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Research Article

A Modern Approach towards an Industry 4.0 Model: From Driving Technologies to Management

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Every so often, a confluence of novel technologies emerges that radically transforms every aspect of the industry, the global economy, and finally, the way we live. These sharp leaps of human ingenuity are known as industrial revolutions, and we are currently in the midst of the fourth such revolution, coined Industry 4.0 by the World Economic Forum. Building on their guideline set of technologies that encompass Industry 4.0, we present a full set of pillar technologies on which Industry 4.0 project portfolio management rests as well as the foundation technologies that support these pillars. A complete model of an Industry 4.0 factory which relies on these pillar technologies is presented. The full set of pillars encompasses cyberphysical systems and Internet of Things (IoT), artificial intelligence (AI), machine learning (ML) and big data, robots and drones, cloud computing, 5G and 6G networks, 3D printing, virtual and augmented reality, and blockchain technology. These technologies are based on a set of foundation technologies which include advances in computing, nanotechnology, biotechnology, materials, energy, and finally cube satellites. We illustrate the confluence of all these technologies in a single model factory. This new factory model succinctly demonstrates the advancements in manufacturing introduced by these modern technologies, which qualifies this as a seminal industrial revolutionary event in human history.

1. Introduction

The term "industrial revolution" is defined as major changes to industrial processes due to the introduction of new technologies. Looking back on previous industrial revolutions helps us understand the genesis of the fourth industrial revolution. Technology was always used to support industrial processes. The water wheel and water turbines can be considered as the precursors of the first industrial revolution [1]. These were used for many "industrial purposes" such

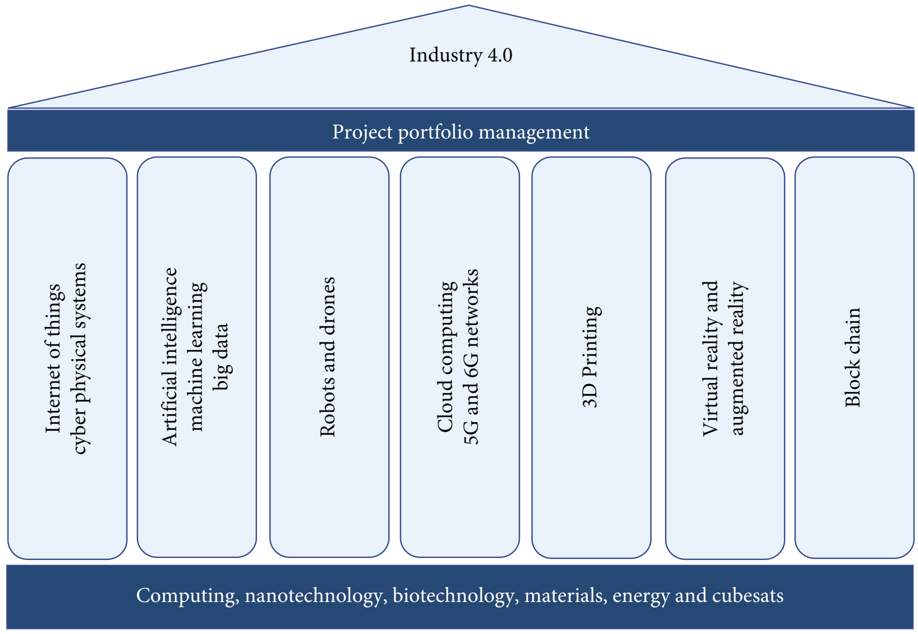

Figure 1: The pillars of Industry 4.0.

as lifting devices, grid grains, sawing, and more [1]. This continued to the early stages of the first industrial revolution, until the use of coal and steam. The first industrial revolution, 1760 to 1830 [2] happened when Watt's steam engine and other steam-powered machines were introduced to the manufacturing process [2]. This led to the increased production at lower costs that initially allowed Britain and later other European countries to play an important role in 18th century trade [2]. The trains also make their appearance during the first industrial revolution as another use case of the steam engine [3]. Unlike the first industrial revolution, which was initiated by advancements in a single field, the second was a result of multiple technological breakthroughs. It included advancements in fertilizers, electricity, and transportation [4]. It was initiated by the introduction of the gas- and air-based internal combustion engine developed in 1859 [4]. However, it was made commercially available towards the end of the 1870s, which marks the beginning of the second industrial revolution. It was the time when cars started becoming commercially available and used for transportation [3, 4]. The third industrial revolution started in the 1960s, and it was based on electronics and automation. Its main achievements were robots and computers [5]. The evolution of computers played a very important role in the 4th industrial revolution. The term fourth industrial revolution was first mentioned in Germany, during the "Hannover Fair" in 2011 by Kalus Schwab [6]. However, it was introduced to the public at the World Economic Forum 2015 [6]. Industry 4.0 is an era of cyber physical systems [5]. According to [6], the main areas are AI, robotics and ML, nanotechnology, biotechnology, quantum computing, blockchain, Internet of Things (IoT), 3D-printing, and others.

In this work, we will look behind the curtains and present the pillar technologies of Industry 4.0. It is not yet clear how quantum computing has impacted or will impact Industry 4.0 as it has not yet proved its potentials, but we can consider the advancements in computational processing power as an equivalent replacement. It is also believed that 5G and 6G networks as well as virtual and augmented reality play an important role in Industry 4.0. Figure 1 summarizes our view of Industry 4.0 from a multidisciplinary point of view.

There are many technological advancements in many areas but the ones that played the key roles were computing, nanotechnology, biotechnology, materials science, energy, and CubeSats. In this research, we identified seven pillars of Industry 4.0. That includes cyber physical systems and IoT, AI, ML and big data, robots and drones, cloud, 5G and 6G networks, 3d printing, virtual and augmented reality, and blockchain. These technological advancements have a huge impact on project portfolio management that has transformed the business to take advantage of all these opportunities as well as manage challenges and risks.

The rest of this paper is structured in the following way. Section 2 includes the foundation technologies where the pillars of Industry 4.0 were based. Section 3 identifies the technologies that are the seven pillars of the fourth industrial revolution. Section 4 presents the modern project portfolio management. Section 5 provides an example of how all these technologies could be applied to a model Industry 4.0 factory, in order to help the readers to realize the impact of modern technologies in the fourth industrial revolution. Finally, Section 6 concludes this paper.

2. Foundation Technologies of Industry 4.0

2.1. Computing. ML and modern advanced AI techniques utilize data in order to produce control decisions, such as simulations, forecasting, and many more outputs that made the Industry 4.0 possible. Most of these algorithms and their theoretical backgrounds were available before but the main difference nowadays is the amount of available data and the advancements in the computational power of modern machines. AI and ML applications utilize the modern central processing units (CPUs) and/or dedicated general-purpose graphics processing units (GPUs) in order to process their data. Over the last decades, the advancement of CPUs followed Moore's Law [7] which states that the amount and transistors in the CPUs are expected to double every two years. Even if this does not correspond to such improvements over the actual performance (applications execution time, etc.) which depends on many parameters which is an indication of the increase in computations power of modern machines. Another computing hardware that played an important role in Industry 4.0 is the GPU. GPUs were originally intended to allow computers to deal with higher quality graphics, and they included instructions to support that at the hardware level. Later, however, it was found that these instructions could be used to do the processing for other types of applications such as ML, key generation, and searches in blockchains, and more. Modern GPU-based solutions are faster and consume less energy than even some high-performance computing (HPC) clusters [8]. Recently, GPU-based solutions found their way to real-time cyberphysical systems [9], which play an important role in applications of Industry 4.0. Commercially available solutions with embedded GPUs like NVIDIA Jetson Xavier AGX [9] offer profound benefits to robots, drones, and other smart/intelligent machines of Industry 4.0.

2.2. Nanotechnology. The term nanotechnology defines the scientific field dealing with the establishment of materials, devices, and systems by manipulating matter and transforming it at nanometer length scale. The result in itself is not necessarily limited to nanoscale but can range at micro or macroscale. A particle of nanometer range (a billionth of a meter) that can be noncrystalline, an accumulation of crystallites, or a single crystallite is categorized as nanoparticle. Performing targeted interventions at the nanometer length scale provides the opportunity to alter the properties and control individual atoms and molecules. In this way, physicochemical, mechanical, electrical, optical, and magnetic properties are being altered, thus providing the ability to come up with innovative products and processes. Therefore, nanotechnology has the potential to revolutionize various technologies in industrial sectors like medicine, automotive and aerospace industry, renewable energy, information technology, and environmental science.

Undoubtedly, the majority of the ongoing research around Industry 4.0 has to do with progress in software and data algorithms [10]. In this automated and interconnected environment of Industry 4.0, nanotechnology plays a vital role. The sensors themselves can greatly benefit from nanotechnology. Sensors incorporating nanomaterials feature increased sensitivity and process ability, thus, minimizing the error margin of the data that they acquire and subsequently feed algorithms and other processes. Sensor robustness is another topic where nanotechnology can assist researchers. Often, demanding operating environments (increased corrosion, temperature, alkalinity etc.) can damage the sensors that will no longer be able to provide accurate data. The use of nanomaterials in the production of sensors can make them chemically inert and robust, broadening the fields of their potential use in environments that were considered not applicable beforehand [11]. The area of quantum computing is another Industry 4.0 field that strongly benefits from the use of nanotechnology. In this case, the use of semiconductor nanomaterials allows increased processing speed and more secure data transmission. Both the aforementioned elements are highly desired characteristics in the context of Industry 4.0 [12].

Another field where nanotechnology can be incorporated within the IoT context is in creating a network that combines different components using communication protocols at nanolevel. The term "Internet of Nano Things" (IoNT) is used to describe such a network. It is still an area considered under development that has great potential for telecommunication and medical fields. Relevant examples can be outdoor field-based applications, where there is a need for remote sensing, or for acquiring measurements within the human body [11]. In conclusion, conventional technologies in the fields of data acquiring and transferring, cloud computing, and data processing are still able to support current needs. However, in the continuously evolving context of Industry 4.0, nanotechnology can assist in shifting to smaller system architectures that will also feature greater processing and data acquiring capabilities.

2.3. Computational Biology and Biotechnology. After the completion of the human genome project in 2003 [13, 14], which was carried out using 'first generation sequencing' or Sanger sequencing technology, there was an emerging need for a cheaper and faster alternative solution to sequence the human genome. High-throughput genomic sequencing technologies, such as next-generation sequencing (NGS) or massively parallel sequencing, emerged that allow the rapid sequencing at low costs of full genomes, many samples of a certain genomic region from different individuals to detect low-frequency mutations or quantification of the abundance of fractions of a genome [15–19]. High-throughput sequencing has myriad applications in many fields such as medicine (e.g., understanding the mode of transmission of infectious agents and precision personalized medicine) [20, 21], forensics (i.e., identifying individuals based on their unique DNA profiles) [22], agriculture (i.e., genetically modified crops and genetically engineered animals) [23, 24], and environmental monitoring [25].

In 2005, the first commercial NGS platform was developed by Roche. Meanwhile, more sequencers were developed by different companies, and the existing ones were improved [26]. The costs associated with NGS continued to drop remarkably. The lower costs allowed scientists to launch the 1000 Genomes Project (or 1KGP), a coordinated international research effort to create an integrated catalogue of human genome variation [27]. The completion of the 1000 Genomes Project (1KGP) project in 2015 [28, 29] would be impossible using first generation sequencing. As of today, whole human genomes can be sequenced in less than a day for less than 1000 dollars.

Recently, ultrarapid genome sequencing enabled clinicians to diagnose rare genetic diseases in five patients in an average of eight hours [30].

The advent of high-throughput technologies in molecular biology resulted in the production of an overwhelming amount of raw, unprocessed biological data, which have to be processed and interpreted in a way to obtain biologically meaningful information. This has led to the emergence of the field of computational biology and bioinformatics which merges cutting-edge software and hardware technologies towards efficiently handling the accelerated generation of biological data. Computational biology constitutes an integral part of the fourth industrial revolution, 4IR [31].

Computational biology and bioinformatics methods are widely applied to genome annotation [32], a very complicated process, consisting of numerous steps. Genome annotation includes the (i) identification of the locations of individual genes and all of the coding regions in a genome, (ii) determination of key features of the sequences (e.g., active sites), and (iii) identification of functional and regulatory elements.

In the postgenomics era, there is an increasing amount of generated biological sequences, the experimental characterization of which is unattainable. If sequences similar to an unannotated sequence can be found in databases for which experimentally verified structural and functional information is available, then the structure and function of the novel sequence can be inferred. Bioinformatics methodologies are utilized to search the sequence (nucleotide or protein) databases for sequences similar to the new ("query") sequence; a process called database sequence similarity search or homology search [33]. In addition, the sequence-structure gap is widening between the number of proteins with experimentally defined structures and proteins with unknown structures. As a result, the most efficient alternative to experimental methods is to use computational and bioinformatics tools to assign structure to a novel protein based on its amino acid sequence [33].

Discovering useful knowledge from the biomedical literature poses a great challenge, given the plethora of published documents (containing information collected from scientific experiments or high-throughput experimental studies) available in premier bibliographic databases such as MEDLINE/PubMed. To address this issue, many bioinformatics tools have been developed for detecting, extracting, and processing biomedical terms through automated text mining [34, 35].

Furthermore, computational methods are employed for the analysis of multiomics Big Data, that is, very large "-omics" (e.g., genomics, transcriptomics, proteomics, epigenomics, and metabolomics) data generated from high-throughput experiments. To this end, relevant datasets are retrieved from public data repositories, processed, integrated, and interpreted, to extract meaningful information [36].

Complex biological networks are widely used to depict the associations of one or more bioentities (genes, proteins, hormones, etc.) and, also, integrate, visualize, and interpret multiomics data [37, 38]. Network-based computational approaches enable the modeling of biological processes and systems [39, 40]. The emerging potential of computational methods for identifying pharmaceutical targets suitable for drug design must be highlighted. Computational tools can facilitate drug target identification, drug candidate screening, as well as the discovery of novel compounds with improved pharmacological and biochemical properties for drug development [41, 42].

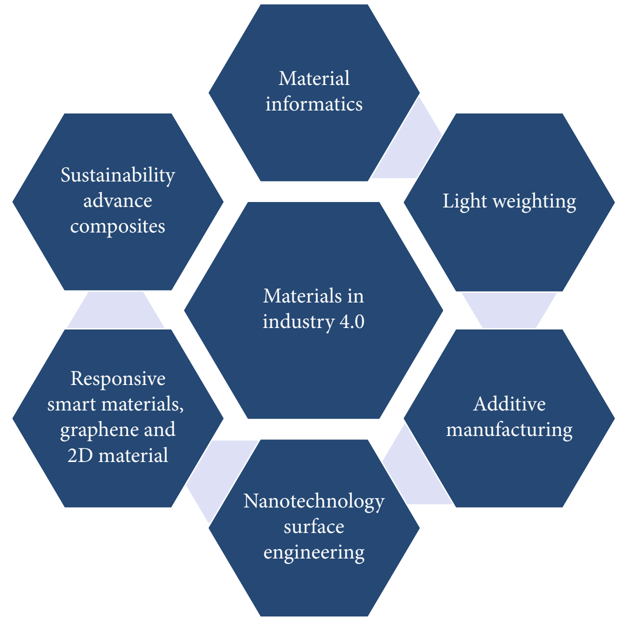

Figure 2: Materials in the context of Industry 4.0.

2.4. Materials. Materials used in Industry 4.0 applications must be able to withstand the high demands that the aforementioned applications place on them. Advanced composites and responsive (smart) materials are required for novel applications that have to be compatible with emerging manufacturing technologies like 3D printing and CNC milling. Assisted by the immense progress in fields like nanotechnology, such materials must exhibit properties like lightweight and elevated mechanical properties while being sustainable both in their production and general life cycle. In the context of circular economy, products made by such materials should be designed and manufactured taking into account such considerations [43]. Figure 2 depicts such material cases in the context of Industry 4.0.

The case of graphene and other 2D materials is a characteristic example of materials developed and used in the context of Industry 4.0 [44]. Graphene represents a novel, new material category exhibit only one-atom thickness, hence, named two-dimensional (2D) materials (they are characterized as 2D since they extend solely in two dimensions: length and width; as the material exhibits one-atom thickness, the third dimension (height) is considered to be zero). The development of silicon semiconductor technology in the late 1960s to early 1970s considered a breakthrough in the field of electronics. Devices like microprocessors enabled the development of computers and smartphones just by downscaling the physical size of circuits and wires to the nanometer scale. Nowadays, materials like graphene and other relevant 2D materials offer unlimited prospects of advancing in device performance at the atomic limit. Also, the parallel use of 2D materials with silicon chips is very promising in terms of achieving great advances in silicon technology.

The use of such innovative materials allowed towards broadening the horizons of existing manufacturing technologies, i.e., while 3D printing technology is considered to be one of the most advanced manufacturing techniques of our time [45], innovative raw materials allowed its transformation from 3D to 4D printing [46, 47]. 4D printing is the process by which a 3D printed object changes its geometry structure in response to external energy inputs like temperature, light, or other environmental stimuli. It is done with the help of a "smart material" with shape memory properties. Such materials are distinguished from ordinary 3D printing materials by their thermomechanical and other material features, which allow them to change shape.

2.5. Energy 4.0. The fourth industrial revolution has been impacted by the advancements in the energy sector, which are most prominently seen in energy storage, smart grids, and renewable energy. Any device (e.g., a robot, a drone, and a wearable) that can operate only for a few minutes is of limited use. The advancements in energy storage such as batteries allow the Industry 4.0 devices to operate for sufficient time in order to be useful in their operating environment. On the other hand, the new information communication technologies (ICT) introduced during Industry 4.0 created new energy distribution and management technologies.

2.5.1. Energy Storage. The decoupling from fossil fuels has made batteries the main technology for storing electricity. Minimizing the size, weight, and cost while increasing the energy capacity of the batteries has been one of the main drivers of Industry 4.0 [48]. Lithium and its polymers are the de facto standard for mobile devices such as mobile robots and mobile phones. The main advantage of such batteries is that they are small, lightweight, and can be easily recharged. There are two types of lithium batteries, lithium-ion and lithium iron phosphate [49]. They both have trade-offs in terms of the amount of energy density, supplied voltage, charging rate, and discharging rate.

In terms of energy density, lithium-iron outperforms iron phosphate. Lithium iron phosphate has lower voltage (approximately 3.2 V) compared to lithium-ion (in the range 3.6 V-3.8 V). On the other hand, the charge rates of both above batteries are equivalent. The discharge rate is the biggest trade-off factor that should be taken into consideration when we need to select Li-irons or Li-polymers. The discharge rate of Li-polymer is higher than Li-irons. Nevertheless, lithium iron phosphate is still the best choice for many applications due to its capability [49].

2.5.2. Smart Electricity Grids. Smart electricity grids depend on sensors and smart switches for monitoring and controlling the power distribution to smart factories, buildings, and cities. The data collected by sensors can be used for triggering automatic alerts and responses to incidents (such as diverting power from one sub grid to another), power consumption prediction, and prediction of possible issues before they occur [50]. Their advanced management capabilities allow them efficient energy management and control, leading to higher and more dependable power outputs at lower prices for the consumers [50].

2.5.3. Renewable Energy. Green technologies and procedures were first launched in the 1960s as part of the industrialized world's environmental movement [51]. Green technologies enable businesses and manufacturers to implement green processes into their operations, reducing the environmental effect of their operations. The scope of green processes (operations) in Industry 4.0 includes everything from product development to product lifecycle management, as well as environmental practices like eco-design, clean production, recycling, and reuse, all with the goal of lowering costs associated with product production, distribution, use, and disposal. Renewable energy can be obtained from various sources such as sun, wind, and biomass. The energy of the sun can be used directly in various industrial applications for numerous processes such as water desalination, improved oil reform, and food production. The other way that the energy of the sun can be indirectly investigated is by storing it in solar cells to produce the required electricity of driving Industry 4.0 [52]. Photovoltaics' growth is incredibly dynamic across the world and varies greatly by nation. A total of 629 GW of solar power has been installed throughout the globe by the end of 2019 [53]. In industries that are constructed in urban areas, turbines are an effective solution to generate electricity in Industry 4.0. For the industries that are located near big rivers, hydroelectric power approaches can be used to generate electricity for Industry 4.0 [54]. Biomass energy is the best solution to generate energy from plants and animals in food industries. In this type of energy, the burning of the biomass is implemented to generate electricity [55]. Renewable energy also plays an important role in terms of sustainability.

2.6. CubeSats. A CubeSat is a small satellite that has a cube shape of size $10\,\mathrm{cm}^3$ and weight 1 Kg [56]. Compared to the traditional satellites, CubeSats are lower cost, lightweight, and much smaller, setting the basis for the new applications. There are more than 6500 in orbit, and their number is increasing rapidly [57]. Some of the main companies that are involved with the launching of these satellites include NASA, SpaceX, and many companies that are producing CubeSats. A CubeSat can work in swarm behavior to reach billions of global targets. Besides this, CubeSat swarm enhances the autonomous locative, data rate, measurements, and temporal settling of the global targets [58]. Referring to these features, CubeSat is the essence of Industry 4.0 future. CubeSat technology will enable the development of new commercial dealings between various industries [59]. It can be applied to enhance communications between IoT devices [60], work together with drone communications [61], take photos of different locations of earth and space, climate research, and weather predicting, and collect sensor data from space [59]. The CubeSat is expected to play a crucial role in the application of current technologies which will assist in making dramatic changes to the technologies that lead the fourth industrial revolution.

3. The Pillars of Industry 4.0

3.1. Cyberphysical Systems. Cyberphysical systems (CPS) integrate sensing, computation, control, and networking into physical objects and infrastructure, allowing them to communicate with one another and with the Internet. IoT and industrial wearable IoT devices are two major examples of cyberphysical systems.

3.1.1. Internet of Things (IoT). The IoT is a network of cyberphysical objects or "things" that are integrated with sensors, software, and other technologies that allow them to communicate with other devices and systems via the Internet. The complexity of these devices ranges from simple household items to major industrial equipment.

Industrial automation and control systems (IACS) have generally been maintained apart from standard digital networks, such as those found in commercial information and communication technologies (ICT). When communication is required, a zoned design is implemented, with firewalls and/or demilitarized zones separating the core control system components from other components. IACS is undergoing architectural changes as a result of the implementation of "IoT technologies, including increased connections to industrial systems. Industry 4.0 relies heavily on the IoT as it has a wide range of applications in the monitoring of industrial and service systems. By permitting increased performance, this technology offers up new and inventive industrial opportunities [62]. The main capacity of the IoT is to gather and distribute data via Internet-connected equipment and gadgets. The primary components of this technology are software, hardware, and network connection enabling data manipulation and collecting. In the sector of manufacturing, the IoT fosters disruptive innovation. Industries see an increase in efficiency during product manufacturing when this technology is properly applied. Manufacturing is done at a lower cost and with fewer mistakes. A typical IoT architecture includes the following three layers [63].

(1) Device layer: architects determine how devices interact with communications networks to link and interconnect in a structure at the device layer

(2) Communications layer: systems utilize protocols to transmit actionable data at the communications layer

(3) Semantic layer: the semantic layer gives the system meaning and context, and it recognizes system elements in the context of business objectives

The primary aim of IoT is automation, and it is a key component of "smart" ecosystems such as smart buildings and factories. The key intersecting point of Industry 4.0 and IoT is connected devices, smart factory grids, and heavy machinery. IoT is advancing the notion of manufacturing excellence by playing a critical role in every industrial operation and significantly enhancing it. Industry-specific IoT is the best match technology since it delivers meaningful results by integrating information and operational technology for processes [64].

IoT technology is considered to be the missing part of CPS realization. CPS technology has been treated either as a wirelessly connected embedded systems domain or as a system modeling domain. Unfortunately, this distinction of attitudes results in two different theoretical spaces aiming to act as a common world. The answer for this barrier is coming to be given from the Industry 4.0 technology of digital twins [65, 66]. According to it, real-time data acquired by embedded IoT-based sensors from real-life physical systems are delivered to a computerized digital system in order to feed with critical information a digital instance, the so-called digital twin. The digital twin aims to reflect the physical system (physical twin). In this context, model-based systems engineering (MBSE) can be supported to deliver better systems, processes, and services design and development [67]. Computer-aided design (CAD), computer graphics, modeling, simulation, and data analytics are some of the key technologies that their use in the digital space can have a tremendous impact on the models' improvement and ultimately the increase of knowledge for the physical systems. Thus, location-aware, and environment-sensitive cyberphysical systems can be studied and developed and help in this way the establishment of a unified, data-driven, and user-directed, federated-based learning space. Such a space will enable Industry 4.0 to blossom and develop the preconditions of getting closer to the next revolution, the Society 5.0. IoT is going to have a multitrillion US dollar contribution to the global economy in the next decade [68]. On the other hand, it also poses the risk of privacy and data security as all the people, devices, and equipment are all connected to the Internet in the present scenario. However, while this technology provides us with greater access to data through the cloud, it also provides opportunities for hackers to get access to networks and exploit the user's data.

3.1.2. Industrial Wearable IoT Devices. Wearable IoT devices are machines with sensors, output devices, processing and connectivity capabilities that can be attached to the human body. Examples of such devices are smart watches, glasses, and so on. Over the past decade, the use of wearable devices has expanded across a number of industries. Wearable gadgets help the Industrial Internet of Things (IIoT) to achieve increased productivity and efficiency [69]. Existing technologies, like radio frequency identification (RFID), have been integrated into garments, watches, goggles, and other protective gear for some years. The high-speed data networks that present in industrial premises provide an environment where wearable IIoT may flourish. The capacity to interact with a variety of sensor data is critical for wearable data-based devices [70]. How data is gathered and then utilized to make practical choices is an important aspect of how wearable technology will evolve across sectors.

The wearable sector is developing due to rising demand. There has been significant growth in the supply of these smart gadgets, particularly in the medical industry. More than 80% of customers throughout the world are open to using this sort of technology to track their vital signs and physical activity, among other things [71]. Wearables are not only for consumers; they may also be a lucrative prospect for companies. Processes have been optimized because of the use of IoT devices, making them more efficient and lowering costs.

Wearables in Industry 4.0 provide supply chains and manufacturers a tremendous chance to optimize and monitor the performance of their personnel on the shop floor, as well as provide more complete real-time data and alarms. They may also be utilized in preexisting device applications to allow portable device usage, such as inventory management and plant maintenance scheduling, all from the worker's wrist [72].

Field service technicians are another use case, since wearables make their outside work more convenient, allowing for quicker and more effective contact with customers as well as more agile movement. Wearable data may be used to influence company choices and improve staff skills and process effectiveness. These gadgets may also alert businesses to issues with their goods and services. This information may then be utilized to customize and adapt the product to the needs of the customer, as well as reduce the need for maintenance and repair.

Wearable gadgets are finding their way into our work settings at an increasing rate, from smart glasses with optical data collection and speech recognition technology to smart safety vests used at building sites to monitor and notify field workers when they reach predefined hazard-zones. From Industry 1.0 to Industry 4.0, robots progressively replace heavy physical labor and simple repetitive processes in terms of human operation and execution. Humans only need to work with machines in the human-centered-automation environment to perform nonreparative, complicated, and unpredictable processes, such as quality control and diagnostics.

The mechanistic, passive, and unidirectional methods of human-machine interaction have all been abandoned. Speech and gesture recognition technologies will enable humans to engage with machines in a more natural and intuitive manner. AI will enhance the human experience. Experienced frontend operators will make an increasing number of decentralized and real-time judgments [73].

Some of the most intriguing applications of wearables in Industry 4.0 are eSIM, reality smart glasses, and smart wearable vests [74].

The recent incorporation of Thales' eSIM in OPPO's new smart wristwatch is an excellent example. Cellular connections may be formed quickly and simply with the help of the eSIM. To create a cellular connection, smartwatches will often need to be linked to a smartphone. The watch is untethered using Thales' eSIM, giving customers seamless access to digital services. This kind of device independence may provide a raft of benefits in the context of wearable IIoT, the most notable of which being off-site process monitoring. Wearable linked devices may also be tiny and light, since there is no need for a hefty SIM card—both of which are criteria for widespread adoption of wearable technology [75].

Users may engage with high-definition 3D material projected into their environment using reality smart glasses. In an industrial context, a physical environment that gives valuable information to organizations might be advantageous to their operations. Users may, for example, be working on a machine that needs maintenance instructions, which may emerge when they point their heads toward the machine. Smart glasses may enable employees to collaborate more effortlessly, much like remote work or visiting clients at their offices, since they can seamlessly share their workplace or real-time virtual environment with peers regardless of their physical location [76].

Wearable smart vests are form-fitting clothing made of rubberized materials that are meant to capture data points on employee movements and location while remaining undetectable to the naked eye. This allows you to acquire a better knowledge of where productivity failures occur so that you may better deploy workers throughout the day and eliminate mistakes on production lines. Furthermore, these vests may be employed for safety, particularly in high-risk areas of industrial production [77].

The concept of "Operator 4.0" has been proposed in the context of Industry 4.0 and is a skillful and intelligent operator who performs not only "cooperative work" with robots but also "work aided" by machines as and when needed—using a variety of human empowering technologies to achieve "human-automation symbiosis work systems." In terms of the drawbacks, the wearables are expensive, some wearables are not stand-alone and can also pose security and privacy issues.

In conclusion, wearable devices must have a variety of useful functions in addition to having qualities such as a distinctive product design, a comfortable fit, and portability. Modules, wearable devices, and interaction mode in industrial wearable system (IWS) must be changed to fulfil the various needs due to the variety of real-world production situations. An important study area is how to optimize the usefulness of IWS in various situations.

3.2. Artificial Intelligence, Machine Learning, and Big Data. The fourth iteration of industry can be described as a vast improvement in our understanding of the exponentially rising quantity of available raw data, which greatly impacts our productivity in many aspects. Focusing solely on industry, the raw data is collected from smart, interconnected robots, sensors, and other machines, as well as from people who are connected to the production process or benefit from it. The data is continuously generated from these entities, and its availability gives rise to the following question: "What do we do with this data now?" Given humanity's experience with vast quantities of data from other fields, the answer is usually that we can benefit from it by understanding it. The data itself is made available through the rise of smart devices, and the interoperability of the IoT and the Internet of People (IoP) which amalgamates it and prepares it for analysis and, more importantly, understanding.

Most of the difficulty is in making the data available, but the next obvious question is how do we understand it once we have it? More importantly, what does understand it even mean? This is addressed in the research field of big data analysis and can be broken down into the ability to find trends and patterns in data, associations between different data points, and to group and classify the actors that generate the data. One of the most famous examples of finding patterns in data came in the retail sales industry where Target Corporation developed a method of determining if a woman is pregnant based on changes in her consumer behavior. More precisely, if she started suddenly purchasing from a pool of items that were statistically linked to pregnant shoppers, then she would receive additional advertisements for other products linked to pregnancy. Shopping tendencies such as frequency and recency, as well as the size of typical purchases, can segment customers into separate groups [78] that can be approached differently from a marketing standpoint in order to maximize sales revenue.

ML has increasingly been used for a variety of large data applications, with notable success in modeling the future behavior of groups of actors based on previous actions. This has found applications in several prediction tasks, such as identifying predators in social media [79] and automatically evaluating the trustworthiness of trading partners based on their past behavior [80]. Additionally, ML has been very successful at extracting sentiment and meaning from text written by humans. Forums can be analyzed for general sentiment on a given subject, and this sentiment has been used to successfully predict such things as election results [81]. Financial markets have also been analyzed with various deep learning-based networks in order to be able to predict price movements of tradable assets.

These examples illustrate the potential power ML methods have in gazing into the future, identifying trends, and in general helping us understand the world around us through data analysis. This technology enables us to understand what people need, and when they need it, making inventories in factories more streamlined and easier to manage. The production chain between factories also becomes more easily manageable as more information becomes available to each link in the chain. These technologies are technologically advanced and proven; however, its efficacy will be advantageous only when large amounts of data are available in the context of Industry 4.0 multilayered datasets representing a wide range of data pertaining to subsystems is required. This leads to another area of research which is still in its nascent stage.

3.3. Robots and Drones. Drones and robotics are considerably impacting Industry 4.0, because of their advantage and ability to adapt various tasks in industrial fields such as maintenance, inspection, and transportation. Thus, companies have started to invest the features of drones and robotics within their flexibility to be integrated into (IoT) for perfecting Industry 4.0. Both robots and drones are mechatronic systems capable of performing autonomous tasks in a physical environment. The main difference between the two is that the term robots is more general and refers to both fixed location and mobile robots. Drones on the other hand can change their location. Another difference is that robots tend to have a higher degree of autonomy and rely less on human input. Drone with high degree of autonomy can be considered as mobile robots. It is not uncommon for drones and robots to work in the same environment.

Robotics is an essential part of Industry 4.0 that supplies comprehensive efficiency in the domain of manufacturing. Robotics intensifies automation sectors and implements jobs in a precise manner with lower cost. Robotics provide a doubtless positive mutation in the performance of Industry 4.0 when integrated within the IoT system to form a new technology called Internet of Robotic Things (IoRT) [82]. IoRT merges the benefits of IoT and robotic features to support Industry 4.0 with a new technology that can provide advanced services with automation approach [83]. Applying IoRT provides industry the ability of using the single, cooperative, and common realization of robotic things with implementing actions under complex and uncertain conditions [84]. In addition, IoRT supports the Industry 4.0 with outstanding services by implementing cloud and networked robots, named Robotics 4.0, rather than conventional robots. Robotics 4.0 is collaborative and cognitive robots which are applied in IoRT rather than the traditional ones. Robotics 4.0 enables close interaction within humans. In turn, both the human and robot workspace have been intersected to implement cooperative tasks. Besides this, Robotics 4.0 increases the level of flexibility in the manufacturing process. Compared with traditional robots, Robotics 4.0 has higher dexterity. From traditional robotics to Robotics 4.0, the operation of robots is directed to be automated instead of only actuated. An essential part of Robotics 4.0 and drones in Industry 4.0 is integrating their information to implement automated tasks. For example, a drone that is performing sky monitoring will order a robotic 4.0 to implement a required task for a specific situation [85]. The major drawbacks of industrial robots and the use of robotic systems in the industry are high initial investment, the ongoing and maintenance costs, and the lack of expert technicians and eliminating the entire labor workers.

Drones can be used in industrial tasks that are difficult or even dangerous to be implemented by humans. Some of these tasks are reaching far distances and working in dangerous regions. Drones can do many tasks with more accuracy than humans due to the ability of integrating various sensor types with the drone platform [86]. For instance, the particularity of equipping infrared and ultraviolet sensors with drones provide the ability of detecting defects precisely in the components of industry. Besides this, involving autonomous drones enhances the features of Industry 4.0 [87]. They operate all the days of week without stopping, do not need a big space, and can do various tasks during a single flight path [88]. Furthermore, implementing autonomous drones to Industry 4.0 is motivating the market into the new technology and enabling new innovations in maintenance operation, safety of employees, security, survey, and map planning [89]. This new technology adopted AI techniques to implement high level tasks such as ordering robots to do repair operations.

In conclusion, applying Robotics 4.0 and drones in the fourth-generation industry will provide a way of implementing complex tasks in advance. Another essential characteristic is Robotics 4.0/drones behavior to interact in a cooperative manner. The benefits of Robotics 4.0, drones, and integrated Robotics 4.0/drones in Industry 4.0 consist of enhancing tasks conditions, increasing productivity, providing safety, and supplying advanced solutions to complex operations. In the market, companies are competing to supply their new technologies in this field. The limited capability of the drone, not being able to carry heavy loads and process information with high speeds, legal limitations, and safety concerns are some of the major drawbacks of drones and aerial robots.

3.4. 5G/6G and Cloud Computing's Impact on Industry 4.0. Industry 4.0 as an industrial revolution is promoted due to the diversified and increased needs of human society. Recent trends show that humans envision having highly customized products, mobile industrial applications, and flexible production lines. These services were served through wired communications but the presence of sensors, robots, drones, and many other devices requires connectivity through wireless mode. Such a need could be met through the enhanced features of 5G/6G [90]. Instead of only relying on cloud-based infrastructure, 5G provides services for extremely heterogeneous vertical applications through network slicing and edge computing techniques [91]. Various aspects of current industrial requirements are tied with time-sensitiveness. Considering time sensitivity, 5G and beyond networks are expected to deliver such requirements effectively through their support for ultrareliable and low-latency communications. Integration of Time-Sensitive Networking (TSN) with 5G and beyond is investigated for QoS requirements [92].

Apart from time sensitivity and quick connectivity, industrial automation requires intelligent networks to consider the dynamic nature of the equipment, the network and the operators involved. Intelligent industrial 5G networks are expected to meet such precise requirements through domain specific knowledge [93]. Furthermore, the requirements of various diversified industries include latency, reliability, jitter-free, lower packet loss, and accuracy [94, 95]. Such stringent and precise requirements could be addressed through 5G nonpublic networks [95]. The combination of various recent technologies such as 5G connectivity, distributed edge computing, and AI in the form of 5G edge intelligence for vertical experimentation (5G-DIVE) was evaluated for its support for real-time autonomous navigation [96].

Supersmart societies consider humans as their center of development. In order to cater for human centric approaches, 6G considers a holistic approach. The presence of cyberphysical-social systems (CPSS) in 6G mobile networks supports recent applications like Tactile Internet and Internet of No Things through human intelligence instead of relying on ML [97]. Such futuristic approaches tend to enhance Industry 4.0 towards Society 5.0. Network-in-a-box (NIB) of 6G provides support for mission critical applications through personalized private network services. Industry 4.0 applications are expected to benefit from 6G-NIB to meet their stringent requirements [98].

The transition to Industry 4.0 is not smooth for different industries, as they have their own legacy devices, which are not smart in nature. One approach to handle this transition is through a cloud-based IoT platform [99]. Meanwhile, the presence of multitenancy and resource heterogeneity in cloud computing platforms could be a challenge for cloud-based applications. Industry 4.0 should consider these challenges along with other stringent requirements like latency-sensitiveness. The stochastic nature of inference time caused by heterogeneous million instruction per second (MIPS) in the cloud computing environments have to be taken care of through Industry 4.0 [100]. Quality of service (QoS) requirements of real-time IoT applications are difficult to be met through cloud-computing infrastructure due to communication latency and geographical distributions. Addition of fog computing to the cloud causes challenges in delivering services in a time-optimized way due to their heterogeneous, distributed, and constrained resource nature. Context-aware application placement policy could assist addressing these challenges in Industry 4.0-oriented applications (I4OAs) [101].

Enhancements of various aspects of cloud computing have also happened through adding intelligence to existing elements like cloud and edge. Such AI-based elements have been tested on various situations like scheduling, optimization, and forecasting [102–104]. Along with the addition of intelligence elements to the existing cloud infrastructure, network-related advancements like software-defined network (SDN) are added to the existing Industry 4.0 network environment to improve data transmission and quality of service [105, 106]. Physical obstructions impacting the connectivity, high rollout costs, and no rural access, causing severe battery consumption are some of the shortcomings of 5G Technology in Industry 4.0.

3.5. 3D Printing. 3D printing is one of the leading emerging technologies within the framework of Industry 4.0. The utilization and implementation of this technology, together with other technologies, are making the industry shift towards an integrated modus operandi where machinery (autonomous, interconnected, and intelligent), systems, and networks can exchange information and transfer the output to the systems of production management [106, 107]. Moreover, as a fabrication technique capable of transforming a 3D design into an item without human intervention, 3D printing features a fundamental role. In addition, the need for surrounding industrial infrastructure is eliminated; postprocessing operations are minimized, as well as raw-material waste and human presence. These are considered key factors that will have a true impact in the industry of the future.

Due to 3D printing, industrial complexes now have the potential to increase their flexibility and adapt to the needs of a demanding and constantly evolving market. Also, it enables all kinds of customized items to be fabricated without the presence of traditional manufacturing tools like molds. Likewise, 3D printing has a minimum environmental impact, which is a desired characteristic considering in the context of Industry 4.0 due to the importance of utilizing sustainable manufacturing processes with low resources consumption [108].

In the last decade, 3D printing equipment has become more versatile in terms of exhibiting portability and wide variety of materials availability. Due to the expiration of relevant patents in the 2010s, the 3D printing market has expanded rapidly, offering desktop 3D printers at affordable prices for individual users and SMEs (small-medium-enterprises) [109]. 3D printing technologies like FDM, SLA, and SLS are now available at desktop sizes and in a user-friendly package. Also, the availability of offered raw materials has rapidly increased. Thermoplastics, resin, and metal raw materials can nowadays be used by the technology, making the fabrication of customized items with tailored properties a reality [110, 111]. Build size constraints, limited materials, postprocessing, inaccuracies in the design and build, and copyright infringement issues are the drawbacks of the 3D printing technology.

3.6. Augmented and Virtual Reality. Virtual reality (VR) is an artificially generated alternative reality, which primarily utilizes 3D images and sound and may use additional input and output devices. [112] VR attempts to convince the person the artificial reality is the actual reality with the user interacting with elements in a "virtual world" which is invisible to others except to the user herself.

One of the key applications for VR is simulations. VR simulations place the user in virtualized settings, surrounded by similar controls of vehicles and other equipment. The idea is to simulate the actual vehicle or equipment usage in a virtual world, allowing users to experience nearly exact situations without its dangers. These types of VR simulations require specialized equipment that sometimes have comparable size to the actual vehicles they mimic [112].

Nowadays, most VR applications will use equipment such as VR headsets. VR headsets are wearable technology which consist of the head-mounted helmets that provide 3D vision and surround-sound audio. The latest headsets will have gyroscopes and accelerometers to track the users head movement, creating a sense of immersion that blinds them from the outside world. Devices such as the Oculus Rift and Oculus Touch provide the user with the means to control, interact, and be immersed in a virtual world [113].

VR currently has many applications that include but are not limited to training, education, simulation, data collection, advanced remote control, social research, psychology research, and entertainment [114].

Virtual reality has evolved over the years by mixing other forms of interface technology such as touch screens to lead to what we can term as "mixed reality" (MR). In MR, the user can actually see a mix between virtual or artificial reality with the real world. This has led to the development of augmented reality. Augmented reality (AR) is a visualization technique that overlays visual artifacts, such as text, images, and other interactive media material, over a reality view acquired by a device's camera. [115]. AR systems work via image recognition that "look for target images." Once a target image is recognized, a virtual object is activated, and further virtual interaction can be conducted by the user. AR can be applied from mobile phones to specialized head mounted displays [116].

Current applications of AR include visualization of information, simulation, environmental interaction, communication, collaboration, and potentially more. Due to the high availability of mobile phones, AR technology has an incredible potential reach. It can be seen applied mainly in museums [117]. However, other points of information such as libraries and shopping centers have also started to utilize AR for various applications.

The delivery of information and a virtual experience that does not put the user at harm is one of the great advantages of utilizing VR, MR, and AR. Information is delivered while providing an immersive experience to simulate an actual situation. In today's world of IR 4.0, the delivery of such experience and information is essential as we move forward with the integration of the other aspects of IR4.0. "Augmented reality (AR) currently plays an important role in undertaking the challenges in integrating technologies to expedite the march towards Industrial Revolution 4.0 (IR 4.0)" [118].

Even though the previous statement focuses on AR, recent developments have also pointed to further growth for virtual reality and mixed reality in general. The development of "the Metaverse" provides a huge opportunity for further research and development for AR, VR, and MR on ways to experience this virtualized world [119]. A future where we may have a totally virtual universe to live our lives in alongside our current reality will require the development of the other supporting pillars and contribute heavily to the growth of Industrial Revolution 4.0. Motion sickness, ethical concerns, nausea, dizziness, and lack of privacy are some of the many disadvantages of the AR and VR technology [120].

3.7. Blockchain. The technology known as blockchain is a shared, distributed ledger (system of records), which is immutable, and quickly provable to contain authentic transactions between parties [121]. Anyone can participate as verifier of transactions, or "miner," where "mining" is incentivized with rewards that come in the form of the coins that belong to the network being mined. Bitcoin is the world's first and most popular cryptocurrency by market capitalization. Although early cryptocurrency networks were designed to be able to transfer information in the form of numbers between parties, recently, any type of information can be transmitted. Therefore, it is now possible to securely and immutably transfer images, video clips, documents, and any other forms of digital media. Several recent research works present blockchain as one of the technologies which enable and empower Industry 4.0 [122–125]. Blockchain can boost and normalize the process of data collection, decentralize the tremendous effort involved in examining and analyzing industrial data, and drive the most useful judgments and decisions based on the learning achieved from the aforementioned operations [126]. Production processes become very trackable, as every step can be documented on a block chain, and errors are easier to identify. With the aid of faster computation power, better intelligent machines, smaller sensors, and more affordable data storage, Industry 4.0 allows for efficient, adequate, individualized, and customized production at an affordable cost [127].

The wealth of a market is measured by the flow of the transactions in the market network. Via the ledger,

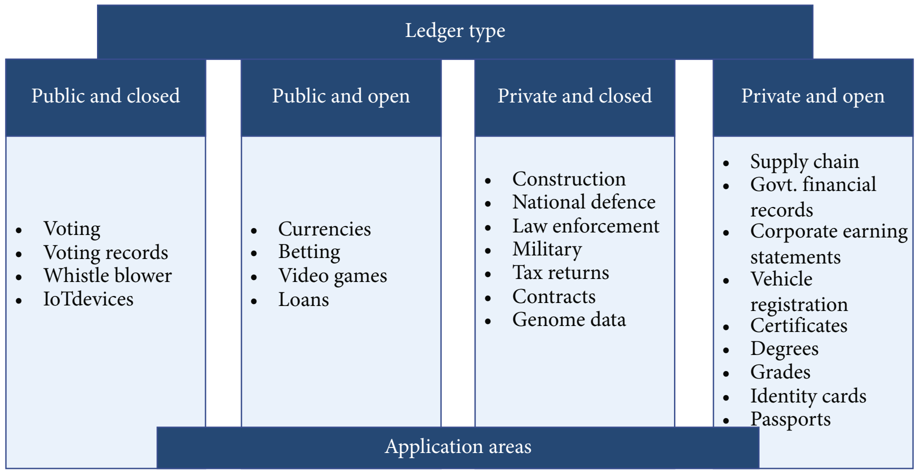

Figure 3: Ledger types and their application areas.

transaction information is attainable to all authorized participants; this feature creates trust, transparency, and a steady business relationship. IBM Food Trust is an example that demonstrates how blockchain is used to maintain quality control and inspect every step of the food production system [128].

Different types of applications can be built on top of the distributed ledger. The nature of the application determines whether a public or private ledger should be used. A clustering of ledger types against their corresponding applications [126] is shown in Figure 3.

Transactions can be very basic, where one party sends information to another party, or they can be more complex, and involve sets of rules that must be satisfied for an event to be triggered. More complex transactions involving rules are called smart contracts, which can be described as digital versions of legal contracts [129]. Applications for smart contracts can be found in decentralized finance and loans, crowd financing, and wills and testaments. Not being a distributed computing system, high energy consumption for its functioning, data being immutable, and not being completely secure are some of the disadvantages of blockchain technology [130].

4. Project Portfolio Management

Industry 4.0 describes a plethora of developments which are expected to lead to a new industrial revolution that is fundamentally characterized by digitalization. To this, technologies such as AI, IoT, nanotechnology, space, robotics, blockchain, cybersecurity, and other emerging domains have a great potential to empower project management.

The applications of AI can fundamentally change the way projects are realized; setting new frontiers for forthcoming future challenges for the modern society and humanity [131] argued that among the changes that Industry 4.0 brings, project managers are also required to adapt to new needs and expectations in an attempt to foster the development of new ubiquitous technologies.

These new technologies have urged industries to embrace a more versatile organizational capability of adopting more agile and hybrid practices [132], readapting their processes around customer-obsessed value delivery. In effect, this has an impact on overall enhanced customer experiences which impacts the organization’s profitability sustainability and digital future footprint.

However, one of the greatest challenges in regard to the project management world is being able to deal with continuous and increasingly complex change(s) in an evolving global digital scene. Undoubtedly, AI can affect projects’ design, development, structure, and execution, reshaping organizational digital capabilities.

For instance, the adaptation of an AI to project management, from planning to risk management, procurement, benefit realization (programs), collection, and information analysis achieves a more robust continuum of procedures, processes, and baselined policies. In turn, the application of actionable insights for future projects is useful, as it provides stakeholders with insights based on a range of data sources.

Moreover, AI can eliminate inconsistencies and complexity. Machines are not predisposed by psychological factors, socioeconomic greed, or grief such as bad days, subpar living standards, which are not tied to a family or relatives and are less, if at all, error prone. The whole picture is important to draw including, what, when, and how AI can give you that picture with real data analysis and optimize projects’ performance with greater confidence.

The more digitally shaped an organization becomes, the greater the new value will be created in the economy. A proper and concise digital strategy in place can guide more businesses to modernize their digital capabilities, gaining a significant competitive advantage, and foster a business culture which focuses on the use of digital technologies leading to tangible and sustainable results [133].

Digital transformation as a key enabler for Industry 4.0 is rather notoriously difficult and complex, more so when linked to terms such as “digital disruption.” The fundamental change brought to operations to deliver value faster, better, and safer to customers coupled by digital and technological advances at an organizational level is a challenge in itself. An approach to realize the benefits of a transformation requires commitment by both; the organization and individuals since the notion of one-sized-transformation-does-not-fit-all materializes rapidly.

Project managers and other key stakeholders need to realize that digital transformations are not purely technological ones rather part of the wider business transformation ecosystem; with culture becoming an instrumental pillar on the path to success. In other words, technology in Industry 4.0 acts as the tooling bandwagon to deliver on promised value. Therefore, technology can offer global businesses diversified potential to engage seamlessly and inclusively with others on the worldwide scene.

Overall, the use of AI in the project management domain can fundamentally change the way projects get delivered to achieve a common purpose. AI leverages the project data to drive strategic decisions with a greater understanding leading to better investments. This means delivering value to communities on the premise that the right type of work improves their experiences, at the right time and in the right way.

5. A Model Industry 4.0 Factory

The fourth industrial revolution differs from earlier ones in that it considers factories as cybersocio-physical systems. The physical system includes all the machinery, physical space, and physical resources. The social part includes all the people and processes. The cyberpart includes all computational parts such as AI and ML algorithms. Most Industry 4.0 technologies work across multiple levels of the cybersocio-technical stack, which includes human information systems and machines working together directly or via the Internet. To understand the impact of new technologies to Industry 4.0, we will introduce a model factory and give some examples of how the technologies introduced in this paper can maximize its potential. To that respect, consider a factory F, which requires resources $r1, r2, \cdots rn$ and produces a product p and subproducts sp1, sp2. Spm.

In order to successfully meet factory automation requirements, the concept of the IIoT can be applied in Industry 4.0 to get processes which are critical, robust, reliable, timely, and have close-to-zero latency. 5G networks will be applied to facilitate the operation of massive IoT deployments in order to deliver high bandwidth and reliability communications. The implementation of IIoT can positively affect the massive machine-type communication (mMTC) and ultra-reliable low-latency communication (URLLC).

Factory workers wearing wearables and automated technology, when used together, may assist businesses, and industries obtain data-driven visibility throughout the supply chain, increase productivity, and make the workplace safer. For example, using a smartwatch can allow workers to constantly monitor certain machines and receive messages or alerts on certain processes. Also, they can be called at any time if required.

ML and AI enables systems and algorithms to learn from their mistakes and improve over time. The model factory F is a digital factory that continuously monitors production and gathers data using smart devices, equipment, and systems. Advanced analytics are provided by this data collecting, enabling manufacturers to make more informed decisions.

It is possible for factory F to save money on health and safety expenditures by having fewer employees participate in potentially hazardous occupational activities, which will result in fewer accidents and less time off for their employees. Many robots require relatively little space to operate and may safely work alongside humans on production lines. The factory can downsize to cheaper workspaces as a result of the probable decrease in necessary space.

In the manufacturing industry, drones will be used for asset inspection, intracompany material and component movement, and inventory taking. Inspection and maintenance will be the most typical applications, as drones equipped with radar or laser scanners, infrared, or stereoscopic cameras can swiftly detect irregularities or issues in industrial equipment. It is especially important in areas like refinery, pipeline, quarries, and other major facilities, where human inspection is either unsafe or worthless due to limited access to all regions.

The existing mobile communication protocols of 2G, 3G, and 4G are being upgraded to 5G. The development of a mobile communications standard focusing on communications between sensors, devices, and machines in the IoT, as well as human digital connectivity, is referred to as 5G. With peak data transfer speeds of 20 Gbps, 5G is up to 20 times faster than 4G, can send data with a millisecond latency (essentially no delay), and is almost as reliable as cable data transfers, with up to 99.9999 percent dependability.

Additive manufacturing, in conjunction with other technologies, is promoting an evolution in the industry toward intelligent production, in which machines, systems, and networks can exchange information and respond to production management systems. 3D printing is important because it is a technology that can turn a 3D design into a product without the need for human intervention. Additionally, expensive tools and fittings are no longer necessary, resulting in reduced postprocessing, waste, and human involvement. Prototyping of new versions of product P and subproduct SP1, SP2, and SPn could also be done using 3D printing technology before production.

Manufacturing and quality control of all products and subproducts could be enhanced while reducing the cost using augmented reality. With the use of augmented reality, F could rely on cheaper junior workers in the assembly lines. The workers could wear augmented reality glasses that guide them on how to assemble P and SPs by understanding what the worker is doing and display the next step. Meanwhile, it could raise an alarm if something goes wrong. In that case, the worker could be connected with a more senior engineer who could also see what the work can see and support him with the help of visual artifacts.

Designers in the manufacturing industry can use virtual reality (VR) to replicate their design prototype or model. This enables them to correct faults at the first stage of manufacturing while also reducing production time and cost. This could be from a simple model of the production line to a digital twin that replicates the whole factory. That also allows the immersive training experiences for their staff, allowing them to practice real-world situations. Workers with demanding occupations may hone their talents away from the perils of the workplace. Because virtual reality is engaging and fascinating, learners acquire knowledge quickly and remember it longer. Virtual reality may assist in the creation of a shared virtual workplace that connects several individuals working on the same project. Users from all around the world will be able to view, visualize, and collaborate on the same virtual model. This may help coworkers communicate more effectively so that validation procedures can be completed without the need for a physical meeting.

Blockchain could aid the model factory by ensuring traceable provenance of all parts in the production and assembly lines. In its most basic form, blockchains can track the origins and final destinations of all parts in the manufacturing process, which will enable managers to easily identify products that contain a series of deficient parts from a particular production line.

Factory F includes many automations at different levels. Not only in the actual production but also at the management level. AI and ML can optimize the business processes, supply chain management, and even aid the marketing of the outputs. Automated rewards systems could be used to ensure fair benefits for the employees. That will enable the managers to reduce their micromanagement and focus more on macro and strategy levels, ensuring the long-term success of the organization.

A point that can be considered a drawback of factory F is that it will occupy significantly less people than a less-automated peer factory. The factory will require more highly skilled manpower but less workers overall.

6. Conclusion

Mechanical production based on water and steam power, mass labor and electrical energy, and electronic, automated manufacturing were the driving forces behind the first three industrial revolutions, correspondingly. The fourth industrial revolution ("Industry 4.0") is defined by its dependence on the usage of cyberphysical systems capable of communicating with one another and making autonomous, decentralized decisions in order to improve industrial efficiency, production, safety, and transparency. This is not the only technology that led to Industry 4.0. In this paper, we identified seven technology families that acted as the pillars of the fourth industrial revolution. IoT, AI and ML, robotics and drones, cellular wireless communications, 3D printing, virtual and augmented realities, and blockchain.

IoT is a network of devices with sensors, processing units, and other systems that have Internet connectivity. IoT is one of the essential pillars of the fourth industrial revolution due to its role in supporting the objective of digital transformation. AI and ML with the help of big data are able to make intelligent decisions at all production and management levels. Robots and drones are capable of performing simple to complex staff reliably, fast for a long period of time. Circular networks such as 5G and the soon to come 6G will offer high speed reliable connection to the Internet allowing the various devices to take advantage of high-performance remote resources from any lower power consumption device, anywhere within the coverage area. 3D printing can produce from prototypes to complex functional products. Augmented reality can enhance the reality of individuals with visual artifacts providing clues on the physical environment. This can enhance remote collaboration and reduce the need for physical presence. Virtual reality can also aid in many areas, such as training and remote control. Blockchain can reliably store information and trace the history of assets. The pillar technologies of Industry 4.0 are based on the advancements of computing, nanotechnology, biotechnology, materials, advancements in energy, and CubeSats. The paper used an imaginary Industry 4.0 model factory to show how all these technologies can be applied on a single production entity and their impact. The main drawback was that it can provide less jobs than a peer, less-automated factory.

The main limitation of this paper is that it only touched the surface of all the presented technologies and their applications. This was done, because the aim of this paper is to provide the readers with an understanding of all the technologies that compose the fourth industrial revolution. In the future, we plan to produce more focused papers that will discuss in more detail the impact and the risk of each of these technologies to the manufacturing process and the society.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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