Review

Exponential Disruptive Technologies and the Required Skills of Industry 4.0: A Review

Ocident Bongomin[1]*, Gilbert Gilibrays Ocen[2], Eric Oyondi Nganyi[1], Alex Musinguzi[1,3], Timothy Omara[4,5]

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

[2] Department of Electrical and Computer Engineering, Faculty of Engineering, Busitema University, P.O. Box 236, Tororo, Uganda.

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

[4] Department of Chemistry and Biochemistry, School of Biological and Physical Sciences, Moi University, P.O. Box 3900-30100, Eldoret, Kenya.

[5] Department of Quality Control and Quality Assurance, Product Development Directory, AgroWays Uganda Limited, Plot 34-60, Kyabazinga Way, P.O. Box 1924, Jinja, Uganda.

* Correspondence: ocidentbongomin@gmail.com, ocident@mu.ac.ke

Abstract: The 21st century has witnessed precipitous changes spanning from the way of life to the technologies that emerged. We have entered a nascent paradigm shift (industry 4.0) where science fictions have become science facts, and technology fusion is the main driver. Thus, ensuring that any advancement in technology reach and benefit all is the ideal opportunity for everyone. In this study, disruptive technologies of industry 4.0 was explored and quantified in terms of the number of their appearances in published literature. The study aimed at identifying industry 4.0 key technologies which have been ill-defined by previous researchers and to enumerate the required skills of industry 4.0. Comprehensive literature survey covering the field of engineering, production, and management was done from multidisciplinary databases: Google scholar, ScienceDirect, Scopus, Sage, Taylor & Francis and Emerald insight. Results of the electronic survey showed that 35 disruptive technologies were quantified and 13 key technologies: Internet of things, Big data, 3D printing, Cloud computing, Autonomous robots, Virtual and Augmented reality, Cyber physical system, Artificial intelligence, Smart sensors, Simulation, Nanotechnology, Drones and Biotechnology were identified. Both technical and personal skills to be imparted into the human workforce for industry 4.0 were reported. The study identified the need to investigate the capability and the readiness of developing countries in adapting industry 4.0 in terms of the changes in the education systems and industrial manufacturing settings. The study proposes the need to address integration of industry 4.0 concepts into the current education system.

Keywords: 3D printing; artificial intelligence; big data; cloud computing; education system; disruptive technologies; industry 4.0; internet of things; skills; virtual and augmented reality.

1. Introduction

At present, industry 4.0 which differs in speed, scale, complexity and transformative power as compared to the previous industrial revolutions can be considered as nascent [1]. Therefore, having prior insight into the speed and measure of the changes being brought by industry 4.0 is a prerequisite for success [2,3]. Industry 4.0 will increase the visibility of the existing inequalities among people, companies and countries worldwide, as every country embraces its technologies in its own way [4]. African countries for example, are embracing Industry 4.0 at extremely slower rates vis-à-vis European countries [5,6]. For survival in the industry 4.0 era, being knowledgeable about the changes and the speed at which they are occurring is indispensable. Thus, ensuring that any advancement in

1

technology reach and benefit all is an ideal opportunity for everyone [7,8]. This is because industry 4.0 technologies are exponentially disruptive in nature [9].

Historically, technological innovations have been considered as the main drivers for sustainable economic development and productivity growth [10,11]. Further, they have been linked to changes in work and employment but this no longer applies to industry 4.0 [12]. This is because industry 4.0 emerged due to the fusion of technologies which are known to be exponentially growing and disruptive in a fashion expected to initiate rapid and massive disruption to all industrial sectors in terms of demand for occupations and skills [13]. Recently, advancement in disruptive technologies and industrial developments have been incisive towards industry 4.0 [14], which is popularized with diametrically different names in various countries. For instance, it is publicized as Made in China 2025 by China [15], Industrial Internet Consortium (IIC) and Smart Manufacturing Leadership in USA and Robot Revolution Initiative (RRI) and Industrial Value Chain Initiative (IVI) in Japan [16].

Industry 4.0 is matchless with the preceding industrial revolutions owing to the substantial role its technologies play in wealth creation and socio-political stability [17,18]. However, the factors that triggered the past revolutions, which include among others various public and private initiatives, are also forthwith stimulating Industry 4.0 developments [19]. The other unique factors which are the major drivers for industry 4.0 include the rapid technological developments and the need for singularities by the manufacturing companies [20]. Industry 4.0 will not only influence manufacturing industries as with the previous industrial revolutions but also leave footprints on the social, economic and education sectors [21–23]. In point of fact, its influence on education system has been under obsessive research in the recent years [24,25]. Thus to secure most jobs, the requisite skills ought to be imparted into people through the right channel of education in higher institutions of learning [26].

Despite the rigorous researches done by distinguished organizations such as the World Bank, World Economic Forum (WEF) and Mckinsey Global Institute, the concept of industry 4.0 remains entirely non-consensual [27,28]. Interestingly, industry 4.0 key technologies have been identified by these organizations and other academic researchers, though these technologies and their rankings dissent from one organization to another and amongst academic researchers [29,30]. For instance, Manyika *et al.* [31] identified nine (9) key disruptive technologies whereas Mckinsey Global Institute on the other hand reported twelve (12) key disruptive technologies of industry 4.0 [32]. Boston Consulting Group in their findings recognized nine (9) key disruptive technologies [33]. Contrastingly, Cheryl and Helena [34] singled out five (5) key disruptive technologies, well less than the ten (10) key disruptive technologies of industry 4.0 pointed out by Mashelkar [35]. The divergent sentiments and inferences drawn by previous researchers about the key technologies of industry 4.0 is quite exigent and can delude many interested researchers and practitioners. The exigency to clearly enumerate and comprehend the above observed differences, explore and recognize the key technologies as well as the requisite skills of industry 4.0 instigated the present study.

2. Methodology

A comprehensive literature search was conducted in the electronic databases: Google scholar, ScienceDirect, Scopus, Sage, Taylor & Francis and Emerald insight. The search terms used included "industry 4.0" or "fourth industrial revolution". A more general search was done on Google search engine to capture all the relevant publications in the field of engineering, production and management published between 2011 to 2019. The relevant literature selected from the databases were in form of journal articles, conference papers, white papers, working papers, books, thesis and reports [27].

3. Results and Discussion

3.1. Industry 4.0 Definitions

The term "Industry 4.0" was coined by German's group of mechanical engineers in the year 2011 to account for the widespread integration and adaptation of ICT in manufacturing industries [18]. The definition of industry 4.0 is ambiguous and no single definition has been conventionally adopted. Institute of Technology Assessment (ITA) [36] defined industry 4.0 as a systemic change bringing about extensive changes in the way works are done. It is further stressed that industry 4.0 is not just about the introduction of a new technology linked with an incremental adaptation of work systems as in the previous three industrial revolutions, but about an assemblage of novel technologies and forms of application, with discrete degrees of technical maturity and systemic effects. Simply put, industry 4.0 is a precipitous transition from the previous industrial revolutions (Table 1).

Schröder [37] defined industry 4.0 as the digital transformation in all areas of industrial processes and production effectuating a new paradigm shift in production systems. In addition, industry 4.0 has also been defined as the massive developmental stage in industrial manufacturing including organisation and the management of the entire value chain [38], and its technologies are the blurring line between the physical, digital and biological sphere of production or manufacturing system [34]. An industry 4.0 definition modified from Cheryl and Helena [34] and Deloitte [38] has been adopted in the present study.

Table 1. Industrial Revolution Transition

Revolution and timeline	Technologies and capabilities	Main industries	Main engineering discipline(s)
Industry 1.0 1760-1900	Mechanization using water and steam (first mechanical weaving loom)	Coal, iron, textile	Mechanical engineering
Industry 2.0 1900-1960	Mass production using electricity (first assembly line)	Semiconductors, automobiles, steel, airplanes	Electrical engineering, industrial engineering
Industry 3.0 1960-2000	Automation using digital electronics and IT (first PLC system)	Electronics, mobile phones, internet, computer, robots.	Computer and electronic engineering, software engineering.
Industry 4.0 2000-today	Innovation based on the "fusion of virtual, physical, digital and biological sphere" (cyber physical production system)	Social media, self-driving cars, drones, virtual assistant.	Integration of many engineering disciplines e.g. mechatronic engineering, biomechanical engineering.

Modified from [1,24,39].

3.2. Exponential Disruptive Technologies

The industry 4.0 is being powered by exponentially growing disruptive technologies that inaugurate changes rapidly but at a nonlinear pace [1,40]. Besides, these technologies have a potential to cause broader societal transformation by changing the existing economic sectors, tenets of work, production and consumption [41]. In the main, two types of technologies can be appreciated: sustaining and disruptive technologies; the former has a constant or incremental rate of improvement of existing customers whereas the latter creates disruption on the status quo as it produces a unique set of values. The major implication of disruptive technology is the demand for new course content, employment, knowledge and skills [35,38,42].

In this electronic survey, 35 disruptive technologies were identified in 70 publications. Ranking of the technologies was done basing on the number of their appearances in the selected publications as shown in Table 2. From the ranking results, 13 key technologies were selected as illustrated by the pareto chart (Figure 1). The current and the future development and application areas of these key disruptive technologies are discussed.

Table 2. Disruptive Technologies of Industry 4.0

Rank	Disruptive technology search terms	Appearances	References
1	Internet of Things (IoT)	33	[1,8,15,16,22,25,27,29,40,43–66]
2	Big data (data mining, data analytics and advanced algorithms)	30	[8,10,16,29,33,44,46,47,49,50,51–53,55,56,59,60,63–65,66–74]
3	Additive manufacturing (3D printing, 3D scanning)	28	[1,7,8,10,33,40,47–50,51–59,61,62–67,69,75]
4	Cloud Computing	27	[8,10,29,33,44–46,48–50,52,53,55,56,59,63–67,69,70,72,76–78]
5	Autonomous robots (industrial robots, robot arms)	24	[1,8,10,15,33,48,50–53,54–57,59,61,62,64,65,67,69,74,79]
6	Virtual Reality (VR) and Augmented Reality (AR)	21	[8,10,33,47,50–53,55,56,61–66,69,74,80,81]
7	Cyber physical systems (CPS)	20	[8,15,16,24,25,27,29,44,46,47,48,52,56,66,69,70,72,82–84,85]
8	Artificial intelligence (AI) and machine learning	19	[1,8,33,50,53–57,59,61,62,64–66,74,78,86]
9	Smart sensors (smart actuators, smart objects and smart dust)	15	[35,48,49,51,54,58,62,63,65,75, 87–91]
10	Advanced simulation (3D Modelling and 3D Visualization)	15	[33,35,40,49,52,56,64,65,69,74,79,91–94]
11	Nanotechnology (advanced materials, nanomaterials, nanobots)	13	[40,51,53–55,57,59,62,64,74,86,89,91]
12	Drones, UAV, UASs and RPA[1]	10	[8,35,40,51,54,55,62,65,74,92]
13	Biotechnology (synthetic biology, molecular biology)	10	[35,40,53–55,57,59,62,86,91]
14	Block chain (Bitcoin, Cryptocurrency, digital currency)	7	[8,37,46,56,58,59,63]
15	Industrial internet of things (IIoT), or Industrial internet	6	[12,24,25,33,37,38]
16	Cybersecurity	6	[37,48,49,54–56]
17	Smart factory and intelligent factory	5	[8,15,16,24,26]
18	Internet of services (IoS)	5	[8,27,29,37,48]
19	Vertical and horizontal (V&H) system integrations	5	[11,33,56,64,69]
20	Renewable energy and advanced energy storage	4	[53,54,59,62]
21	Machine to Machine communication (M2M)	4	[8,29,57,67]
22	5G network (Advanced network technology)	4	[49,56,58,73]
23	Information and communication technology (ICT)	3	[16,44,46]
24	Quantum computing	3	[53,54,62]
25	Mobile devices (smart phones, smart cameras)	3	[51,63,67]
26	Manufacturing execution system (MES) and SCADA[2]	2	[16,53]
27	Neurotechnology	2	[59,62]
28	Predictive Maintenance	2	[71,74]
29	Advanced Human to Machine interface (HMI)	2	[63,74]
30	Material science	1	[53]
31	Internet of data (IoD)	1	[52]
32	Internet of Energy (IoE) (Smart grid)	1	[66]
33	Flexible Production system (FMS) and Cluster concept	1	[49]
34	Location detection (Digital traceability and GPS)[3]	1	[63]
35	Digital Twin	1	[74]

Notes: [1]UAV-Unmanned Aerial Vehicle, RPA- Remotely Piloted Aircraft, UASs-Unmanned Aircraft Systems, [2]SCADA Supervisory Control And Data Acquisition, [3]GPS-Global Positioning System.
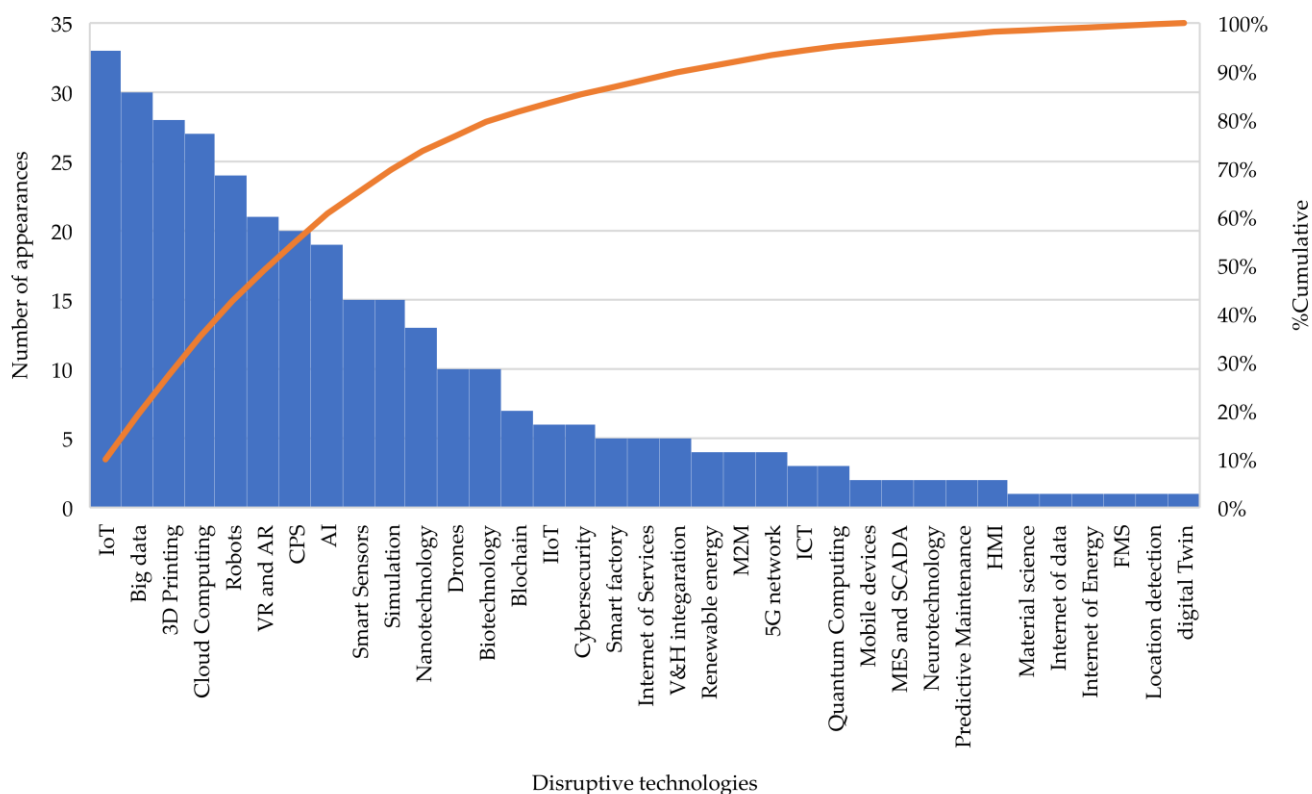
Figure 1. Identification of key disruptive technologies of industry 4.0

3.2.1. Internet of Things (IoT)

IoT is not just machine-to-machine (M2M) connectivity but its definition spans beyond by creating an intelligent, invisible network fabric that can be sensed, controlled and programmed through which the physical world objects become intelligent and communicate independently, online [95]. Characteristically, IoT is referred to as internet of everything (IoE) [96]. The 'things' can be electronic sensors, actuators, other digital devices or any other objects (e.g. people, buildings) [59]. The integration of internet to everything was meant to facilitate production systems [50,97]. In industries, IoT has been exploited in automation for lighting, heating, robotic vacuums, remote monitoring and control of machines [50]. Despite it being a dateless technology, IoT has enormous innovative applications of its technologies [98]. For instance, automatic identification technology such as radio frequency identification (RFID) [99] and Beacons [100] are currently used to make any object (such as product) to become smart [101]. The other application domains of IoT include supply chain management, healthcare [102,103], disaster vigilance and recovery [104]. The IoT systems has also found application in predictive maintenance systems and real-time urban microclimate monitoring [105]. Most of IoT applications have been classified as components of smart cities [103,106].

Typical IoT architecture consists of three layers; (i) perception layers (ii) network layers and (iii) application layers [107]. The first layer function as sensors for data acquisition. The second layer operate as a data transmission platform and the last layer is the application layer in which the smart environment is created. Examples of smart environment include smart city, smart home, smart grid and smart government [108]. The great barriers to IoT applications are cyber-attack (i.e. security and forensic challenges) and low connectivity. For these salient reasons, the major development of IoT

during the move to industry 4.0 will focus on exploring innovative solutions that will pave way to secure forensically sound deployment of IoT networks [109,110] as well as increase the IoT systems connectivity [111]. The foremost companies behind the IoT inventions and deployment include GE, IBM, CISCO, Google, Amazon, Microsoft, SAP and AG [112]. These companies are respectively responsible for Microsoft Azure IoT, Oracle IoT cloud services, Google cloud IoT core, IBM Watson IoT, AWS IoT and Bosch IoT suite IoT platform markets [113].

3.2.2. Big Data

The Big Data are rather distinct from the traditional data due to their large growing dataset [114]. Lately, Big data have been defined in terms of huge datasets that consists of six main characteristics namely: volume, variety, velocity, veracity, value and complexity [115]. The intricacy of Big data brought its own problem as it demand for new skills and knowledge [114,116]. In addition, it has a pronounced impact on board level or stakeholders decision making [117]. With the move to industry 4.0, the main application areas of Big data include smart grid [118], smart meter [119], internet of things [120], E-health (notably pharmaceutical data, lab and clinical data), public utilities (such as water supply and sewage system), transportation and logistics (for example, the number of passengers using buses, number of accident occurring per year), agricultural remote sensing (data obtained from soil moisture, temperature changes) [121]. Another application area of Big data is the digital finance, where it is used as big data credit investment which fully utilizes modern digital information techniques [122]. Finally, Big data have recently been adopted for massive open online course (MOOC) and its application in this area is expected to grow explosively in the era of industry 4.0 [123].

The major techniques commonly used in Big data are relational and non-relational data stores, computations, and MapReduce while the software frameworks in Big data include Hadoop, Spark, Hive, and Google's BigQuery [124]. However, with the continuous advancement required to shape industry 4.0 movements, more advanced Big data software frameworks that can handle extensively huge amounts of data are expected to emerge.

3.2.3. 3D Printing

3D printing (additive manufacturing) unlike subtractive manufacturing is the technology that build up physical objects based on 3D-CAD file by consecutive addition of liquid, sheet or powered materials [125]. The populously employed materials by 3D printers are plastics (such as polylactic acid, acrylonitrile butadiene styrene and hydrogel composites) [126,127], and metallic materials notably steel, stainless-steel, titanium, gold and silver [128]. The recently developed materials used by 3D printers are liquid crystal elastomers and jammed microgel ink [129]. The technologies behind 3D printing advancement include nanoparticles jetting, laser engineering net shape, wire and arc additive manufacturing, electron beam melting, selective laser sintering/melting, atomic diffusion additive manufacturing, single pass jetting, fused deposition modeling, direct ink printing and filament extrusion method [130].

Universally, 3D printing has been applied to produce nearly everything, ranging from buildings to human organs (such as the kidney and the heart) and tissues (bones, muscles, teeth) [127,129,131,132]. Though its application for printing body parts (3D bioprinting) is in its infancy, it is anticipated to rise astronomically with industry 4.0 movements [133]. Beyond, the growth of 3D printing will strategically explore innovations for bioproduction of living responsive materials (such as shape-memory polymers, aqueous droplet) and devices such as soft robots [134].

3.2.4. Cloud Computing

Cloud computing is a service model where computing services that are available remotely permit users to access applications, data and physical computation resources over a network, on demand or pay-per-use fashion [135,136]. The application domains of cloud computing technology in education include e-learning (such as curriculum content management, virtual lab environment,

office productivity suite, library management, collaborative learning), communication (email and notifications) and administration (such as students registration management, human resources management) [137]. Cloud computing has not only been used in the education sector but also in other sectors such as healthcare [138], manufacturing, entertainment, transportation and energy [139].

Over the years, cloud computing has been used for some enterprise and analytics applications, but in the era of industry 4.0, the performance of cloud technologies is expected to improve particularly following the security in both network, application and host level [135]. The main companies behind cloud computing development and deployment are Amazon, Microsoft, Google and IBM. These cloud providers often implement inflexible pricing schemes for cloud users based on the duration [139].

3.2.5. Autonomous Robots

Autonomous robots as the name suggests, performs autonomous production more precisely and can work alongside humans or even in human restricted places. They have the faculty to complete assigned tasks accurately and perspicaciously in time, focusing on safety, flexibility, versatility and collaboratively [140], contrary to the olden days when robots were designed primarily to tackle complex assignments in manufacturing industries. The autonomous robots are also being utilized in logistics such as warehouses and container terminals [141]. The development of autonomous robots has been continuously advancing to meet the need of industry 4.0 [142,143]. The major companies behind the autonomous robots' innovations and development are Kuka, Rethink Robotics, Bionic robotics, Roberta Gomtec, Honda, ABB and Fanuc. The autonomous robot architecture entails functional and decisional components [144] which with the upsurge of industry 4.0 will have to be developed as the exploration of new areas of applications of autonomous robots increases.

3.2.6. Virtual and Augmented Reality

Virtual reality (VR) and augmented reality (AR) are complementary technologies of industry 4.0. With VR, the users are transported, usually via a headset, into a virtual world while with AR, applications present an illusion of layers of graphic information superimposed on some portion of the user's field of view [80]. In most cases, the two technologies are combined (also known as Mixed reality) to yield gigantic applications by transcending the distance, time and scale and increasing comprehension, teamwork, communications and decision making. Although AR is regarded as a developing technology with some of its technical manuals missing [145], it remains emblematic of industry 4.0 as it bring together the physical and digital worlds, and indeed, the public and the private sphere [66].

The foremost application domain of VR and AR has been in education since the 1990s to teach subjects like mathematics, geometry, physics, chemistry and anatomy [146]. In the past few years, VR has been applied in virtual training. For instance, a virtual plant-operator training module is being used to train plant personnel to handle emergencies [147]. In maintenance, AR has been used for repairing and servicing complex systems such as hydraulic breakers [80,148]. Other application areas of VR and AR include tourism, retail and fashion, business, marketing, storytelling, healthcare, defense, design and development. The main companies behind the development of VR and AR are Google, Microsoft, Apple and Espon. Examples of currently used AR smart glasses include Google Glasses, Microsoft HoloLens, Apple Headset and Espon Moverio Pro BT-2000 [145].

3.2.7. Cyber Physical System (CPS)

CPS is referred to as a networked system in which the cyber or computational part is tightly integrated with the physical components. CPS uses multiple sensors such as touch, light and force sensors to achieve distinct purposes. This makes CPS exceedingly discrete from just an embedded system [149]. Lately, CPS frameworks have been congruously utilized in various fields including manufacturing [150], laboratory and teaching factory [151,152]. The latest development of CPS is the Mobile CPS that extend CPS application domains [153]. With the precipitous shift to industry 4.0,

further development of CPS will focus on the protection of critical industrial systems, manufacturing lines and other CPS application frameworks from cyber security threats. Consequently, secure, reliable communications as well as sophisticated identity and access management of machines and users are very essential [153,154]. Hence, CPS will be integrated with other technologies including IoT, cloud computing and smart sensors to form the new smart CPS that will link the virtual, physical and digital worlds. This will enable intelligent or smart objects to properly and rapidly communicate and interact with each other [154].

3.2.8. Artificial Intelligence (AI)

AI is the knowledge-based and thinking program coded and designed in machines to imitate human or animal reasoning ability [155]. For the past few years, AI has been applied in complex operations such as drilling fluid, underground mining [156,157] and maintenance as well as monitoring of sophisticated manufacturing systems [158]. The emerging AI applications that are currently shaping industry 4.0 journey include self-driving cars, human speech and face recognition, interpreting of complex data and medicines (for example cardiovascular medicine) [159]. As we move to industry 4.0, AI advancement gear towards integration of AI technology with other technologies such as Big data, Cloud computing to perform gigantic tasks and to widen their application in all fields. For example, a recent finding indicate that AI can be properly applied to handle infectious disease big data analytics in healthcare sectors [160]. Notable companies behind AI development include Google, SpaceX, Apple, GE and Microsoft [159,161].

3.2.9. Smart Sensors

Several types of smart sensors have been developed in the recent past to furnish the need of industry 4.0. These sensors are engineered in the manufacture of smart devices or objects such as smart dust, smart cameras, smart phones and smart homes [162]. Smart sensors have been largely used for monitoring purposes [163]. Monitoring systems for water and flood levels, gas, environmental, structural health, remote and equipment fault diagnostic systems, as well as advanced medical applications employ smart sensors [162,164,165]. In industry 4.0 era, these smart sensors will be integrated with the IoT system and the advancement of smart sensors will continue to grow tremendously [166]. Smart home, smart cities and smart grids are now available because of various installed temperature, proximity, optical, pressure and ultrasonic smart sensors [167,168].

3.2.10. Simulation

Simulation is a routine method of analyzing the behavior of complex systems. Simulation is a classical antiquity technology which dates far back to the era of analog computers [169]. Nonetheless, its application have proliferated in different fields because of its demonstrated ability to improve components of manufacturing systems (products, materials and ergonomic design, energy consumption, production processes and efficiency) [170], education and other industrial sectors [171]. For instance, simulation has been utilized in complex automobile manufacturing, ceramic production and chemical processes [172], medical operation training in pediatric urology and surgery [173]. Additionally, it has also been applied to study complex systems such as cloud based system [174] and group safety especially for underground miners [175].

Simulation is forecasted to advance swiftly due to the need to understand the behavior of complex systems with the latest technological innovations in fields such as transportation, communication, medicine and metrology. Evidently, simulation software developers are continuously advancing (updating) their software to meet the needs of industry 4.0 for example Siemens, Rockwell automation, MathWorks and Festo which are respectively developers of Solid edge, Arena, Simulink and FluidSim software have released updated (latest) versions of these software [169].

3.2.11. Nanotechnology

Nanomaterials are the smallest materials with singular unit within nanoscale (1-100 nm) [176]. They evolved following obsessive research in the field of materials science [177]. The ideology of nanotechnology is "science small" as it is the technology applied to produce nanomaterials. Though an aged technology, its novel and numerous innovative applications have paved the way for nanotechnology to industry 4.0 movements. It has been applied in making vital components in aerospace, automobile, construction, manufacturing, food processing and packaging fields [178,179], medicine [180] and forensic science [181]. An emerging application of nanotechnology is in the production of the biofuels [182]. In industry 4.0 age, the applications of nanotechnology in energy storage, lighting and photovoltaics are extensively needed to support the popularly growing application areas of industry 4.0. Furthermore, medical and high-tech applications of nanotechnology will also continue to advance [183], especially in areas such as new materials for batteries, 3D printing [184] and DNA nanotechnology [185].

3.2.12. Drones

Drones, frequently called Unmanned Aerial Vehicle (UAV), Remotely Piloted Aircraft (RPA) and Unmanned Aircraft Systems (UASs) [186] are aircrafts without pilots on board (flying robots) [187,188]. There are three main types of drones: rotary wing, fixed wing and lighter-than-air. The most common drone configuration is multirotor with four, six or eight propellers and made with very small, powerful and affordable electronic components that are also used in smartphones. Some of the manufacturers of drones include Kuleuven, Delair, Vives, Vito, AltiGator, Flying- Cam and Drone Matrix [189].

Initially, drones were considered as toys for children before they later got adopted as gadgets of leisure that are sent to the skies to shoot impressive photographs and high-definition videos. In general, drones have been majorly used for entertainment and media [186]. However, with the move to industry 4.0, drones are being equipped with smart devices (sensors, cameras) combined with other technologies like Big data analytics and machine learning. Significantly, this has widened its field of applications to agriculture [190,191], energy and utility, entertainment and media, infrastructure [192], insurance, security, telecom, transport, logistics, space exploration [193] and wildlife monitoring [194].

3.2.13. Biotechnology

Biotechnology encompasses many fields such as synthetic biology, molecular biology, genetic biology, gene editing, proteomics, biomimicry and genomes [195]. In the era of industry 4.0, synthetic biology will be more explored than any other fields of biotechnology. Synthetic biology is an emerging field where biology and engineering disciplines are in unison [196]. It has been cited as a lucrative technology in industry 4.0 movements. The main function of synthetic biology is to create different artificial biological pathways, devices or organisms, that can imitate the naturally-made biological systems [197,198]. The main application domains of synthetic biology is in agriculture [197] and healthcare where it has been used in the treatment of complex diseases such as cancer. In industry 4.0 epoch, synthetic biology will be extensively utilized in the field of renewable and clean energy with improved efficiency for power supply to many systems such as robots and self-driving cars [55,143].

3.3. *Skills of Industry 4.0*

3.3.1. Required Skills

In industry 4.0 revolution, all skills are required. This is fundamentally because all the previously disconnected technologies and applications have come into convergence. However, the opus of the existing workforce will need to change to match the skills required to support the success

of industry 4.0. Further, the development of novel technologies such as smart sensors, intelligent assistant, robots and automation will continue to demand change in the types of skills as well as the labour landscape [199]. Eventually, there will be great transition for job demand from lower-skilled to highly-skilled jobs [200,201]. In order to clearly describe the skill requirements for industry 4.0, the present study categorized the required skills in two major groups: technical and personal (soft) skills. The technical skills are required for highly technical tasks while soft skills are mainly needed for teamwork on the shop floor level and communication in the daily business. Technical skills are subcategorized into theory and expertise skills, hardware skills, and software and algorithm skills (digital skills) as summarized in **Table 3.**

3.3.2. Building Skills into the Workforce of Industry 4.0

There is a dire need to identify and develop the disciplines, and the required missing abilities in order to build suitable skills into the workforce of industry 4.0 [202]. The following measures therefore need to be taken seriously to prepare the workforce of the future.

Higher education (universities and technical colleges) play a critical role in shaping the societal transitions necessary for industry 4.0 movements. However, today's higher education was developed in context of the previous three industrial revolutions which do not provide the necessary skills for shaping industry 4.0 movements [203]. In addition, most manufacturing and service industries will no longer demand for specialist personnel but the generalists. Therefore, higher education especially the Universities ought to properly and extensively educate and develop capacity for knowledge retention among the graduates to prepare them for a productive life necessary for the ever-changing labour landscape [204,205].

Another crucial issue in building the skills of industry 4.0 is the need for diversifying education and credentialing systems. This can be achieved by empowering and encouraging the education market places especially online learning platforms (MOOC) to continuously put much effort to accommodate the widespread needs of those willing to learn [123]. In addition, employers are required to develop attitude towards training and retraining their workers. Also, self-teaching efforts by jobholders themselves should be encouraged [26]. More importantly, to survive in the job market of industry 4.0, there is need to nurture human skills such that the AI is unable to replicate [206].

Furthermore, skills of industry 4.0 can be built by developing new curriculum especially in the old field of studies such as industrial and mechanical engineering to incorporate industry 4.0 infrastructures. The development of these curriculum can only be achieved through extensive research along this line. In the recent years, few researches have been conducted in the area of curriculum development with industry 4.0 context. For instance Sackey and Bester [204] examined the impact of industry 4.0 on existing industrial engineering curriculum. More research is on-going to ensure curriculum development reach all the technology and engineering fields of study [205]. However, the curriculum development in context to industry 4.0 should not only target the technical fields of study but also cut across other fields such as business, economics and management studies [207,208].

Table 3. Required Skills of Industry 4.0

Technical skills			Personal (soft) skills
Theory and expertise skills	**Hardware skills**	**Software and algorithms skills (digital skills)**	
Material and production skills, Process skills, Electrical engineering, Software, ICT, Statistical knowledge Knowledge of management, Organizational and processual, Understanding Interdisciplinary/generic knowledge about technologies and organisations, Understanding of legal affairs, Product management, Multi-project management, Supply chain and support services, Logistics, Abilities in the STEM subjects (science, technology, engineering, and mathematics), General understanding of machine interactions, General interdisciplinary knowledge of methods	Mechanical and plant engineering, Automation technology, Mechatronics, Microsystems technology, Electronics, Hydraulics, Specialized knowledge of manufacturing activities and process, Awareness of ergonomics, Designers, Grid optimization engineering, Manufacturing operations management	Documentation and reading, Integration, Customizing (process mapping), Maintenance, servicing and further development of the systems, Training and continuous professional development, IT knowledge and abilities, Data and information processing and analytics, Ability to interact with modern interfaces (human -machine/human-robot), Awareness for IT security and data protection, Computer programming/ coding abilities, Software engineering, Data science, Analytical/logic thinking, Data/big data analytics, Visualization, Internet of things (IoT), IT architecture, Digital media, Virtual modelling, Information complexity and data management, Process simulation knowledge, Server's knowledge, Emotional intelligence	Self and time management, Adaptability and ability to change, Team working abilities, Social skills, Communication skills, Trust in new technology, Creativity, Design, Innovation, Leadership, Mindset for continuous improvement and lifelong learning, Complexity, Abstraction and problem-solving, Self-directed action, Self-organization, Project management, Human interaction, Languages (English, German etc.), Autonomy, Cognitive flexibility, Responsibility, Reliability, Service orientation, Negotiation, Critical thinking, People management, Coordinating, decision making, Service orientation

Modified from [13,19,26,36,116,200,202,203,209–211].

Conclusion

The present study identified differences in the view of previous researchers on the key technologies of industry 4.0. These differences were due to the different scopes of the case studies undertaken by the researchers. This is because industry 4.0 technologies are being adopted among countries or industries at different paces. Most literature focused their case studies on countries like China, USA, Germany, UK, South Africa, Korea, Russia, Philippines and Malaysia. This accounts for the differences because these countries have different capabilities in terms of resources, knowledge and finances to implement industry 4.0 technologies. Thus, 35 disruptive technologies were explored and 13 key disruptive technologies were identified. This implies that the rate of industry 4.0 adaptation has been increasing among countries and industries over the years. The race among countries and companies toward industry 4.0 will further increase the rate of adaptation of these technologies. However, the more the industry 4.0 implementations, the more the skills required to support its growth. It is therefore proposed that further research should investigate the capability and readiness of developing countries in adapting industry 4.0 in terms of changes in education systems and industrial manufacturing settings.

Conflicts of Interest: The authors declare that there is no conflict of interests.

References

[1]   M. Xu, J. M. David, and S. H. Kim, "The Fourth Industrial Revolution : Opportunities and Challenges," *Int. J. Financ. Res.*, vol. 9, no. 2, pp. 90–95, 2018.

[2]   B. Kajanth, "Industry 4.0: Securing the Future for German Manufacturing Companies," University of Twente, 2016.

[3]   B. Rick, M. Adam, L. Stephen, H. Marty, and S. Brenna, "The smart factory; Responsive, adaptive, connected manufacturing," 2017.

[4]   Y. Liao, L. Eduardo Rocha, F. Deschamps, G. Brezinski, and V. André, "The impact of the fourth industrial revolution : a cross-country / region comparison," *Production*, vol. 28, no. e20180061, 2018.

[5]   Deloitte, "Industry 4.0 ; Is Africa ready for digital transformation ?," 2016.

[6]   W. Naudé, "Entrepreneurship, Education and the Fourth Industrial Revolution in Africa," IZA DP No. 10855, 2017.

[7]   L. M. N. Daniel *et al.*, "Exploring Industry 4 . 0 technologies to enable circular economy practices in a manufacturing context: A business model proposal," *J. Manuf. Technol. Manag.*, 2018.

[8]   M. Lee *et al.*, "How to Respond to the Fourth Industrial Revolution , or the Second Information Technology Revolution ? Dynamic New Combinations between Technology , Market , and Society through Open Innovation," *J. Open Innov.*, vol. 21, no. 4, pp. 1–24, 2018.

[9]   M. Chiarvesio and R. Romanello, "Industry 4.0 Technologies and Internationalization: Insights from Italian Companies," *Int. Bus. Inf. Digit. Age*, vol. 13, pp. 357–378, 2018.

[10]   I. Dorleta, G. Jaione, and I. I. Juan, "Business model innovation through Industry 4.0: A review," *Procedia Manuf.*, vol. 22, pp. 4–10, 2018.

[11]   T. Stock and G. Seliger, "Opportunities of Sustainable Manufacturing in Industry 4.0," *Procedia CIRP*, vol. 40, pp. 536–541, 2016.

[12]   J. M. Müller, K. Daniel, and V. Kai-Ingo, "What Drives the Implementation of Industry 4.0 ? The Role of Opportunities and Challenges in the Context of Sustainability," *Sustainability*, vol. 247, no. 10, pp. 1–24, 2018.

[13]   S. Pi-Shen, J. Janice, S. John, and H. Ann-Louise, "The Fourth Industrial Revolution : the implications of technological disruption for Australian VET," Adelaide, 2018.

[14]   E. Paravizo, O. C. Chaim, D. Braatz, B. Muschard, and R. Hanrique, "Exploring gamification to support manufacturing education on industry 4.0 as an enabler for innovation and sustainability," *Procedia Manuf.*, vol. 21, pp. 438–445, 2018.

[15]   L. Li, "Change China' s manufacturing locus in 2025 : With a comparison of " Made-in-China," *Technol. Forecast. Soc. Chang.*, vol. 135, pp. 66–74, 2018.

[16]   R. Y. Zhong, X. Xu, E. Klotz, and S. T. Newman, "Intelligent Manufacturing in the Context of Industry 4 . 0 : A Review," *Engineering*, vol. 3, no. 5, pp. 616–630, 2017.

[17]   M. Schäfer, "The fourth industrial revolution : How the EU can lead it," *Eur. View*, vol. 17, no. 1, pp. 5–12, 2018.

[18]   S. Günther, A. Reiner, J. Gausemeier,   ten H. Michael, and W. Wolfgang(Eds.), "Industrie 4.0 Maturity Index; Managing the digital transformation of companies (acatech STUDY)," Munich, 2017.

[19]   L. Gehrke *et al.*, "Industry 4.0; A Discussion of Qualifications and Skills in the factory of the Future: A German and American Perspective (VDI and ASME Project)," VDI and ASME project; Düsseldorf, 2015.

[20]   J. W. Strandhagen, E. Alfnes, J. O. Strandhagen, and L. R. Vallandingham, "The fit of Industry 4.0 applications in manufacturing logistics – a multiple case study," Trondheim, 2017.

[21]   R. Morrar, H. Arman, S. Mousa, and K. Schwab, "The Fourth Industrial Revolution (Industry 4.0): A Social Innovation Perspective," *Technol. Innov. Manag. Rev.*, vol. 7, no. 11, pp. 12–21, 2017.

[22]   E. G. Popkova and B. S. Sergi, "Will Industry 4 . 0 and Other Innovations Impact Russia ' s Development ?," in *Exploring the Future of Russia's Economy and Markets:*, Emerald Publishing Limited, 2018, pp. 51–68.

[23]   T. K. Sung, "Industry 4.0 : A Korea perspective," *Technol. Forecast. Soc. Chang.*, vol. 132, pp. 40–45, 2018.

[24]   K. Thoben, S. Wiesner, and T. Wuest, "'Industrie 4.0' and Smart Manufacturing – A Review of Research Issues and Application Examples," *Int. J. Autom. Technol.*, vol. 11, no. 1, pp. 4–16, 2017.

[25]   E. Mo, D. Centea, I. Singh, and T. Wanyama, "SEPT Learning Factory for Industry 4.0 Education and Applied Research," *Procedia Manuf.*, vol. 23, pp. 249–254, 2018.

[26]   B. Andrea and T. Jiří, "Requirements for Education and Qualification of People in Industry 4.0," *Procedia Manuf.*, vol. 11, pp. 2195–2202, 2017.

[27]   A. C. Pereira and F. Romero, "A review of the meanings and the implications of the industry 4.0," *Procedia Manuf.*, vol. 13, pp. 1206–1214, 2017.

[28]   M. Crnjac, V. Ivica, and N. Banduka, "From Concept to the Introduction of Industry 4 . 0," *Int. J. Ind. Eng. Manag.*, vol. 8, no. 1, pp. 21–30, 2017.

[29]   H. Mario, P. Tobia, and B. Otto, "Design Principles for Industrie 4.0 Scenarios: A Literature Review," Lukasstr, No. 01 / 2015, 2015.

[30]   B. Chen, J. Wan, L. Shu, L. Peng, M. Mithun, and Y. Boxing, "Smart Factory of Industry 4.0 : Key Technologies , Application Case , and Challenges," *IEEE Access*, vol. 6, pp. 6505–6519, 2018.

[31]   World Economic Forum (WEF), "The Future of Jobs; Employment, Skills and Workforce Strategy for the Fourth Industrial Revolution," Cologny/Geneva, Switzerland, 2016.

[32]   J. Manyika, M. Chui, J. Bughin, R. Dobbs, P. Bisson, and A. Marrs, "Disruptive technologies : Advances

that will transform life , business , and the global economy," 2013.

[33] R. Michael *et al.*, "Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries," Boston Consulting Group, Inc.: Boston, Munich, USA, 2015.

[34] M. Cheryl and L. Helena, "Technology and Innovation for the Future of Production : Accelerating Value Creation," World Economic Forum; Cologny/Geneva, Switzerland, White paper no. 00030896, 2017.

[35] R. A. Mashelkar, "Exponential Technology , Industry 4 . 0 and Future of Jobs in India," *Rev. Mark. Integr.*, vol. 10, no. 2, pp. 1–20, 2018.

[36] Institute of Technology Assessment (ITA), "Effects of Industry 4.0 on vocational education and training," Vienna, Austria, ITA-15-04, 2015.

[37] C. Schröder, "The Challenges of Industry 4.0 for Small and Medium-sized Enterprises," 2017.

[38] Deloitte, "Industry 4.0; Challenges and solutions for the digital transformation and use of exponential technologies," Zurich, 2015.

[39] R. Davies, "Industry 4.0: Digitalisation for productivity and growth," EPRS-PE 568.337, 2015.

[40] Deloitte, "Exponential technologies in manufacturing; Transforming the future through technology, talent, and the innovation ecosystem," 2018.

[41] M. Burri, "Current and Emerging Trends in Disruptive Technologies : Implications for the Present and Future of EU's Trade Policy," Switzerland, 2017.

[42] D. Leipziger and V. Dodev, "Disruptive Technologies and their Implications for Economic Policy : Some Preliminary Observations," IIEP-WP-2016-13 Danny, 2016.

[43] V. Roblek, M. Meško, and A. Krapež, "A Complex View of Industry 4 . 0," *SAGE Open*, pp. 1–11, 2016.

[44] M. Faheem *et al.*, "Smart grid communication and information technologies in the perspective of Industry 4 . 0 : Opportunities and challenges," *Comput. Sci. Rev.*, vol. 30, pp. 1–30, 2018.

[45] M. Lezzi, M. Lazoi, and A. Corallo, "Cybersecurity for Industry 4 . 0 in the current literature : A reference framework," *Comput. Ind.*, vol. 103, pp. 97–110, 2018.

[46] Y. Lu, "Industry 4.0 : A survey on technologies , applications and open research issues," *J. Ind. Inf. Integr.*, vol. 6, pp. 1–10, 2017.

[47] S. Mittal, M. Ahmad, D. Romero, and T. Wuest, "A critical review of smart manufacturing & Industry 4 . 0 maturity models : Implications for small and medium-sized enterprises (SMEs)," *J. Manuf. Syst.*, vol. 49, no. June, pp. 194–214, 2018.

[48] C. Santos *et al.*, "Towards Industry 4.0: an overview of European strategic roadmaps," *Procedia Manuf.*, vol. 13, pp. 972–979, 2017.

[49] L. Santos, G. Brittes, N. Fabián, and A. Germán, "The expected contribution of Industry 4 . 0 technologies for industrial performance," *Intern. J. Prod. Econ.*, vol. 204, no. August, pp. 383–394, 2018.

[50] A. Moktadir, S. M. Ali, S. Kusi-sarpong, and A. A. Shaikh, "Assessing challenges for implementing Industry 4.0: Implications for process safety and environmental protection," *Process Saf. Environ. Prot.*, 2018.

[51] D. Vuksanovi, J. Ugarak, and D. Korčok, "Industry 4.0: The Future Concepts and New Visions of Factory of the Future Development," *Adv. Manuf. Syst.*, pp. 293–298, 2016.

[52] M. Ghobakhloo, "The future of manufacturing industry : a strategic roadmap toward Industry 4.0," *J. Manuf. Technol. Manag.*, pp. 1–28, 2018.

[53] M. Joshua, "The Fourth Industrial Revolution Launches into Space," *Japan SPOTLIGHT*, pp. 12–15, 2018.

[54] ADB and WEF, "What does the Fourth Industrial Revolution mean for regional economic integration ?," Geneva/ Metro Manila, 2017.

[55]   B. Combes, D. Nassiry, L. Fitzgerald, and T. Moussa, "Emerging and exponential technologies : New opportunities for low-carbon development," London: CDKN, 2017.

[56]   A. Petrillo, F. De Felice, R. Cioffi, A. Petrillo, and F. De Felice, "Fourth Industrial Revolution : Current Practices , Challenges , and Opportunities," *INTECH*, pp. 1–20, 2018.

[57]   Acess Partnership, "Delivering the Fourth Industrial Revolution : The Role of Government," Abu Dhabi/Brussels/Dakar/London/ Singapore/ Washington, DC, 2017.

[58]   European Parliament Office (EPO), "Patents and the Fourth Industrial Revolution: The inventions behind digital transformation," Munich, Germany, 2017.

[59]   D. Elmer P. *et al.*, "Preparing the Philippines for the Fourth Industrial Revolution : A Scoping Study," Quezon, Philippines, PIDS-Discussion paper seies No. 2018-11; Philippine Institute for Development Studies, 2018.

[60]   F. Chiarello, L. Trivelli, A. Bonaccorsi, and G. Fantoni, "Computers in Industry Extracting and mapping industry 4 . 0 technologies using wikipedia," *Comput. Ind.*, vol. 100, no. September 2017, pp. 244–257, 2018.

[61]   World Economic Forum (WEF), "Technology and Innovation for the Future of Production: Accelerating Value Creation," 2017.

[62]   World Economic Forum (WEF), "Harnessing the Fourth Industrial Revolution for Oceans," Cologny/Geneva Switzerland, 2017.

[63]   PwC, "Global Industry 4.0 Survey; Building the digital enterprise," 2016.

[64]   Ministry of International trade and Industry Malasiaya, "National industry 4.0 Policy Framework," 2018.

[65]   A. G. Frank, L. S. Dalenogare, and N. F. Ayala, "ndustry 4.0 technologies: implementation patterns in manufacturing companies," *Int. J. Prod. Econ.*, pp. 1–40, 2019.

[66]   UNIDO, "Industry 4.0: opportunities behind the challenge, Background paper," Vienna, Austria, 2017.

[67]   K. Santos, E. Loures, F. Piechnicki, and O. Canciglieri, "Opportunities Assessment of Product Development Process in industry 4.0," *Procedia Manuf.*, vol. 11, no. June, pp. 1358–1365, 2017.

[68]   S. S. Fernandez-Miranda, M. Marcos, M. . Peralta, and F. Aguayo, "The challenge of integrating Industry 4.0 in the degree of mechanical Engineering," *Procedia Manuf.*, vol. 13, pp. 1229–1236, 2017.

[69]   S. Vaidya, P. Ambad, and S. Bhosle, "Industry 4 . 0 – A Glimpse," *Procedia Manuf.*, vol. 20, pp. 233–238, 2018.

[70]   R. Schmidt, M. Michael, H. Ralf-christian, C. Reichstein, P. Neumaier, and P. Jozinovi, "Industry 4 . 0 - Potentials for Creating Smart Products : Empirical Research Results," in *Business Information System*, 2015, vol. 2, pp. 16–27.

[71]   J. Lee, H. Kao, and S. Yang, "Service innovation and smart analytics for Industry 4 . 0 and big data environment," *Procedia CIRP*, vol. 16, pp. 3–8, 2014.

[72]   J. Wan, "Industrie 4 . 0 : Enabling Technologies," in *Proceedings of 2015 International Conference on Intelligent Computing and Internet of Things*, 2015, pp. 135–140.

[73]   R. Kumar, S. P. Singh, and K. Lamba, "Sustainable robust layout using Big Data approach : A key towards industry 4 . 0," *J. Clean. Prod.*, vol. 204, pp. 643–659, 2018.

[74]   Prime Minister's Industry 4.0 Taskforce, "Industry 4 . 0 Testlabs in Australia Preparing for the Future," Hawthorn, Victoria, Australia, 2017.

[75]   U. M. Dilberoglu, B. Gharehpapagh, U. Yaman, and M. Dolen, "The role of additive manufacturing in the era of Industry 4 . 0," *Procedia Manuf.*, vol. 11, pp. 545–554, 2017.

[76]   D. Mishra, R. Basu, S. Dutta, S. K. Pal, and D. Chakravarty, "A review on sensor based monitoring and

control of friction stir welding process and a roadmap to Industry 4 . 0," *J. Manuf. Process.*, vol. 36, no. October, pp. 373–397, 2018.

[77]   K. Ooi, V. Lee, G. W. Tan, T. Hew, and J. Hew, "Cloud computing in manufacturing: The next industrial revolution in Malaysia?," *Expert Syst. Appl.*, 2017.

[78]   Microsoft, "Winning in the fourth industrial revolution; How the financial sector must transform digitally to lead the race for relevance," 2017.

[79]   M. Dopico, A. Gomez, D. De la Fuente, N. García, R. Rosillo, and J. Puche, "A vision of industry 4 . 0 from an artificial intelligence point of view," in *Int'l Conf. Artificial Intelligence*, 2016, pp. 407–413.

[80]   M. Gattullo, G. W. Scurati, M. Fiorentino, A. E. Uva, F. Ferrise, and M. Bordegoni, "Towards augmented reality manuals for industry 4.0 : A methodology," *Robot. Comput. Integr. Manuf.*, vol. 56, pp. 276–286, 2019.

[81]   G. Wally, M. Gattullo, M. Fiorentino, F. Ferrise, M. Bordegoni, and A. Emmanuele, "Converting maintenance actions into standard symbols for Augmented Reality applications in Industry 4.0," *Comput. Ind.*, vol. 98, pp. 68–79, 2018.

[82]   C. O. Klingenberg, "Industry 4 . 0 : what makes it a revolution ?," in *EurOMA 2017*, 2017, pp. 1–11.

[83]   S. Wang, J. Wan, D. Zhang, D. Li, and C. Zhang, "Towards smart factory for industry 4 . 0 : a self-organized multi-agent system with big data base d fee dback and coordination," *Comput. Networks*, vol. 101, pp. 158–168, 2016.

[84]   J. Lee, B. Bagheri, and H. Kao, "A Cyber-Physical Systems architecture for Industry 4 . 0-based manufacturing systems ScienceDirect A Cyber-Physical Systems architecture for Industry 4 . 0-based manufacturing systems," *Manuf. Lett.*, vol. 3, no. December, pp. 18–23, 2014.

[85]   A. M. M. S. Ullah, "Advanced Engineering Informatics Modeling and simulation of complex manufacturing phenomena using sensor signals from the perspective of Industry 4 . 0 Semantic Modeling of Manufacturing Enablers (Objects ," *Adv. Eng. Informatics*, vol. 39, no. July 2018, pp. 1–13, 2019.

[86]   World Economic Forum, "Readiness for the Future of Production Report 2018," World Economic Forum, Cologny/Geneva, Switzerland, 2018.

[87]   S. Mittal, M. A. Khan, D. Romero, and T. Wuest, "Smart manufacturing : Characteristics , technologies and enabling factors," *Proc IMechE Part B J Eng. Manuf.*, vol. 233, no. 5, pp. 1342–1361, 2019.

[88]   A. Venkatachalam and K. Fukunari, *Empowering ASEAN for the Circular Economy*. Economic Research Institute for ASEAN and East Asia (ERIA), 2018.

[89]   D. Vuksanović, J. Ugarak, and D. Korčok, "Industry 4.0: The Future Concepts and New Visions of Factory of the Future Development," in *Advanced Engineering Systems*, 2016, pp. 1–7.

[90]   C. Cimini, G. Pezzotta, R. Pinto, and S. Cavalieri, "Industry 4 . 0 Technologies Impacts in the Manufacturing and Supply Chain Landscape : An Overview :," in *Proceedings of SOHOMA 2018*, 2018, pp. 1–13.

[91]   UNIDO, "Industry 4.0: the opportunities behind the challenge," Vienna International Centre, Austria, 2018.

[92]   V. Cruz-machado, V. Alcácer, and V. Cruz-machado, "Scanning the Industry 4.0 : A Literature Review on Technologies for Manufacturing Systems," *Eng. Sci. Technol. an Int. J.*, vol. 22, no. July, pp. 899–919, 2019.

[93]   Interreg North Sea Region, "Industry 4 . 0 – opportunities and challenges for SMEs in the North Sea Region," 2018.

[94]   N. Enose and S. Ramachandran, "Industry 4.0 as an Evolution, not a Revolution," 2019.

[95]   J. Chase, "The Evolution of the Internet of Things," Texa Instruments; Dallas, Texas, 2013.

[96]   K. Witkowski, "Internet of Things , Big Data , Industry 4 . 0 – Innovative Solutions in Logistics and Supply Chains Management," *Procedia Eng.*, vol. 182, pp. 763–769, 2017.

[97]   L. Changhong and R. Y. Zhong, "Internet of Things for Manufacturing in the Context of Industry 4.0," *Transdiscipl. Eng. Paradig. Shift*, pp. 1013–1022, 2017.

[98]   E. Oriwoh, P. Sant, and G. Epiphaniou, "Guidelines for Internet of Things deployment approaches – The Thing Commandments," *Procedia Comput. Sci.*, vol. 21, pp. 122–131, 2013.

[99]   Y. P. Raiwani, "Internet of Things : A New Paradigm," *Int. J. Sci. Res. Publ.*, vol. 3, no. 4, pp. 1–4, 2013.

[100]   P. Nowodzinski, A. Puto, and L. Katarzyna, "Internet Of Things (Iot) In A Retail Environment . The New Strategy For Firm ' s Development," *Eur. Sci. J.*, pp. 332–341, 2016.

[101]   T. Saarikko, U. H. Westergren, and T. Blomquist, "The Internet of Things : Are you ready for what ' s coming ?," *Bus. Horiz.*, vol. 60, no. 5, pp. 667–676, 2017.

[102]   G. Manogaran, R. Varatharajan, D. Lopez, P. M. Kumar, R. Sundarasekar, and C. Thota, "A New Architecture of Internet of Things and Big Data Ecosystem for Secured Smart Healthcare Monitoring and Alerting," *Futur. Gener. Comput. Syst.*, 2017.

[103]   S. Albishi, B. Soh, A. Ullah, and F. Algarni, "Challenges and Solutions for Applications and Technologies in the Internet of Things," *Procedia Comput. Sci.*, vol. 124, pp. 608–614, 2018.

[104]   K. Govinda and R. A. . Saravanaguru, "Review on IOT Technologies," *Int. J. Appl. Eng. Res.*, vol. 11, no. 4, pp. 2848–2853, 2016.

[105]   P. Rathore *et al.*, "Real-Time Urban Microclimate Analysis Using Internet of Things," *IEEE Internet Things J.*, vol. 5, no. 2, pp. 500–511, 2018.

[106]   L. Dong, R. Mingyue, and M. Guoying, "Application of Internet of Things Technology on Predictive Maintenance System of Coal Equipment," *Procedia Eng.*, vol. 174, pp. 885–889, 2017.

[107]   P. P. Ray, "A survey on Internet of Things architectures," *J. King Saud Univ. - Comput. Inf. Sci.*, 2016.

[108]   D. Miorandi, S. Sicari, F. De Pellegrini, and I. Chlamtac, "Ad Hoc Networks Internet of things : Vision , applications and research challenges," *Ad Hoc Networks*, vol. 10, no. 7, pp. 1497–1516, 2012.

[109]   M. Conti, A. Dehghantanha, K. Franke, and S. Watson, "Internet of Things Security and Forensics: Challenges and Opportunities," *Futur. Gener. Comput. Syst.*, pp. 2–8, 2018.

[110]   I. Yaqoob, I. Abaker, T. Hashem, A. Ahmed, S. M. A. Kazmi, and C. Hong Seon, "Internet of things forensics : Recent advances , taxonomy , requirements , and open challenges," *Futur. Gener. Comput. Syst.*, vol. 92, pp. 265–275, 2019.

[111]   S. Li, S. Zhao, and S. Zhao, "5G Internet of Things : A Survey," *J. Ind. Inf. Integr.*, 2018.

[112]   Advantech, "Industry 4.0," 2015.

[113]   J. K. Gerrikagoitia, G. Unamuno, E. Urkia, and A. Serna, "applied sciences Digital Manufacturing Platforms in the Industry 4 . 0 from Private and Public Perspectives," 2019.

[114]   A. Oussous, F. Benjelloun, A. Ait, and S. Belfkih, "Big Data technologies : A survey," *J. King Saud Univ. - Comput. Inf. Sci.*, vol. 30, no. 4, pp. 431–448, 2018.

[115]   M. Mohammadpoor and F. Torabi, "Big Data Analytics in Oil and Gas Industry: An Emerging Trend," *Petroleum*, 2019.

[116]   A. De Mauro, M. Greco, M. Grimaldi, and P. Ritala, "Human resources for Big Data professions : A systematic classification of job roles and required skill sets," *Inf. Process. Manag.*, pp. 1–11, 2017.

[117]   A. Merendino *et al.*, "Big data , big decisions : The impact of big data on board level decision- making,"

J. Bus. Res., vol. 93, no. November 2017, pp. 67–78, 2018.

[118]   C. Tu, H. Xi, S. Zhikang, and J. Fei, "Big data issues in smart grid – A review," *Renew. Sustain. Energy Rev.*, vol. 79, pp. 1099–1107, 2017.

[119]   L. Wen, K. Zhou, S. Yang, and L. Li, "Compression of smart meter big data : A survey," *Renew. Sustain. Energy Rev.*, vol. 91, pp. 59–69, 2018.

[120]   M. Ge, H. Bangui, and B. Buhnova, "Big Data for Internet of Things : A Survey," *Futur. Gener. Comput. Syst.*, 2018.

[121]   Y. Huang, C. Zhong-xin, Y. U. Tao, H. Xiang-zhi, and G. U. Xing-fa, "Agricultural remote sensing big data: Management and applications," *J. Integr. Agric.*, vol. 17, no. 9, pp. 1915–1931, 2018.

[122]   L. Dawei, H. Anzi, and L. Gen, "Big Data Technology : Application and Cases," in *Handbook of Blockchain, Digital Finance, and Inclusion, Volume 2*, 1st ed., vol. 2, CreditEase, China: Elsevier Inc., 2018, pp. 65–82.

[123]   T. Tong and H. Li, "Demand for MOOC-an application for Big Data," *China Econ. Rev.*, 2017.

[124]   J. Eckroth, "A course on big data analytics," *J. Parallel Distrib. Comput.*, 2018.

[125]   T. D. Ngo, A. Kashani, G. Imbalzano, K. T. Q. Nguyen, and D. Hui, "Additive manufacturing (3D printing): A review of materials , methods , applications and challenges," *Compos. Part B*, vol. 143, pp. 172–196, 2018.

[126]   R. Colella and L. Catarinucii, "Wearable UHF RFID Sensor Tag in 3D-Printing Technology for Body Temperature Monitoring," *URSI*, pp. 3–6, 2018.

[127]   M. Houwen *et al.*, "advances in technology for tissue engineering 3D printing of hydrogel composite systems : Recent advances in technology for tissue engineering," *Int. J. Bioprinting*, vol. 4, no. 1, pp. 0–28, 2018.

[128]   Y. Soliman, A. H. Feibus, and N. Baum, "Applications," *Rev. Urol.*, vol. 17, no. 1, pp. 20–24, 2015.

[129]   A. Kotikian, R. L. Truby, J. W. Boley, T. J. White, and J. A. Lewis, "3D Printing of Liquid Crystal Elastomeric Actuators with Spatially Programed Nematic Order," *Adv. Mater.*, vol. 1706164, pp. 1–6, 2018.

[130]   A. Zocca, P. Colombo, C. M. Gomes, and G. Jens, "Additive Manufacturing of Ceramics: Issues, Potentialities, and Opportunities €," *J. Am. Ceram. Soc.*, vol. 98, no. 7, pp. 1983–2001, 2015.

[131]   E. Bae *et al.*, "Efficacy of rhBMP-2 Loaded PCL / bdECM Scaffold Fabricated by 3D Printing Technology on Bone Regeneration," *Biomed Res. Int.*, 2018.

[132]   A. J. Cresswell-Boyes, A. H. Barber, .A. Tatla Mills, and G. R. Davis, "Approaches to 3D printing teeth from X-ray microtomography," *J. Microsc.*, vol. 272, no. 3, pp. 207–212, 2018.

[133]   N. Vermeulen, G. Haddow, T. Seymour, A. Faulkner-jones, and W. Shu, "3D bioprint me : a socioethical view of bioprinting human organs and tissues," *J Med Ethics*, vol. 43, pp. 618–624, 2017.

[134]   X. Liu *et al.*, "3D Printing of Living Responsive Materials and Devices," *Adv. Mater.*, 2017.

[135]   N. Subramanian and A. Jeyaraj, "Recent security challenges in cloud computing," *Comput. Electr. Eng.*, vol. 71, pp. 28–42, 2018.

[136]   M. García-valls, A. Dubey, and V. Botti, "Introducing the new paradigm of Social Dispersed Computing : Applications , Technologies and Challenges," *J. Syst. Archit.*, vol. 91, no. March, pp. 83–102, 2018.

[137]   K. Njenga, L. Garg, A. Kumar, V. Prakash, and S. Bawa, "The cloud computing adoption in higher learning institutions in Kenya : Hindering factors and recommendations for the way forward," *Telemat. Informatics*, pp. 1–22, 2018.

[138]   O. Ali, A. Shrestha, S. Jeffrey, and S. Wamba Fosso, "Cloud computing-enabled healthcare opportunities , issues , and applications : A systematic review," *Int. J. Inf. Manage.*, vol. 43, pp. 146–158, 2018.

[139]   A. Vafamehr and M. E. Khodayar, "Energy-aware cloud computing," *Electr. J.*, vol. 31, no. 2, pp. 40–49, 2018.

[140]   G. Graetz and G. Michaels, "Robots at Work," *Rev. Econ. Stat.*, vol. 100, no. 5, pp. 753–768, 2018.

[141]   D. Stavrou, S. Timotheou, S. Member, C. G. Panayiotou, S. Member, and M. M. Polycarpou, "Optimizing Container Loading With Autonomous Robots," *IEEE Trans. Autom. Sci. Eng.*, vol. 15, no. 2, pp. 717–731, 2018.

[142]   A. G. C. Gonzalez, M. V. S. Alves, G. S. Viana, L. K. Carvalho, and B. Joao C., "Supervisory Control-Based Navigation Architecture : A New Framework for Autonomous Robots in Industry 4 . 0 Environments," *IEEE Trans. Ind. Informatics*, vol. 14, no. 4, pp. 1732–1743, 2018.

[143]   P. Gotovtsev *et al.*, "Bioenergy Based Power Sources for Mobile Autonomous Robots," *robotics*, pp. 1–18, 2018.

[144]   C. B. Highley, K. H. Song, A. C. Daly, and J. A. Burdick, "Jammed Microgel Inks for 3D Printing Applications," *Adv. Sci.*, vol. 1801076, no. 6, pp. 1–6, 2019.

[145]   T. Jung and M. C. tom Dieck(eds.), *Augmented Reality and Virtual Reality; Empowering Human, Place and Business*, Progress i. Manchester, UK: Springer, 2018.

[146]   P. P. Rau, J. Zheng, Z. Guo, and J. Li, "Speed reading on virtual reality and augmented reality," *Comput. Educ.*, vol. 125, pp. 240–245, 2018.

[147]   ARC Insight, "Immersive Training Simulator Enhances Safety on Total FPSOs," 2014.

[148]   R. Palmarini, J. Ahmet, R. Roy, and H. Torabmostaedi, "A systematic review of augmented reality applications in maintenance," *Robot. Comput. Integr. Manuf.*, vol. 49, pp. 215–228, 2018.

[149]   S. Rho, A. V Vasilakos, and W. Chen, "Cyber physical systems technologies and applications," *Futur. Gener. Comput. Syst.*, vol. 56, pp. 436–437, 2015.

[150]   T. Bauernhansl, S. Kondoh, S. Kumara, L. Monostori, and B. Ka, "CIRP Annals - Manufacturing Technology Cyber-physical systems in manufacturing," *CIRP Ann. - Manuf. Technol.*, vol. 65, pp. 621–641, 2016.

[151]   D. Mourtzis, E. Vlachou, G. Dimitrakopoulos, and V. Zogopoulos, "Cyber- Physical Systems and Education 4.0 – Teaching Factory 4.0 Concept," *Procedia Manuf.*, vol. 23, pp. 129–134, 2018.

[152]   O. Cardin, "Classification of cyber-physical production systems applications : Proposition of an analysis framework," *Comput. Ind.*, vol. 104, pp. 11–21, 2019.

[153]   Y. Guo, X. Hu, B. I. N. Hu, J. Cheng, M. Zhou, and K. K. Kwok, "Mobile Cyber Physical Systems : Current Challenges and Future Networking Applications," *IEEE Access*, vol. 6, pp. 12360–12368, 2018.

[154]   D. Ding, Q. Han, Y. Xiang, X. Ge, and X. Zhang, "A survey on security control and attack detection for industrial cyber-physical systems," *Neurocomputing*, vol. 275, pp. 1674–1683, 2018.

[155]   C. Krittanawong, H. Zhang, Z. Wang, M. Aydar, and T. Kitai, "Artificial Intelligence in Precision Cardiovascular Medicine," *J. Am. Coll. Cardiol.*, vol. 69, no. 21, pp. 2658–2664, 2017.

[156]   O. E. Agwu, J. U. Akpabio, S. B. Alabi, and A. Dosunmu, "Artificial Intelligence Techniques and their Applications in Drilling Fluid Engineering: A Review," *J. Pet. Sci. Eng.*, 2018.

[157]   J. Li and K. Zhan, "Intelligent Mining Technology for an Underground Metal Mine Based on Unmanned Equipment," *Engineering*, vol. 4, no. 3, pp. 381–391, 2018.

[158]   M. Zuccolotto, L. Fasanotti, S. Cavalieri, and C. E. Pereira, "Artificial Immune Intelligent Maintenance System – Diagnostic Agents," *IFAC World Congr.*, vol. 47, no. 3, pp. 7116–7121, 2014.

[159]   A. Mayr, M. Weigelt, M. Masuch, M. Meinersa, F. Hüttel, and J. Frankea, "Application Scenarios of Artificial Intelligence in Electric Drives Production," *Procedia Manuf.*, vol. 24, pp. 40–47, 2018.

[160] Z. S. Y. Wong, J. Zhou, and Q. Zhang, "Artificial Intelligence for infectious disease Big Data Analytics," *Infect. Dis. Heal.*, vol. 24, no. 1, pp. 44–48, 2019.

[161] S. J. Russell and N. Peter, *Artificial Intelligence; A Modern Approach*, 3rd ed. Harlow; England: Pearson, 2016.

[162] C. Manali and D. Srinu, "Study of Smart Sensors and their Applications," *Int. J. Adv. Res. Comput. Commun. Eng.*, vol. 3, no. 1, pp. 5031–5034, 2014.

[163] D. Spirjakin, A. Baranov, and S. Akbari, "Wearable Wireless Sensor System With RF Remote Activation for Gas Monitoring Applications," *IEEE Sens. J.*, vol. 18, no. 7, pp. 2976–2982, 2018.

[164] V. Agarwal, "Smart Sensors for Structural Health Monitoring- Overview , Challenges and Advantages," *Sensors & Transducers*, vol. 221, no. 3, pp. 1–8, 2018.

[165] V. F. Cardoso, D. M. Correia, C. Ribeiro, M. M. Fernandes, and S. Lanceros-m, "Fluorinated Polymers as Smart Materials for Advanced Biomedical Applications," *Polymers (Basel).*, vol. 161, no. 10, pp. 1–26, 2018.

[166] A. S. Fiorillo, C. D. Critello, and A. S. Pullano, "Theory, Technology and Applications of Piezoresistive Sensors:," *Sensors Actuators A. Phys.*, 2018.

[167] M. U. Hagera, K. L. Krishna, and K. Anuradha, "Implementation of Smart Home Automation with Enhanced Security," *Int. J. Sci. Res. Sci. Eng. Technol.*, vol. 4, no. 4, pp. 528–532, 2018.

[168] O. Alvear, C. T. Calafate, J. Cano, and P. Manzoni, "Crowdsensing in Smart Cities : Overview , Platforms , and Environment Sensing Issues," *Sensors*, vol. 460, no. 18, pp. 1–28, 2018.

[169] K. Harold and A. Randal, *Simulation of Dynamic Systems with Matlab and Simulink*, 3rd ed. Boca Raton: Taylor & Francis, 2018.

[170] L. I. Xiang, "Simulation System of Car Crash Test in C-NCAP Analysis Based on an Improved Apriori Algorithm *," *Phys. Procedia*, vol. 25, pp. 2066–2071, 2012.

[171] J. Xu, B. Li, and S. Luo, "Practice and Exploration on Teaching Reform of Engineering Project Management Course in Universities Based on BIM Simulation Technology," *EURASIA J. Math. Sci. Technol. Educ.*, vol. 14, no. 5, pp. 1827–1835, 2018.

[172] V. Vuckovic, V. V Mitic, L. Kocic, B. Arizanovic, V. Paunovic, and R. Nikolic, "Tesla's Fountain – Modeling and Simulation in Ceramics Technology," *J. Eur. Ceram. Soc.*, 2018.

[173] R. M. Nataraja, N. Webb, and P. J. Lopez, "Simulation in paediatric urology and surgery, part 2: An overview of simulation modalities and their applications," *J. Pediatr. Urol.*, 2018.

[174] F. Bonchi, A. Brogi, A. Canciani, and J. Soldani, "Science of Computer Programming Simulation-based matching of cloud applications," *Sci. Comput. Program.*, vol. 1, pp. 1–22, 2017.

[175] K. Yu, Q. Cao, and L. Zhou, "Study on qualitative simulation technology of group safety behaviors and the related software platform," *Comput. Ind. Eng.*, 2018.

[176] K. L. Garner, S. Suh, and A. A. Keller, "Assessing the Risk of Engineered Nanomaterials in the Environment: Development and Application of the nanoFate Model," *Environ. Sci. Technol.*, vol. 51, no. 10, pp. 5541–5551, 2017.

[177] M. Vinardell, H. Llanas, L. Marics, and M. Mitjans, "In Vitro Comparative Skin Irritation Induced by Nano and Non-Nano Zinc Oxide," *Nanomaterials*, vol. 7, no. 3, p. 56, 2017.

[178] T. Singh, S. Shukla, P. Kumar, V. Wahla, and V. K. Bajpai, "Application of nanotechnology in food science: Perception and overview," *Front. Microbiol.*, vol. 8, pp. 1–7, 2017.

[179] M. Pal, "Nanotechnology: A New Approach in Food Packaging," *J. Food Microbiol. Saf. Hyg.*, vol. 02, no. 02, pp. 8–9, 2017.

[180] A. P. Nikalje, "Nanotechnology and its Applications in Medicine," *Med. Chem. (Los. Angeles).*, vol. 5, no. 2, pp. 81–89, 2015.

[181] V. Chauhan, V. Singh, and A. Tiwari, "Applications of Nanotechnology in Forensic Investigation," *Int. J. Life-Sciences Sci. Res.*, vol. 3, no. 3, pp. 1047–1051, 2017.

[182] A. Nizami and M. Rehan, "Towards nanotechnology-based biofuel industry," *Biofuel Res. J.*, vol. 18, pp. 798–799, 2018.

[183] S. Nummelin, J. Kommeri, M. A. Kostiainen, and V. Linko, "Evolution of Structural DNA Nanotechnology," *Adv. Mater.*, vol. 1703721, pp. 1–12, 2018.

[184] M. Wang, G. Mi, D. Shi, N. Bassous, D. Hickey, and T. J. Webster, "Nanotechnology and Nanomaterials for Improving Neural Interfaces," *Adv. Funct. Mater.*, vol. 28, no. 1700905, pp. 1–28, 2018.

[185] R. V Ulijn and R. Jerala, "Peptide and protein nanotechnology into the 2020s : beyond biology Multi-component," *R. Soc. Chem.*, vol. 47, pp. 3391–3394, 2018.

[186] B. Vergouw, H. Nagel, G. Bondt, and B. Custers (eds.), "Drone Technology: Types, Payloads, Applications, Frequency Spectrum Issues and Future Developments," in *The Future of Drone Use, Information Technology and Law Series 27*, T.M.C ASSER PRESS, 2016, pp. 21–46.

[187] P. Kardasz, J. Doskocz, M. Hejduk, P. Wiejkut, and H. Zarzycki, "Drones and Possibilities of Their Using," *J. Civ. Environ. Eng.*, vol. 6, no. 3, pp. 1–7, 2016.

[188] G. Vásárhelyi, C. Virágh, G. Somorjai, and T. Nepusz, "Optimized flocking of autonomous drones in confined environments," *Sci. Robot.*, vol. 3, no. eaat3536, pp. 1–13, 2018.

[189] PwC and Agoria, "A drone's eye view: Overview of the Belgian UAV ecosystem & the development of commercial drone application in Belgium," 2018.

[190] FAO and ITU, "E-Agriculture in Action: Drones for Agriculture," Bangkok, 2018.

[191] S. G. Potts, P. Neumann, B. Vaissière, and N. J. Vereecken, "Science of the Total Environment Robotic bees for crop pollination : Why drones cannot replace biodiversity," *Sci. Total Environ.*, vol. 642, pp. 665–667, 2018.

[192] A. Otto, N. Agatz, J. Campbell, B. Golden, and E. Pesch, "Optimization approaches for civil applications of unmanned aerial vehicles (UAVs) or aerial drones : A survey," *Networks*, vol. 72, pp. 411–458, 2018.

[193] M. Hassanalian, D. Rice, and A. Abdelke, "Evolution of space drones for planetary exploration : A review," *Prog. Aerosp. Sci.*, vol. 97, pp. 61–105, 2018.

[194] J. C. Hodgson *et al.*, "Drones count wildlife more accurately and precisely than humans," *Methods Ecol. Evol.*, pp. 1160–1167, 2018.

[195] World Economic Forum (WEF), "Harnessing the Fourth Industrial Revolution for the Earth," Cologny/Geneva, Switzerland, REF 211117-case 00035532, 2017.

[196] A. W. Betten, J. E. W. Broerse, and F. Kupper, "Dynamics of problem setting and framing in citizen discussions on synthetic biology," *Public Underst. Sci.*, vol. 27, no. 3, pp. 294–309, 2018.

[197] H. D. Goold, P. Wright, and D. Hailstones, "Emerging Opportunities for Synthetic Biology in Agriculture," *Genes (Basel).*, vol. 341, no. 9, pp. 1–17, 2018.

[198] E. T. Wurtzel *et al.*, "Carotenoids and synthetic biology," *Am. Soc. Plant Biol.*, 2018.

[199] D. Acemoglu and P. Restrepo, "Artificial Intelligence, Automation and Work," 24196, 2018.

[200] M. J. Sousa and Á. Rocha, "Skills for disruptive digital business," *J. Bus. Res.*, pp. 1–7, 2018.

[201] G. Smith and C. Talent, "The intelligent solution : automation , the skills shortage and cyber-security," *Comput. Fraud Secur. Bull.*, no. 8, pp. 6–9, 2018.

[202] KPMG, "The Factory of the Future; industry 4.0 - The challenges of tomorrow," 2016.

[203]   N. W. Gleason, *Higher Education in the Era of the Fourth Industrial Revolution*. Gateway East, Singapore: palgrave macmillan, 2018.

[204]   S. M. Sackey and A. Bester, "Industrial engineering curriculum in industry 4.0 in a South African context," *South African J. Ind. Eng.*, vol. 27, no. 4, pp. 101–114, 2016.

[205]   C. Selim, K. Yasanur, and G. Eray, "Adapting Engineering Education to Industry 4.0 Vision," *technologies*, vol. 10, no. 7, pp. 1–13, 2019.

[206]   M. A. Peters, "Technological unemployment : Educating for the fourth industrial revolution," *Educ. Philos. Theory*, vol. 49, no. 1, pp. 1–6, 2017.

[207]   P. Maresova *et al.*, "Consequences of Industry 4.0 in Business and Economics," *economies*, vol. 46, no. 6, pp. 1–14, 2018.

[208]   M. Piccarozzi and B. Aquilani, "Industry 4.0 in Management Studies : A Systematic Literature Review," *Sustainability*, vol. 3821, no. 10, pp. 1–24, 2018.

[209]   EEF, "The Fourth Industrial Revolution- A primer for Manufacturers," 2016.

[210]   W. Schroeder, "Germany ' s Industry 4 . 0 strategy; Rhine capitalism in the age of digitalisation," FES; London, 2016.

[211]   A. van der Zeeuw, A. Jam, V. Deursen, and G. Jansen, "Inequalities in the social use of the Internet of things : A capital and skills perspective," *new media Soc.*, pp. 1–18, 2019.