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Review Article

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

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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 complemental 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

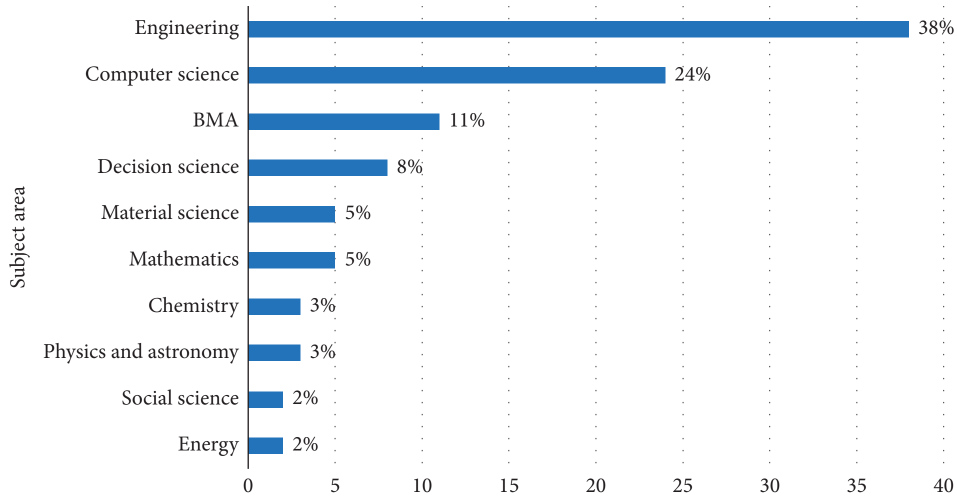

Figure 1: Percentage of industry 4.0 published papers per subject area (adapted from Chiarello et al. [52]). BMA: business, management and accounting.

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," "Robotic 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

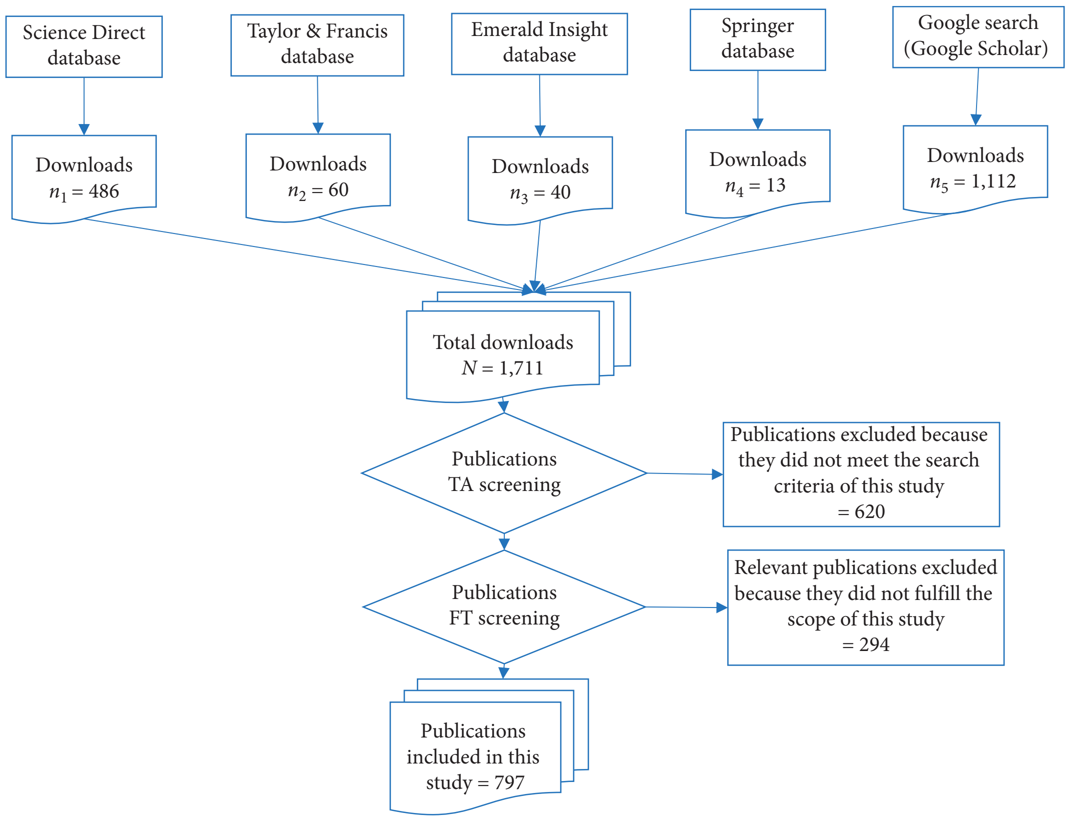

Figure 2: The flowchart diagram for the literature search strategy used in this study. $N = n_1 + n_2 + n_3 + n_4 + n_5$ represents the total number of PDF files downloaded from the respective databases.

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]
		Industrial Maintenance 4.0	[77]
2	Industry (oil and gas, manufacturing, agriculture, engineering and technology, construction, pharmaceutical, textiles and apparel, energy, and web)	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]
		Web 4.0	[101]
		Energy Cloud 4.0	[102]
		Energy System 4.0	[103]
		Manufacturing 4.0	[104]
3	Education and training	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]
		Delivery Process Maturity Model 4.0, DPMM 4.0	[141]
		Procurement 4.0	[142]
		Customer 4.0	[127]
		Consumer 4.0	[143]
		Finance 4.0	[144]
		Bank 4.0	[145]
5	Society, government, economy, human resource, workforce, management, leadership, globalization	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 complemental 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

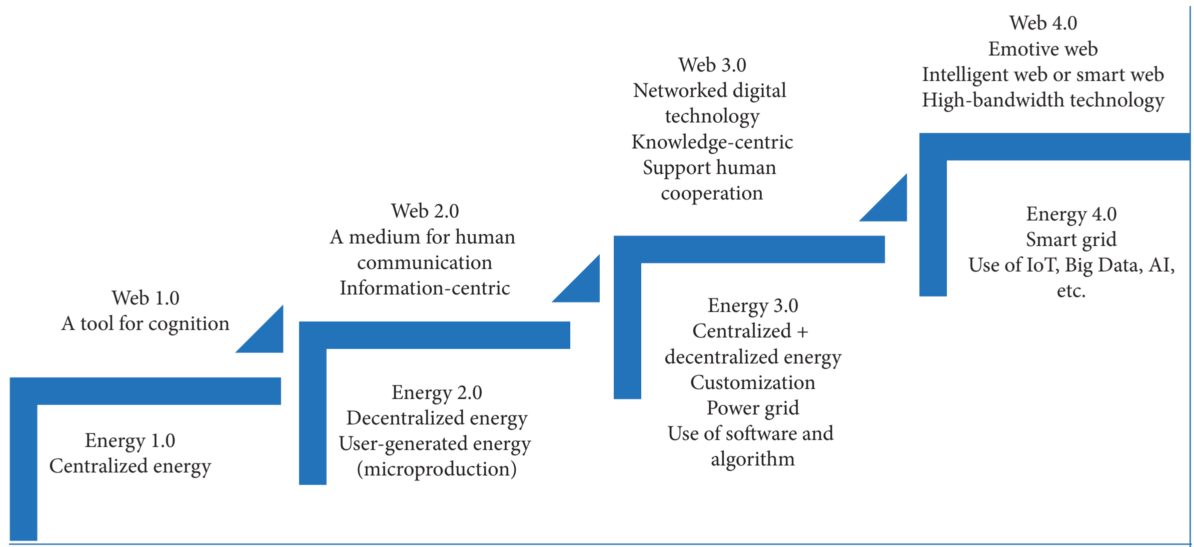

Figure 3: The transition in web and energy systems.

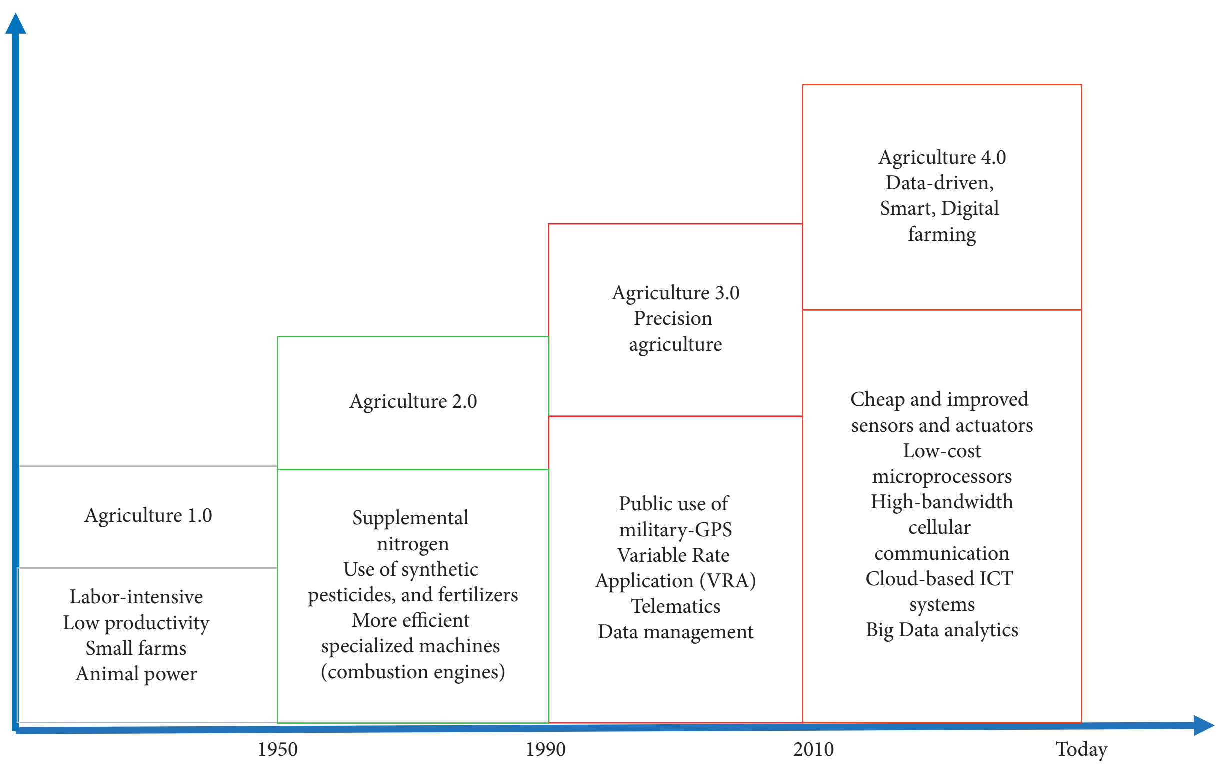

Figure 4: Paradigm shifts in agriculture.

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	[280, 282, 284–287]
		FPM: food (supply chain) traceability and safety	[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	[295, 297, 300, 301]
		WEM: weather forecasting	[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 agrologistics, 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	[330, 332, 333]
		WEM: frost protection	[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 nanobisensors	[353–361]
		CLGIP: plant bleeding (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.

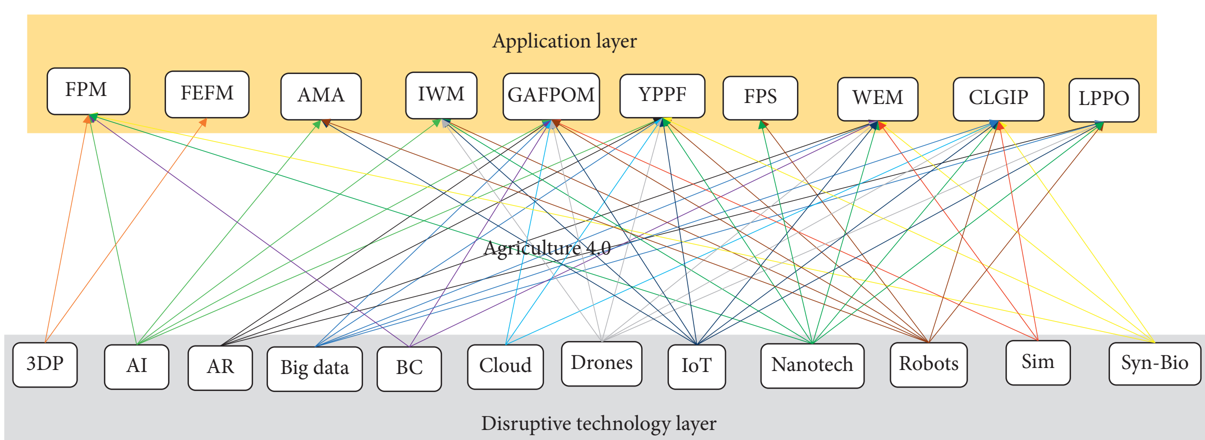

Figure 5: The convergence of disruptive technologies in agriculture and food systems.

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,

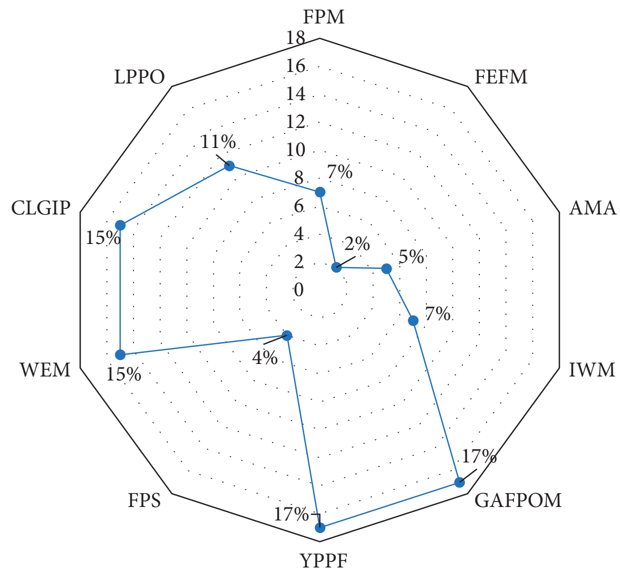

Figure 6: Percentage technology convergence in agriculture and food systems.

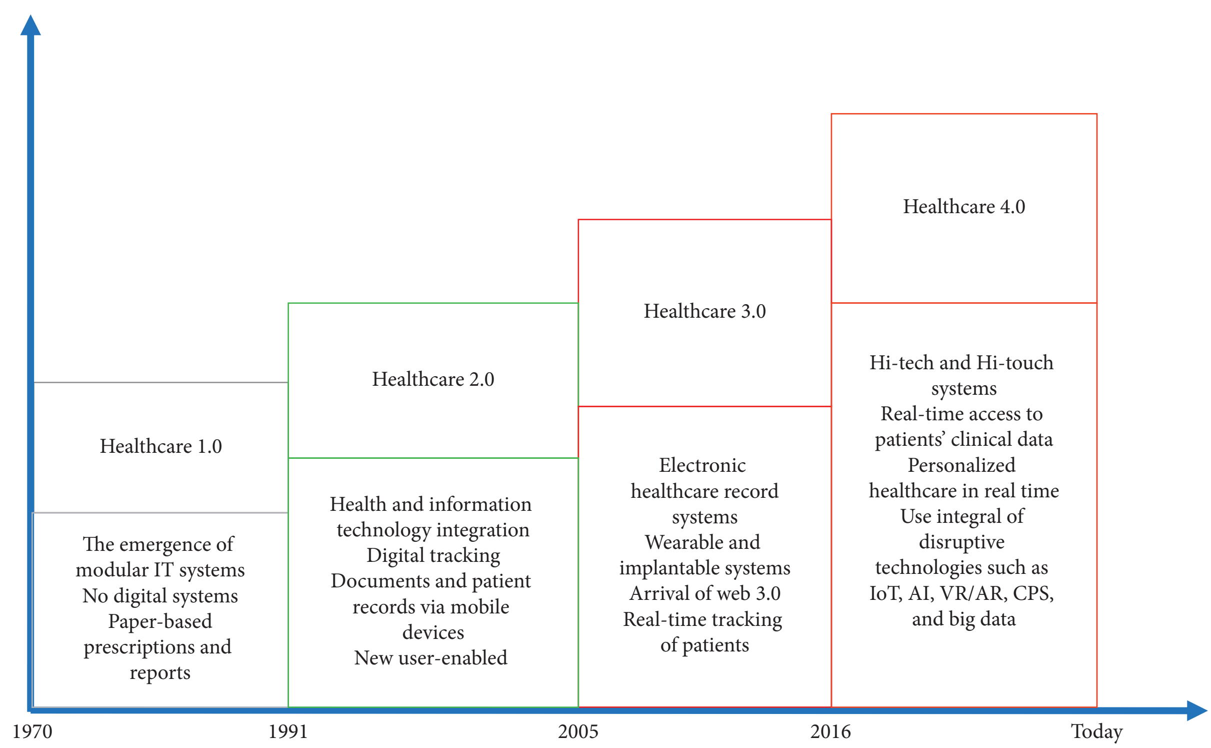

Figure 7: Evolution of the healthcare system.

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]
		Dentistry	[431, 432, 437, 439]
2	AI	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]
		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]
3	AR	MERT: medical education and training	[449–455]
		Monitoring: wellness (adult care)	[453, 455–458]
		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]
4	Big data	Medical imaging	[461, 462]
		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]
		HFMPO: fraud detection in healthcare facilities and workflow process optimization	[463, 465]
5	Blockchain	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]
		Monitoring: blockchain for 5G-enabled IoT	[483]
6	Cloud computing	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	HFMPO: 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	HFMPO: 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 HFMPO: 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

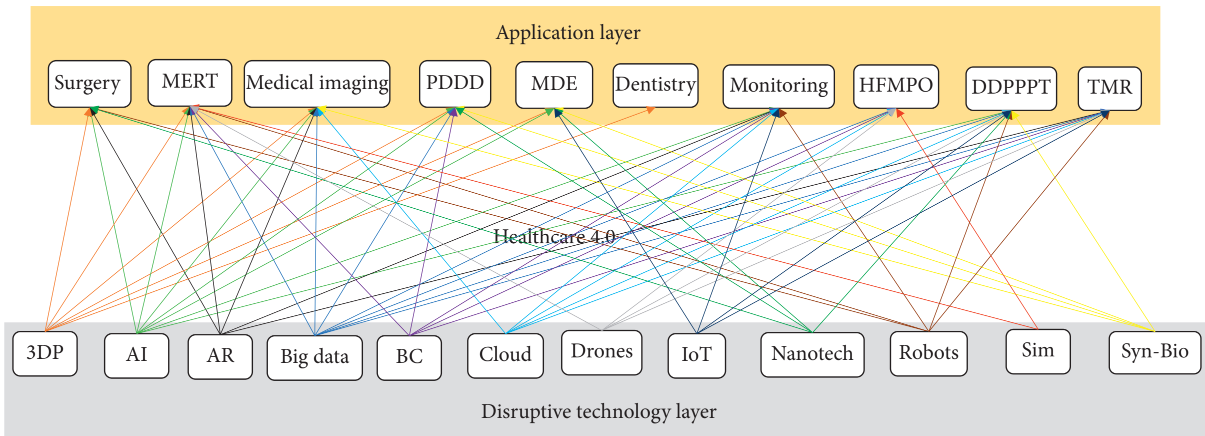

Figure 8: The convergence of disruptive technologies in healthcare.

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

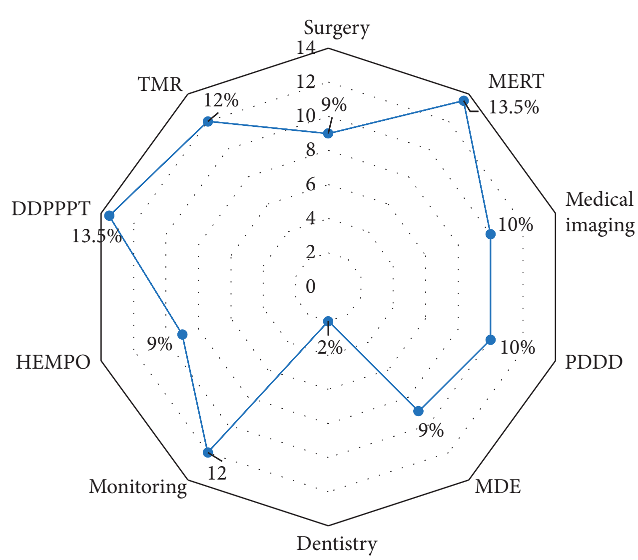

Figure 9: Percentage convergence of technologies in the healthcare system.

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

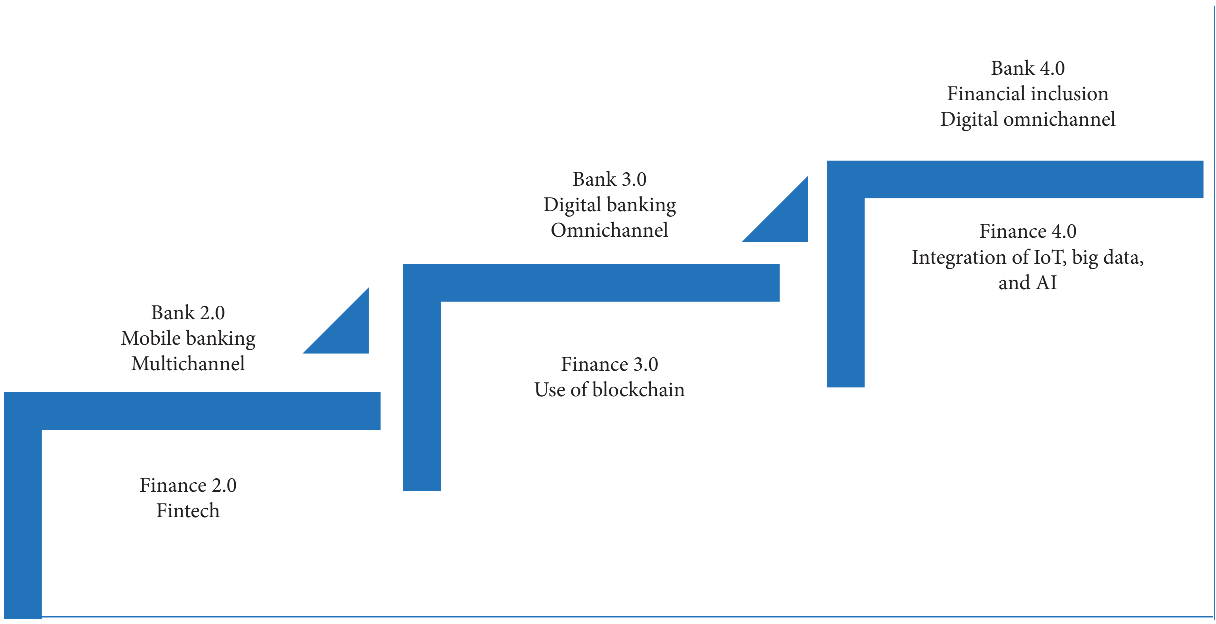

Figure 10: Generations of finance and banking systems.

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.

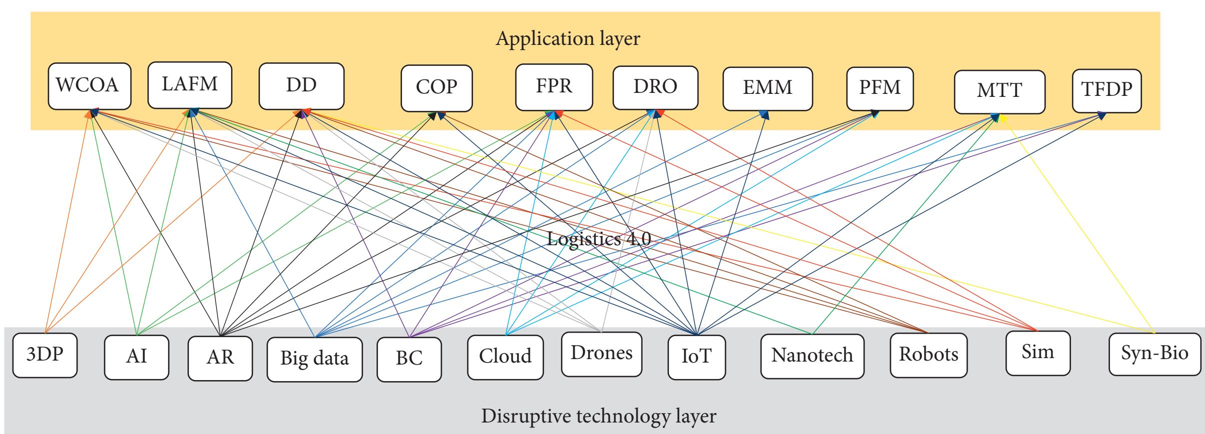

Figure 11: The convergence of disruptive technologies in logistics.

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.

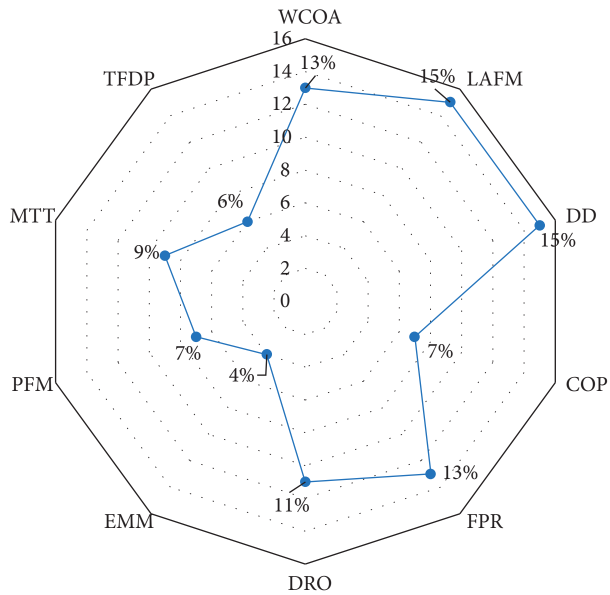

Figure 12: Percentage convergence of technologies in logistics.

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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