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Review

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

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Abstract: The 21st century has witnessed a number of incredible changes ranging from the way of life and the technologies that emerged. Currently, we have entered a new paradigm shift called industry 4.0 where science fictions have become science facts, and technology fusion is the main driver. Therefore, ensuring that any advancement in technology reach and benefit all is the ideal opportunity for everyone. In this paper, disruptive technologies of industry 4.0 have been explored and quantified in terms of the number of their appearances in literature. This research mainly aimed at identifying industry 4.0 key technologies which have been ill-defined by previous researchers and to enlighten the required skills of industry 4.0. Comprehensive literature survey covering the field of engineering, production, and management from both academia and business was done from publication databases: Google scholar, ScienceDirect, Scopus, Sage, Taylor & Francis and Emerald insight. The results of the study show 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. Moreover, both technical and personal skills to be imparted into the human workforce for industry 4.0 were identified. The study reveals the need to investigate the capabilities and the readiness of some developing countries in adapting industry 4.0 in terms of the changes in the education systems and industrial manufacturing settings. In addition, the study proposes the need to address the ways for integration of industry 4.0 concepts into the current education system.

Keywords: Disruptive technologies, Education systems, Industry 4.0, Key technologies, Qualifications and skills, Internet of things, Big data, 3D Printing, Cloud computing, Artificial intelligence, 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 three 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 in this new revolution [2], [3]. Industry 4.0 will increase the visibility of the inequalities among the people, companies and countries worldwide, as every country embraces its technologies in different ways [4]. For example, African countries are embracing it at extremely slower rates vis-à-vis European countries [5], [6]. For survival in industry 4.0 era, being knowledgeable about the changes and the speed at which they are occurring is vital. Thus, ensuring that any advancement in 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, any technological innovation has been considered as the main driver for sustainable economic development and productivity growth [10], [11]. Further, it has been linked to changes in work and employment but this no longer apply in the era of 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 the manner that are expected to cause rapid and massive disruptions to all industrial sectors in terms of demand for occupations and skills [13]. Recently, advancement in disruptive technologies and industrial developments have increasingly pointed towards industry 4.0 [14], which is known with other names in different countries. For instance, Made in China 2025 by China [15], Industrial internet consortium (IIC) and Smart manufacturing Leadership by USA, Robot Revolution Initiative (RRI) and Industrial Value Chain Initiative (IVI) by Japan [16].

Industry 4.0 is unique from the past industrial revolutions because of the great role that its technologies play in wealth creation and socio-political stability [17], [18]. However, the factors that led to the past revolutions, which include various public and private initiatives, are also currently stimulating its 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 impact the manufacturing industries as with the previous industrial revolutions but also have greater impact on the social, economic and education sectors [21]–[23]. However, its influence on education system has been under research by vast academia and companies in the recent years [24], [25]. Therefore, in order to protect most jobs, the necessary skills have to be imparted into the people through the proper channel of education in higher institutions of learning [26].

Vast research have been done but the concept of industry 4.0 remains non-consensual [27], [28]. Additionally, different organizations such as World Bank, World Economic Forum (WEF), and Mckinsey Global Institute have been doing a lot of research and debates and have reported about industry 4.0. Interestingly, industry 4.0 key technologies have been identified by these organizations and academic researchers. However, these key technologies of industry 4.0 and their rankings differ from each organization and amongst academic researchers [29], [30]. For instance, Manyika *et al.* [31] identified nine key disruptive technologies. While Mckinsey Global Institute identified twelve key disruptive technologies [32]. Moreover, Boston Consulting Group identified nine key disruptive technologies [33]. Similarly, Cheryl and Helena [34] identified five key disruptive technologies while Mashelkar [35] identified ten key disruptive technologies of industry 4.0.

The diverse point of views and conclusions drawn by previous researchers about the key technologies of industry 4.0 is quite challenging and can mislead many interested researchers and practitioners. To clearly understand the above observed differences, explore and identify key technologies and the required skills of industry 4.0 ignited 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 adopted. Institute of Technology Assessment [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 one new technology linked with an incremental adaptation of work systems as in the previous three industrial revolutions, but about a multitude of new technologies and forms of application, with different degrees of technical maturity and systemic effects. In other words, it is the new transition from the previous industrial revolutions as shown in **Table 1**.

Schröder [37] defined industry 4.0 as the digital transformation in all areas of industrial process and production bringing about a new paradigm shift in production system. 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].

The combined definitions of industry 4.0 according to Cheryl and Helena [34] and Deloitte [38] has been adopted in the present paper.

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 etc.
Industry 3.0 1960-2000	Automation using digital electronics and IT (first PLC system)	Electronics, Mobile phones, internet, computer, robots, etc.	Computer and electronic engineering, software engineering, etc.
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, etc.	Integration of many engineering disciples e.g. Mechatronic engineering, biomechanical engineering, etc.

Adapted from [1], [24], [39].

3.2. Exponetial Disruptive Technologies

The industry 4.0 is being powered by exponentially growing disruptive technologies that bring about changes at an extremely rapid acceleration but at a nonlinear pace [1], [40]. Moreover, the disruptive technologies has a potential to cause broader societal transformation by changing the existing economic sectors, modes of work, production and consumption [41].

Generally, there are two types of technology; sustaining technology and disruptive technology. The former has a constant or incremental rate of improvement of existing customers. While 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].

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In this 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 **(Fig. 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]–[53], [55], [56], [59], [60], [63]–[74]
3	Additive manufacturing (3D printing, 3D scanning)	28	[1], [7], [8], [10], [33], [40], [47]–[59], [61]–[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]–[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]–[48], [52], [56], [66], [69], [70], [72], [82]–[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, nanorobots)	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]

Rank	Disruptive technology search terms	Appearances	References
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.

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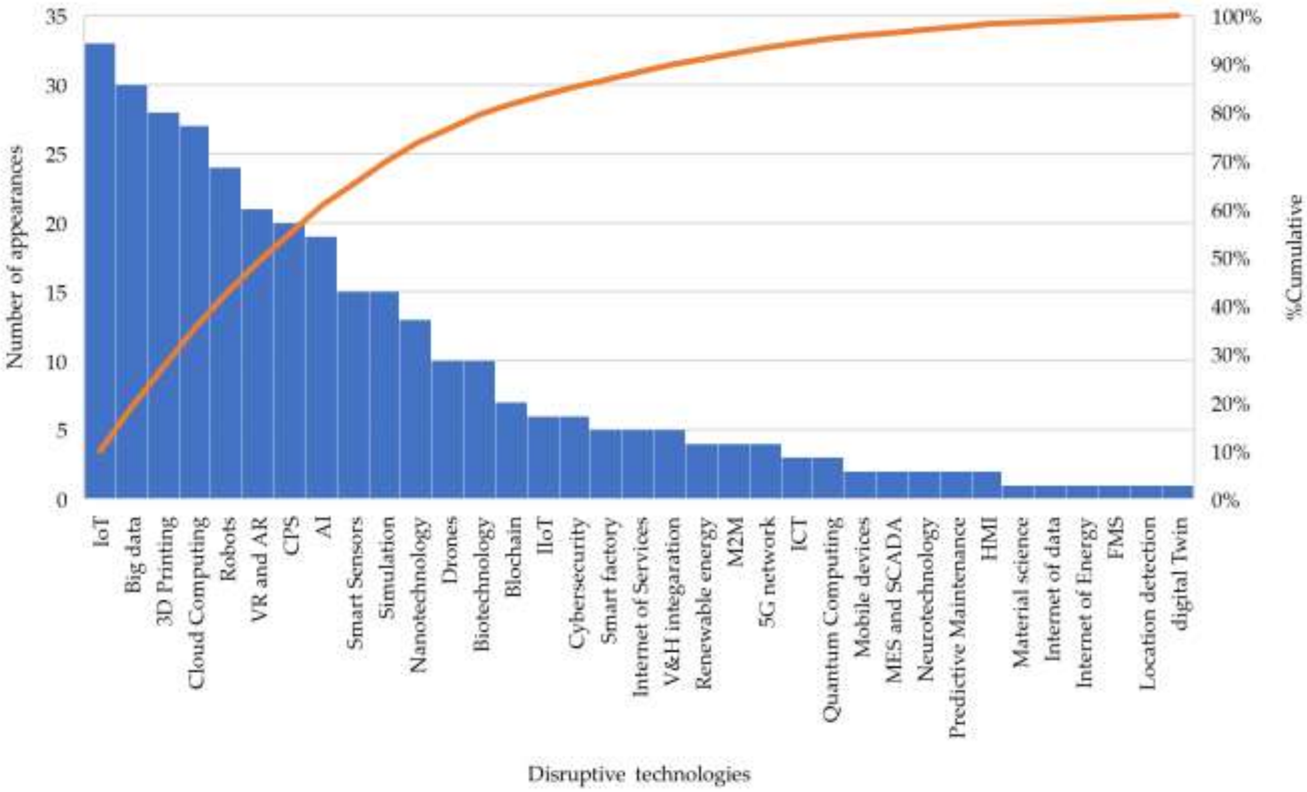

Figure 1. Identification of key disruptive technologies of industry 4.0

3.2.1. Internet of Things (IoT)

IoT is not just machine-to-machine (M2M) connectivity but its definition goes beyond by creating an intelligent, invisible network fabric that can be sensed, controlled and programmed whereby the physical world objects become intelligent and communicate independently, online [95]. More specifically, 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 many industries, IoT has been utilized in automation for lighting, heating, robotic vacuums, remote monitoring and control of machines [50]. Despite it being an old technology, IoT has got massive 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 alert 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].

The typical IoT architecture [107] consists of three layers; (i) perception layers (ii) network layers and (iii) application layers. The first layer acts as sensors for data acquisition. The second layer acts as data transmission platform and the last layer is the application layer in which smart environment can be created. Examples of smart environment include smart city, smart home, smart grid and smart government [108].

The great barriers to IoT applications are the cyber-attack (i.e. security and forensic challenges) and low connectivity. Therefore, with the move to industry 4.0, the major development of IoT will focus on exploring innovative solutions that will pave way to secure forensically sound deployment of IoT networks [109], [110] as well as increasing the IoT systems connectivity [111].

The main companies behind the IoT inventions and deployment include; GE, IBM, CISCO, Google, Amazon, Microsoft, SAP and AG [112]. The above companies are responsible for the following IoT platform market; Microsoft Azure IoT, Oracle IoT cloud services, Google cloud IoT core, IBM Watson IoT, AWS IoT and Bosch IoT suite [113].

3.2.2. Big Data

The Big data are different from the traditional data because of their large growing dataset [114]. Recently, Big data have been defined in term of huge datasets that consist of six main characteristics such as volume, variety, velocity, veracity, value, and complexity [115]. The complexity of Big data brought its own problem as it demand for new skills and knowledge [114], [116]. Moreover, it has a great 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 (lab and clinical data, pharmaceutical data, etc.), public utilities (e.g. water supply, sewage system, etc.), transportation and logistics (e.g. number of passengers using buses, number of accident occurring per year, etc.), agricultural remote sensing (data obtained from soil moisture, temperature changes, etc.) [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 technique [122]. Lastly, Big data have recently been adopted for massive open online course (MOOC) and its application in this area is expected to grow exponentially in the era of industry 4.0 [123]. The three major techniques that are commonly used in Big data are relational and non-relational data stores, computations and MapReduce while the Big data software frameworks include Hadoop, Spark, Hive, and Google's BigQuery [124]. However, with the continuous advancement needed to shape industry 4.0 movements, more advanced Big data software frameworks that can handle extensively huge amount 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 or sheet or powered materials [125]. The commonly used plastic materials by 3D printers include polylactic acid, acrylonitrile butadiene styrene and hydrogel composites [126], [127]. While the metal materials include steel, stainless-steel, titanium, gold, silver, etc.[128]. The newly 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].

Generally, 3D printing has been applied to produce anything ranging from buildings to human organs (such as the kidney and the heart) and tissue (bones, muscles, teeth) [127], [129], [131], [132]. However, its application for printing body parts also known as 3D bioprinting is still at its early stage but it is expected to rise tremendously in the industry 4.0 movements [133]. In addition, the growth of 3D printing will majorly tend toward exploring the innovative ways of making 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 allow 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 education sector but also in other industrial sectors such as healthcare services [138], manufacturing, entertainment, transportation, and energy [139].

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

3.2.5. Autonomous Robots

Autonomous robots as the name suggests, perform autonomous production method more precisely and can work alongside human or even in human restricted places. They have the ability to complete the given tasks precisely and intelligently within just the given time and also focus on safety, flexibility, versatility and collaboratively [140]. However, in the previous years, robots were designed mainly to tackle complex assignments in the manufacturing industries. Recently, the autonomous robots are also being used in logistics such as warehouses and container terminals [141]. The development of autonomous robots has been growing exponentially to meet the need of the 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 includes functional and decisional components such as software [144]. With the move to industry 4.0, the need to develop these components and explore new areas of applications of autonomous robots is expected to increase.

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 worker'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 private sphere [66].

The first application domain of VR and AR has been in education since the 1990s to teach subjects like mathematics, geometry, physics, chemistry, anatomy and so on [146]. In the recent years, VR and AR have 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]. The 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 augmented reality 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 different purposes. This makes CPS to be very different from just an embedded system [149]. In the recent years, the CPS frameworks have been properly utilized in many fields of application such as manufacturing [150], laboratory, learning or teaching factory [151] and many others [152].

The recent development of CPS is called mobile CPS that extend CPS application domains [153]. While, with the move to industry 4.0, the 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]. Furthermore, CPS will be integrated with other technologies including IoT, cloud computing and smart sensors to form the new smart CPS that will bring together 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]. In the recent 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 system [158]. The emerging AI applications that are currently shaping the industry 4.0 journeys include self-driving cars, human speech and face recognition, interpreting complex data and medicine (e.g. Cardiovascular medicine) [159]. With the move to industry 4.0, the major AI development will be directed 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 diseases big data analytics in healthcare sectors [160].

AI technologies are machine learning and knowledge-based systems and the main companies behind AI development include Google, SpaceX, Apple, GE and Microsoft [159], [161].

3.2.9. Smart Sensors

In the recent years, varieties of smart sensors have been developed to meet the need of industry 4.0. These sensors are being used to make smart devices or objects such as smart dust, smart camera, smart phone, smart home and many others [162]. Smart sensors have been mainly used as monitoring device in many application areas [163]. For instance, monitoring system such as water and flood level, gas, environmental, structural health, remote system and equipment fault diagnostics [162], [164]. They have also been used for advanced biomedical applications [165]. With the move to industry 4.0, these smart sensors will be used as an integral to the IoT system. More so, the advancement of smart sensors will continue to grow tremendously [166]. Smart home, smart cities and smart grids are now available because of the varieties of installed smart sensors such as temperature sensor, proximity sensor, optical sensors, pressure sensors and ultrasonic sensor [167], [168].

3.2.10. Simulation

Simulation is a common method of analyzing the behavior of a complex system. Simulation is an old technology which existed long way back since the time of analog computers [169]. However, its fields of application are exponentially growing because of its ability to improve the major components of manufacturing systems such as products, materials and ergonomic design, energy consumption, production processes and efficiency [170].

Recently, simulation has been applied in many areas in education and manufacturing industry and other industrial sectors [171]. In manufacturing, simulation have had huge applications such as in complex automobile manufacturing, ceramic production and chemical processes [172]. Simulation has also been used for 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].

With the move to industry 4.0, simulation is expected to advance rapidly because of the need to understand the behavior of the complex systems with the latest technological innovations in fields such as transportation, communication, medicine and metrology. There are so many simulation software developers which are currently advancing their software to meet the needs of industry 4.0. These include Siemens (e.g. solid edge software), Rockwell automation (Arena software), MathWorks (Simulink software) and Festo (FluidSim software) [169].

3.2.11. Nanotechnology

Nanomaterials are the smallest materials with singular unit within nanoscale (1-100 nm) [176]. Nanomaterials evolved as results of incredible researches in the field of materials science [177]. The ideology of nanotechnology is "science small" as it is the technology applied to produce nanomaterials. Nanotechnology is not a new technology but its novel and numerous innovative applications paved its ways to industry 4.0 movements. Recently, nanotechnology has been applied for making vital components in different fields such as aerospace, automobile, construction, manufacturing, food processing and packaging [178], [179], medicine [180] and forensic science [181]. The emerging application of nanotechnology is the production of the biofuel [182].

In the era of industry 4.0, the applications of nanotechnology in energy storage, lighting and photovoltaics are extensively needed to support the popularly growing application areas of industry 4.0. Further, the medical application of nanotechnology will also continue to grow [183] as well as in high-tech areas such as new materials for batteries and 3D printing [184]. It is also expected to grow toward the field of making living materials and devices, a field currently known as DNA nanotechnology [185].

3.2.12. Drones

Drones, sometimes known as Unmanned Aerial Vehicle (UAV), Remotely Piloted Aircraft (RPA) and Unmanned Aircraft Systems (UASs) [186]. They are aircrafts without pilot on board (flying robots) [187], [188]. There are three main types of aerial drones: rotary wing, fixed wing and lighter-than-air. The most common Drone's configuration is multirotor with four, six or eight propellers. The multirotor type has been available for about a decade, and it has been 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, camera) 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 is emerging as a lucrative technology in the 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]. Recently, the main application domains of synthetic biology include agriculture [197] and healthcare. In healthcare, it has been used in the treatment of complex

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diseases such as cancer. With the move to industry 4.0, 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

With the move to industry 4.0, all skills are required. This is 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. Furthermore, the exponential development of the novel technology such as smart sensors, intelligent assistant, robots and automation will continue to change the need for new types of skills as well as 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 the industry 4.0, the present paper has categorized the required skills in two major groups: technical and personal (soft) skills. The technical skills are required for highly technical tasks and are subcategorized into theory and expertise skills, hardware skills, and software and algorithm skills (digital skill) as shown in **Table 3.**

3.3.2. Building Skills into the Workforce of Industry 4.0

There is need to identify and develop the disciplines, and the required missing abilities in order 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) plays 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 University has 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 (also known as 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].

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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], [211], [26], [36], [116], [200], [202], [203], [209], [210].

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, Philippine 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. 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 required skills to support its growth. It is therefore proposed that field 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.

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