With Applications*, vol. 139, pp. 1–24, 2020.
- [611] R. Domański, J. Olesków-szłapka, H. Wojciechowski, R. Domański, and G. Pawłowski, "Logistics 4.0 maturity levels assessed based on GDM (grey decision model) and artificial intelligence in logistics 4.0- trends and future perspective," *Procedia Manufacturing*, vol. 39, pp. 1734–1742, 2019.
- [612] H. C. W. Lau, L. Zhao, and D. Nakandala, "An intelligent approach for optimizing supply chain operations," *Journal of Economics, Business and Management*, vol. 3, no. 6, pp. 571–575, 2015.
- [613] S. Danielsson and E. Ekström, *Improving the Supply Chain Using Artificial Intelligence*, Lund University, London, UK, 2018.
- [614] W. Kersten, T. Blecker, and C. M. Ringle, "Artificial intelligence and digital transformation in supply chain management: innovative approaches for supply chains," 2019.
- [615] Y. Li, M. K. Lim, and M.-L. Tseng, "A green vehicle routing model based on modified particle swarm optimization for cold chain logistics," *Industrial Management & Data Systems*, vol. 119, no. 3, pp. 473–494, 2019.
- [616] C.-F. Chien, S. Dauzère-Pères, W. T. Huh, Y. J. Jang, and J. R. Morrison, "Artificial intelligence in manufacturing and logistics systems: algorithms, applications, and case studies," *International Journal of Production Research*, vol. 58, no. 9, pp. 2730–2731, 2020.
- [617] M.-H. Stoltz, V. Giannikas, D. McFarlane, J. Strachan, J. Um, and R. Srinivasan, "Augmented reality in warehouse operations: opportunities and barriers," *IFAC-PapersOnLine*, vol. 50, no. 1, pp. 12979–12984, 2017.
- [618] D. Puljiz, G. Gorbachev, and B. Hein, "Implementation of augmented reality in autonomous warehouses: challenges and opportunities," 2018.
- [619] W. Wang, F. Wang, W. Song, and S. Su, "Application of augmented reality (AR) technologies in inhouse logistics," *E3S Web of Conferences*, vol. 145, 2020.
- [620] M. Merlino and I. Spro e, "The augmented supply chain," *Procedia Engineering*, vol. 178, pp. 308–318, 2017.
- [621] S. Koul, "Augmented reality in supply chain management and logistics," *International Journal of Recent Scientific Research*, vol. 10, no. 2, pp. 30732–30734, 2019.
- [622] M. K. Williams, *Augmented Reality Supported Batch Picking System*, University of Twente, Twente, France, 2019.
- [623] K. Govindan, T. C. E. Cheng, N. Mishra, and N. Shukla, "Big data analytics and application for logistics and supply chain management," *Transportation Research Part E: Logistics and Transportation Review*, vol. 114, pp. 343–349, 2018.
- [624] S. F. Wamba, A. Gunasekaran, T. Papadopoulos, and E. Ngai, "Guest editorial: big data analytics in logistics and supply chain management," *International Journal of Logistics Management*, vol. 29, no. 2, pp. 478–484, 2018.
- [625] S. S. Darvazeh, I. R. Vanani, and F. M. Musolu, "Big data analytics and its applications in supply chain management," *IntechOpen*, vol. 29, pp. 1–26, 2020.
- [626] S. Rowe and M. Pournader, "Supply Chain Big Data Series Part 1: How Big Data Is Shaping the Supply Chains of Tomorrow," *KPMG Australia and Macquarie Graduate School of Management*, vol. 29, 2017.
- [627] G. Wang, A. Gunasekaran, E. W. T. Ngai, and T. Papadopoulos, "Big data analytics in logistics and supply chain management: certain investigations for research and applications," *International Journal of Production Economics*, vol. 176, pp. 98–110, 2016.
- [628] M. Brinch, J. Stentoft, and J. K. Jensen, "Practitioners understanding of big data and its applications in supply chain management," *The International Journal of Logistics Management*, vol. 29, no. 2, pp. 555–574, 2018.
- [629] Z. Rajkumar, H. Ismail, L. Chen, X. Zhao, and L. Wang, "The application of big data analytics in optimizing logistics: a developmental perspective review," *Journal of Data, Information and Management*, vol. 1, no. 1–2, pp. 33–43, 2019.
- [630] Y. Issaoui, A. Khiat, A. Bahnasse, and H. Ouajji, "Smart logistics: study of the application of blockchain technology," *Procedia Computer Science*, vol. 160, pp. 266–271, 2019.

- [631] A. Goudz and V. Steiner, "An evaluation for the use of blockchain technology in logistics," *International Journal of Transportation Engineering and Technology*, vol. 5, no. 1, pp. 11–17, 2019.
- [632] Capgemini Research Institute, "Does blockchain hold the key to a new age of supply chain transparency and trust?" *How Organizations Have Moved from Blockchain Hype to Reality*, vol. 29, 2018.
- [633] N. Kshetri, "1 Blockchain's roles in meeting key supply chain management objectives," *International Journal of Information Management*, vol. 39, pp. 80–89, 2018.
- [634] DHL and Accenture, "Blockchain in logistics: Perspectives on the Upcoming Impact of Blockchain Technology and Use Cases for the Logistics Industry," 2018.
- [635] J. Duan, C. Zhang, Y. Gong, S. Brown, and Z. Li, "A content-analysis based literature review in blockchain adoption within food supply chain," *International Journal of Environmental Research and Public Health*, vol. 17, 2020.
- [636] M. Dobrovnik, D. M. Herold, E. Fürst, and S. Kummer, "Blockchain for and in logistics: what to adopt and where to start," *Logistics*, vol. 2, no. 18, 2018.
- [637] Deloitte, "Continuous interconnected supply chain: using blockchain & internet-of-things in supply chain traceability," 2017.
- [638] F. Poszler, A. Ritter, and I. Welpé, "Blockchain startups in the logistics industry: the technology's potential to disrupt business models and supply chains," 2019.
- [639] E. Tijan, S. Aksentijevi, K. Ivanic, and M. Jardas, "Blockchain Technology Implementation in Logistics sustainability Blockchain Technology Implementation in Logistics," *Sustainability*, vol. 11, p. 1185, 2019.
- [640] T. Leonard, *Blockchain for Transportation: Where the Future Starts*, Cleveland/Dallas/Nashville, Switzerland, 2017.
- [641] World Economic Forum, *Inclusive Deployment of Blockchain for Supply Chains: Part 1-Introduction*, Cologny, Geneva, Switzerland, 2019.
- [642] A. Sivula, A. Shamsuzzoha, and P. Helo, "Blockchain in logistics: mapping the opportunities in construction industry," *Proceedings of the International Conference on Industrial Engineering and Operations Management September*, vol. 27–29, pp. 1954–1960, 2018.
- [643] L. Koh, A. Dolgui, and J. Sarkis, "Blockchain in transport and logistics-paradigms and transitions," *International Journal of Production Research*, vol. 58, no. 7, pp. 2054–2062, 2020.
- [644] G. Blosssey, J. Eisenhardt, and G. J. Hahn, "Blockchain technology in supply chain management: an application perspective," 2019.
- [645] S. Agarwal, *Blockchain Technology in Supply Chain and Logistics*, Massachusetts Institute of Technology, Massachusetts, MA, USA, 2018.
- [646] A. Schmahl, *Resolving the Blockchain Paradox in Transportation and Logistics*, Boston Consulting Group (BCG), Boston, MA, USA, 2019.
- [647] M. Pournader, Y. Shi, S. Seuring, and S. C. L. Koh, "Blockchain applications in supply chains, transport and logistics: a systematic review of the literature," *International Journal of Production Research*, vol. 7543, no. 58, p. 7, 2020.
- [648] D. Dujak and D. Sajter, "Blockchain applications in supply," *Springer International Publishing AG*, vol. 75, pp. 21–46, 2019.
- [649] A. Jabbari and P. Kaminsky, "Blockchain and supply chain management," 2018.
- [650] DAC, "Blockchain in Transport, Shipping and Logistics," 2019.
- [651] E. Petersson and K. Baur, *Impacts of Blockchain Technology on Supply Chain Collaboration: A Study on the Use of Blockchain Technology in Supply Chains and How it Influences Supply Chain Collaboration*, Jonkoping University, Boston, MA, USA, 2018.
- [652] C. F. Durach, T. Blesik, M. Von Doring, and M. Bick, "Blockchain Applications in Supply Chain Transactions," *Journal of Business Logistics*, vol. 16, 2020.
- [653] G. Perboli, S. Musso, and M. Rosano, "Blockchain in logistics and supply chain: a lean approach for designing real-world use cases," *IEEE Access*, vol. 6, pp. 62018–62028, 2018.
- [654] G. Niharika and V. Ritu, "Cloud Architecture for the Logistics Business," *Procedia-Procedia Computer Science*, vol. 50, pp. 414–420, 2015.
- [655] C. G. Kochan, *The Impact of Cloud Based Supply Chain Management on Supply Chain Resilience*, University of North Texas, Boston, MA, USA, 2015.
- [656] O. Akinrolabu, S. New, and A. Martin, "Cyber supply chain risks in cloud computing-bridging the risk assessment gap," *Open Journal of Cloud Computing*, vol. 5, no. 1, pp. 1–19, 2018.
- [657] E. Aghamohammadzadeh, M. Malek, and O. F. Valilai, "A novel model for optimisation of logistics and manufacturing operation service composition in Cloud manufacturing system focusing on cloud-entropy," *International Journal of Production Research ISSN*, vol. 58, no. 7, p. 1987, 2020.
- [658] Z. Benotmane, G. Belalem, and A. Neki, "A cloud computing model for optimization of transport logistics process," *Transport and Telecommunication Journal*, vol. 18, no. 3, pp. 194–206, 2017.
- [659] J. Yang, "Construction and optimization of port logistics service supply chain based on cloud computing," *Journal of Coastal Research*, vol. S1, no. 98, pp. 83–86, 2019.
- [660] B. E. Al-jawazneh, "The prospects of cloud computing in supply chain management (A theoretical perspective)," *Journal of Management Research*, vol. 8, no. 4, pp. 145–158, 2016.
- [661] S. K. Singh, P. S. Srinivasan, and D. Kaur, "SOA cloud computing: modernized the supply chain management applications," *IOSR Journal of Engineering*, vol. 09, no. 3, pp. 67–74, 2019.
- [662] B. Nicoletti, "Cloud computing and procurement," 2016.
- [663] FlytBase, "2020 Guide: Inventory Counts Using Drones," 2020.
- [664] E. Companik, M. J. Gravier, and M. T. Farris II., "Feasibility of warehouse drone adoption and implementation," *Journal of Transportation Management*, vol. 28, no. 2, pp. 33–50, 2018.
- [665] E. J. U. Hernández, J. A. S. Martínez, and J. A. M. Saucedo, "Optimization of the distribution network using an emerging technology," *Applied Sciences*, vol. 10, no. 857, 2020.
- [666] V. Olivares, F. Cordova, J. M. Sepúlveda, and I. Derpich, "Modeling internal logistics by using drones on the stage of assembly of products," *Procedia Computer Science*, vol. 55, pp. 1240–1249, 2015.
- [667] UNICEF, "Innovation Case Study: Drones for Delivering Results for Children," 2019.
- [668] K. Kuru, D. Ansell, W. Khan, and H. Yetgin, "Analysis and optimization of unmanned aerial vehicle swarms in logistics: an intelligent delivery platform," *IEEE Access*, vol. 7, pp. 15804–15831, 2019.

- [669] B. A. McCunney and K. P. Van Cauwenberghe, "Simulation Test Bed for Drone-Supported Logistics Systems," *Massachusetts Institute of Technology*, vol. 7, 2019.
- [670] A. J. Lohn, *What's the Buzz? The City-Scale Impacts of Drone Delivery*, RAND Corporation: Santa Monica, California, 2017.
- [671] M. Roca-Riu and M. Menendez, "Logistic deliveries with Drones. State of the art of practice and research," 2019.
- [672] J. Aurambout, K. Gkoumas, and B. Ciuffo, "Last mile delivery by drones: an estimation of viable market potential and access to citizens across European cities," *European Transport Research Review*, vol. 11, no. 30, pp. 1–21, 2019.
- [673] I. Zubin, "introduction of drones in the last-mile logistic process of medical product delivery: a feasibility assessment applied to the case study of BENU't slag," *Delft University of Technology*, vol. 11, 2019.
- [674] I. Marsh, "Drones-a View into the Future for the Logistics Sector," 2015.
- [675] A. Kujawski, J. Lemke, and T. Dudek, "Concept of using unmanned aerial vehicle (UAV) in the analysis of traffic parameters on Oder Waterway," *Transportation Research Procedia*, vol. 39, pp. 231–241, 2019.
- [676] L. Juntao and M. Yinbo, "Research on internet of things technology application status in the warehouse operation," *International Journal of Science, Technology and Society*, vol. 4, no. 4, pp. 63–66, 2016.
- [677] S. Trab, E. Bajic, A. Zouinkhi et al., "A communicating object's approach for smart logistics and safety issues in warehouses," *Concurrent Engineering*, vol. 25, no. 1, pp. 53–67, 2017.
- [678] Zebra Technologies, *How the Internet of Things Is Improving Transportation and Logistics*, ZIH Corporation, California, 2015.
- [679] N. Mostafa, W. Hamdy, and H. Alawady, "Impacts of internet of things on supply chains: a framework for warehousing," *Social Sciences*, vol. 8, no. 84, pp. 1–10, 2019.
- [680] AT&T, *IoT: A Strategic Approach to Logistics: A Focus on Innovation to Meet the Mission*, Gallows Road, Vienna, 2016.
- [681] T. Khare and R. K. Dubey, *Leveraging IoT for Logistics*, NEC Corporation, Vienna, 2017.
- [682] P. Tadejko, "Application of internet of things in logistics-current challenges," *Economics and Management*, vol. 7, no. 4, pp. 54–64, 2015.
- [683] AT&T and Eft, "The Internet of Things (IoT) in Supply Chain and Logistics," 2016.
- [684] H. S. Birkel and E. Hartmann, "Internet of Things-the future of managing supply chain risks," *Supply Chain Management: An International Journal*, vol. 7, 2020.
- [685] M. Tu, "An exploratory study of Internet of Things (IoT) adoption intention in logistics and supply chain management," *The International Journal of Logistics Management*, vol. 29, no. 1, pp. 131–151, 2018.
- [686] C. Liu, Y. Feng, D. Lin, L. Wu, and M. Guo, "Iot based laundry services: an application of big data analytics, intelligent logistics management, and machine learning techniques," *International Journal of Production Research*, vol. 7, pp. 1–20, 2020.
- [687] G. Xie, "Smart logistics management of hazardous chemicals based on internet of things," *Chemical Engineering Transactions*, vol. 67, pp. 85–90, 2018.
- [688] M. Ben-daya, E. Hassini, and Z. Bahroun, "Internet of things and supply chain management: a literature review," *International Journal of Production Research*, vol. 57, no. 15-16, pp. 4719–4742, 2019.
- [689] Y. Cui, *Supply Chain Innovation with IoT*, IntechOpen, London, UK, 2018.
- [690] Z. Zhao, M. Zhang, G. Xu, D. Zhang, and G. Q. Huang, "Logistics sustainability practices: an IoT-enabled smart indoor parking system for industrial hazardous chemical vehicles," *International Journal of Production Research*, vol. 7, pp. 1–17, 2020.
- [691] K. Buntak, M. Kovačić, and M. Mutavdžija, "Internet of things and smart warehouses as the future of logistics," *Tehnički Glasnik*, vol. 13, no. 3, pp. 248–253, 2019.
- [692] M. Tu, M. Lim, and M.-F. Yang, "Internet of Things-Based Production Logistics and Supply Chain System-Part 2: IoT-Based Cyber-Physical System: A Framework and Evaluation," *Industrial Management & Data Systems*, vol. 7, pp. 1–30, 2016.
- [693] S. Zaib and J. Iqbal, *Nanotechnology: Applications, Techniques, Approaches, & the Advancement in Toxicology and Environmental Impact of Engineered Nanomaterials*, Med-Docs Publishers LLC, London, UK, 2019.
- [694] J. E. M. Allan, *Technology Transfer in Nanotechnology*, Publication Office of the European Union, Luxembourg, 2019.
- [695] J. T. Li and H. Liu, "Design optimization of amazon robotics," *Automation, Control and Intelligent Systems*, vol. 4, no. 2, pp. 48–52, 2016.
- [696] M. Johnson, "Quiet Logistics' Next Step into Robotics: Modern System Report," 2016.
- [697] T. Wozniakowski, K. Zmarzłowski, and M. Nowakowska, "Automation and innovations in logistic processes of electronic commerce," *Information Systems in Management*, vol. 7, no. 1, pp. 72–82, 2018.
- [698] A. Dekhne, G. Hastings, J. Murnane, and F. Neuhaus, "Automation in Logistics: Big Opportunity, Bigger Uncertainty," 2019.
- [699] D. Küpper, *Advanced Robotics in the Factory of the Future*, Boston Consulting Group (BCG), Boston, MA, USA, 2019.
- [700] Institute for Supply Management, "New types of robots are providing opportunities for logistics, manufacturing and other industries, while enabling workers to do what they do best: interacting and performing more highly skilled jobs," 2018.
- [701] G. Q. Huang, M. Z. Q. Chen, and J. Pan, "Robotics in e-commerce logistics," *HKIE Transactions ISSN*, vol. 22, no. 2, pp. 68–77, 2015.
- [702] T. Bonkenburg, "Robotics in Logistics: A DPDHL Perspective on Implications and Use Cases for the Logistics Industry," 2016.
- [703] R. Strulak-Wójcikiewicz and J. Lemke, "Concept of a simulation model for assessing the sustainable development of urban transport," *Transportation Research Procedia*, vol. 39, pp. 502–513, 2019.
- [704] J. Maina and P. Mwangangi, "A critical review of simulation applications in supply chain management," *Journal of Logistics Management*, vol. 9, no. 1, pp. 1–6, 2020.
- [705] N. Belyak, *Simulation Methods for Transport Logistics*, Lappeenranta University of Technology School, London, UK, 2017.
- [706] C. Fu and Z. Shuai, "The simulation and optimization research on manufacturing enterprise's supply chain process from the perspective of social network," *Journal of Industrial Engineering and Management*, vol. 8, no. 3, pp. 963–980, 2015.
- [707] M. Zhang and C. S. Liu, "Cost simulation and optimization of fresh cold chain logistics enterprises based on SD," *IOP*

Conference Series: Materials Science and Engineering, vol. 392, 2018.

- [708] F. S. Yanikara and M. E. Kuhl, "A simulation framework for the comparison of reverse logistic network configurations," 2015.
- [709] A. Ghadge, M. Er Kara, and H. Moradlou, "The impact of Industry 4.0 implementation on supply chains," *Journal of Manufacturing Technology Management*, vol. 31, no. 4, pp. 669–686, 2020.
- [710] M. F. Goswami, K. K. Castillo-villar, M. Aboytes-ojeda, and M. H. Giacomoni, "Simulation-optimization approach for the logistics network design of biomass Co-firing with coal at power plants," *Sustainability*, vol. 10, 2018.
- [711] J. González-reséndiz, K. C. Arredondo-soto, A. Realyvázquez-vargas, H. Híjar-rivera, and T. Carrillo-gutiérrez, "Integrating simulation-based optimization for lean logistics: a case study," *Applied Sciences*, vol. 8, no. 2448, 2018.
- [712] S. Mutke, C. Augenstein, M. Roth, A. Ludwig, and B. Franczyk, "Real-time information acquisition in a model-based integrated planning environment for logistics contracts," *Journal of Object Technology*, vol. 14, no. 1, pp. 1–25, 2015.
- [713] A. Muravjovs, *Inventory Control System Analysis Using Different Simulation Modelling Paradigms*, Transport and Telecommunication Institute, Berlin, Germany, 2015.
- [714] Department of Defense for Research & Engineering, "Technical Assessment: Synthetic Biology," 2015.
- [715] IICA, "Proceedings of the first seminar on synthetic biology for biotechnology-regulatory decision makers from the americas," IICA, Berlin, Germany, 2017.
- [716] P. Sachsenmeier, "Industry 5.0-the relevance and implications of bionics and synthetic biology," *Engineering*, vol. 2, no. 2, pp. 225–229, 2016.
- [717] A. Tinafar, K. Jaenes, and K. Pardee, "Synthetic biology goes cell-free," *BMC Biology*, vol. 17, no. 64, 2019.