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REVIEW PAPER

Sustainability of Industry 6.0 in Global Perspective: Benefits and Challenges

S. Chourasia[1,2], A. Tyagi[1,2]*, S. M. Pandey[3], R. S. Walia[4] and Q. Murtaza[2]

[1]Department of Mechanical Engineering, SGT University, Gurugram, Haryana, India

[2]Department of Mechanical Engineering, Delhi Technological University, Delhi, India

[3]Department of Mechanical Engineering, NIT Patna, Patna, India

[4]Department of Production Industrial Engineering, PEC, Chandigarh, India

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Abstract: In the present area, the outbreak of COVID-19, customer behavior have been seen toward their individual specific need, which encourages advanced-manufacturing industries to provide mass personalization of goods and services. The Covid-19 crises bring opportunities for industries and service providers to enhance their capability for a fault-free environment, zero failure, anti-fragile, and improve production capacity. The present paper provides an overview of the sustainability of Industry 6.0 in a global perspective with vision, objective, and transformation of Industrial Revolutions. The sole aim of industry 6.0 is to seizure the new technologies, which can be applied worldwide and deliver wealth, prosperity away from the job and provide growth to nations across all planetary boundaries. This revolution would promote living harmony with nature, support the principle of sustainability where technology would not be a thing, and promote the human virtual digital twin where all can simultaneously see physical goods and virtual product information.

Keywords: Industry 6.0; Digital manufacturing; Internet of thing; Big data; Robots

1. Introduction

Today, advanced digital technologies have been grooming worldwide with the speed of light. In contrast, industries and businesses face lots of trouble embracing advanced technologies to teach their changing behavior. Industries have to work with the speed of light to get their momentum, to conquer with these advanced high-speed technologies. These transformations can quickly be adopted by moderating or the agile mindset of industries. Digitalization in technology is the voyage, not a terminus; it supports the business models, medical system, manufacturing industries, etc., for their growth and shapes business and benefits customers. Now, all are at the hinge point where things are changing exponentially changing from mechanization to electrification to electronification to computation to mass customization to mass personalization to virtualization to digitization to intelligization to robotization to mobilization [1]. Nowadays, researchers are starting to think beyond industry 5.0, industry 6.0, a futuristic idea. Industry 6.0 is the idea, which varies according to the need of industries. Sometimes it is ubiquitous, customer-driven, human-centric, anti-fragile manufacturing, virtualized, human co robot centric and homogeneous assets, etc. The future prediction for industry 6.0 is to hyper-connect the industries to industries, highly mass customization, highly mass personalization of services and products with the attachment of dynamic supply chain management concept, highly customized class one lot size thinking where all the information can drift all across the countries.

The spread of coronavirus has broken the economic backbone of all countries and left its instances for many years. This worldwide crisis has compelled industrialists and service providers, medical, non-medical, and policy-makers, to rethink how to manufacture the products and provide customer services. Presently, customers' behavior and necessities are shifting vividly because of this, and it raises the various challenges for manufacturing industries

*Corresponding author, E-mail: tyagiankit10506@yahoo.com

regarding providing services to them according to their demands, Since the customers are looking for mass personalization of products and services rather than mass customization in every field such as medical services and manufacturing services.

To deliver the first discussion over industry 6.0, authors tried to glimpse industry 6.0, its transformation journey from industry 1.0 to industry 6.0, vision and objectives, need of industry 6.0, supporting techniques, benefits, and challenges. Firstly, the authors present the inspiration behind the evolution of industry 6.0 from the industry perspective. Then elaborate on the futuristic idea behind industry 6.0 and its transformation from industry 1.0 to industry 6.0. In the subsequent division of this paper, the vision and objective of the industrial revolution, including industry 6.0, are defined. Successively, researchers discusses assisting technologies for industry 6.0 such as the Internet of Things, Cyber-physical systems, Autonomous Robots, Big Data, Additive Manufacturing, Augmented and Virtual Reality, Digital Transformation, Cyber Security, System Integration, Simulation, Smart Factories, Artificial Intelligence, Quantum Computing, and Cloud Computing [2–6]. In conclusion, the authors finally climax the benefits and challenges in adopting industry 6.0 for industries.

2. Meaning of Industry 6.0

Industry 6.0 is the convergence of various ideas, which generates in the millions of minds of leaders, scientists, predicators, and researchers. Industry 6.0 is the one-step further than industry 4.0 and industry 5.0, where every operation would be controlled by human minds and performed by automated robots by covering all the planetary boundaries. It combines human intelligence, artificial intelligence, cloud computing energy, human–robot working big data, quantum computing [2], etc. It is a futuristic idea, where various manufacturing operations and services are provided to customers using artificial intelligence, cloud computing energy, human–robot working, big data, where satellite and industrial AI (Artificial intelligence) enabled robots would assist [3]. It is the amalgamation of sustainability, anti-fragile goals, and digitization, which could significantly help the medical system and manufacturing industries, and it would take approximately 10 to 15 years to implement. This revolution focuses on providing virtualized antifragile manufacturing and anti-fragile services focused on customer-centric, customer-focused ethos, super-connected industries with vibrant supply chain, automated flexibility, internal value networks where proper interactions within the organization or outside across the various nations and its administrative areas. This revolution would boost quantum computing [2] for solving the complex and colossal massive algorithms of present AI models and Machine learning techniques and open the door of opportunities for novel programming and AI algorithms, making human work more accessible and practical [4].

3. The Vision of Industry 6.0 Toward Sustainability

Industry 6.0 is looking like a futuristic industry, where its vision is far broader than the remaining industrial revolutions, which held up till now. This revolution will work to influence the industries 6.0 toward changing the work culture of humans, with the use of noble creativity of human beings associated with machines and advanced production systems in the highly cutting-edge digital technologies environment [4]. In this environment, humans can directly operate the machines using brainpower, which would be enabled with digital technologies and perceived resource competent and user-oriented manufacturing solutions compared to other industrial revolutions. The future industry 6.0 focuses on sustainability, homogeneous assets, safety, resilience, Antifragility, harmony with nature, co-working use of technologies (digital twins), and eco economy [4–6]. Industry 4.0 and industry 5.0 consist of promising cutting-edge technologies and applications expected to assist the futuristic industry 6.0. Figure 1. Shows the distinguish vision of industry 1.0 to industry 6.0.

4. Transformation Journey from Industry 1.0 to Industry 6.0

Earlier, many industrial revolutions have occurred so far, and these comprise of industrial revolution 1 (I.1), industrial revolution 2 (I.2), industrial revolution 3 (I.3), industrial revolution 4 (I.4), and newly introduced industrial revolution 5 (I.5). Figure 2 demonstrates the transformation journey of industrial revolution 1 to industrial revolution 6 (Futuristic Idea). The first industrial revolution came into existence from late 1784 to 1800, where the mechanized production system was introduced, the first mechanical loom. In this revolution, mechanical machines were introduced in the industries, which has reduced the workload of humans. The second industrial revolution brought the division of work, mass production, and electrical energy to run the machines in 1870. Industry revolution 3.0 came into the light in 1969, brought advanced computer technology, Information and Technology systems, and automated production, which enhanced the productivity of industries. After that, a new revolution era started in 2011, i.e., industry 4.0. This revolution has brought recent changes in the entire manufacturing market.

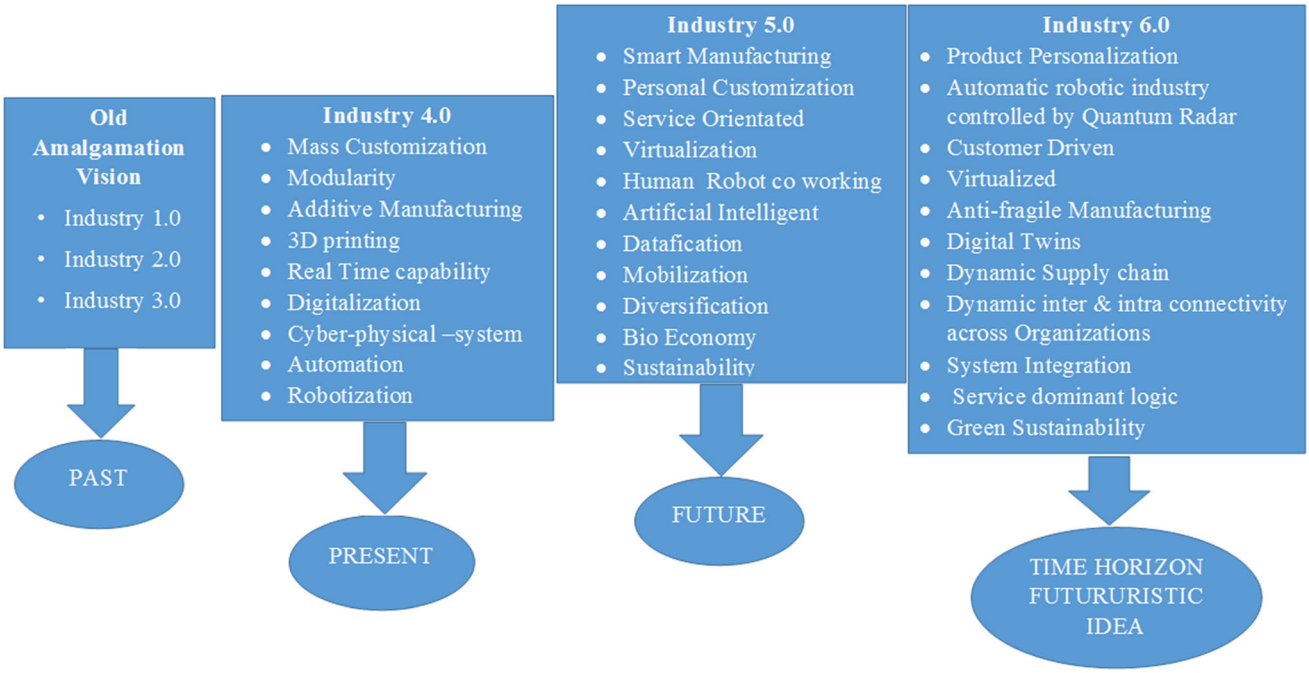

Fig. 1 The vision of industry 1.0 to industry 6.0

This revolution reformed manufacturing and communication channels with customers to fulfill their requirements. This revolution develops new digitized trends for the market comprised of new technologies such as the Internet of Things, 3D printing technology, Robotics, Big data, Cloud computing, and many more. In addition, many researchers, scientists, leaders, and scholars have also started to think about industry 5.0 [4, 5]. Industry 5.0 is an emerging field that lies in the concept of human co-working with AI-enabled robots [4, 6]. This revolution works for the mass personalization of products rather than mass customization.

Industry 5.0 consists of two far visions, wherein first vision focuses on the culture of humans working with robots, development of smart societies, use of the renewable supply of power or sources, development of the smart and safe environment, new innovative ideas, research, developed smart administration work enabled with digital technologies. The second future vision of industry 5.0 is to bring bio-economy, sustainability, bionics, preventing wastage, digitalization, new innovative ideas research, and developed smart administration work [4]. In addition, industries have started to think about industry 6.0, which is one step ahead of the fifth revolution. Industry 6.0 is a futuristic concept that industries will implement approximately 10 to 15 years later. This revolution focuses on providing service takers with virtualized antifragile manufacturing and antifragile services. It would focus on customer-centric, customer-focused ethos, super-connected

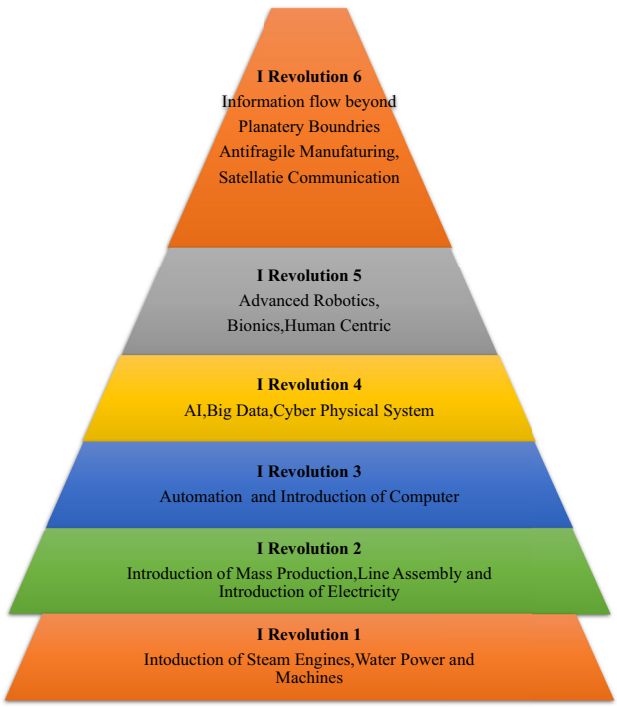

Fig. 2 The transformation journey of industrial revolution 1 to industrial revolution 6 (futuristic idea)

industries with vibrant supply chains, automated flexibility, and internal value networks—the proper interactions within the organization or organization across the various nations and its administrative areas. Table 1 shows the glimpse of comparison among industry 1.0 to industry 6.0

Table 1 A glimpse of comparison among industry 1.0 to industry 6.0

Industrial Revolutions	Industry 1.0	Industry 2.0	Industry 3.0	Industry 4.0	Industry 5.0	Industry 6.0
Time period	1784–1800	1870–1900	1969–2000	2000–2020	2020 onwards	2050–2070
Sole objective	Mechanization	Electrical powered mass Production Division of work	Machine automation	Smart manufacturing 3D printing	Mass customization to mass personalization Humans are working with AI-enabled robots Focused on bio-economy Sustainable development goals	Homogeneous assets Living with synchronization with nature Mastering the economics of learning [7]
Impetus	Machines performed work without contact with human being direct	Electrical powered mass production	Machine automation Computerization	Based on the mass production concept	Based on the futuristic idea of making a smart society Based on sustainability	Automatic robotic industry Quantum radar control Cloud renewable energy Antifragile Manufacturing Ubiquitous
Technologies used	Mechanized factory structure	Railroad assembly line Telegraph sewage systems	First programmable logic controller Clever software's High-speed computers Direct Broad casting's [8] Additive manufacturing IOT	Cyber-physical system IOT AI Data mining Robotics 3D printing Cloud computing etc	Human–robot co-working culture enabled with all digital technologies Sustainable production system Bionics Renewable resources	Quantum technology Artificial intelligence Minds control machines Digital twins Quantum biology [9] Cognitive technology
Resources used	Electricity Fuel Coal Hydropower	Steel Electricity Petroleum	Renewable energy Semiconductors Electricity [10]	Electricity Fossil-fuel Renewable energy	Electricity Renewable energy	Radar quantum Satellite control Internet
Emerging research	Steam engine	Technological commencement Organization research oriented Thinking toward assembly line production system	Organization thinking toward automation	Organization research oriented Innovation Believed in Product Process improvement	Smart environment Organization research oriented Innovation Believed in product process improvement Waste prevention	Molecular nanotechnology Smart environment Organization research oriented Innovation Believed in product process improvement

by its sole objective of various industrial revolutions, impetus, resources used, technologies used, and emerging research trends.

5. Research Objective of Present Work

Industry 6.0 is a futuristic concept; if it applies to industries, it will change the entire scenario of the manufacturing world. The sole aim of industry 6.0 is to seizure the new

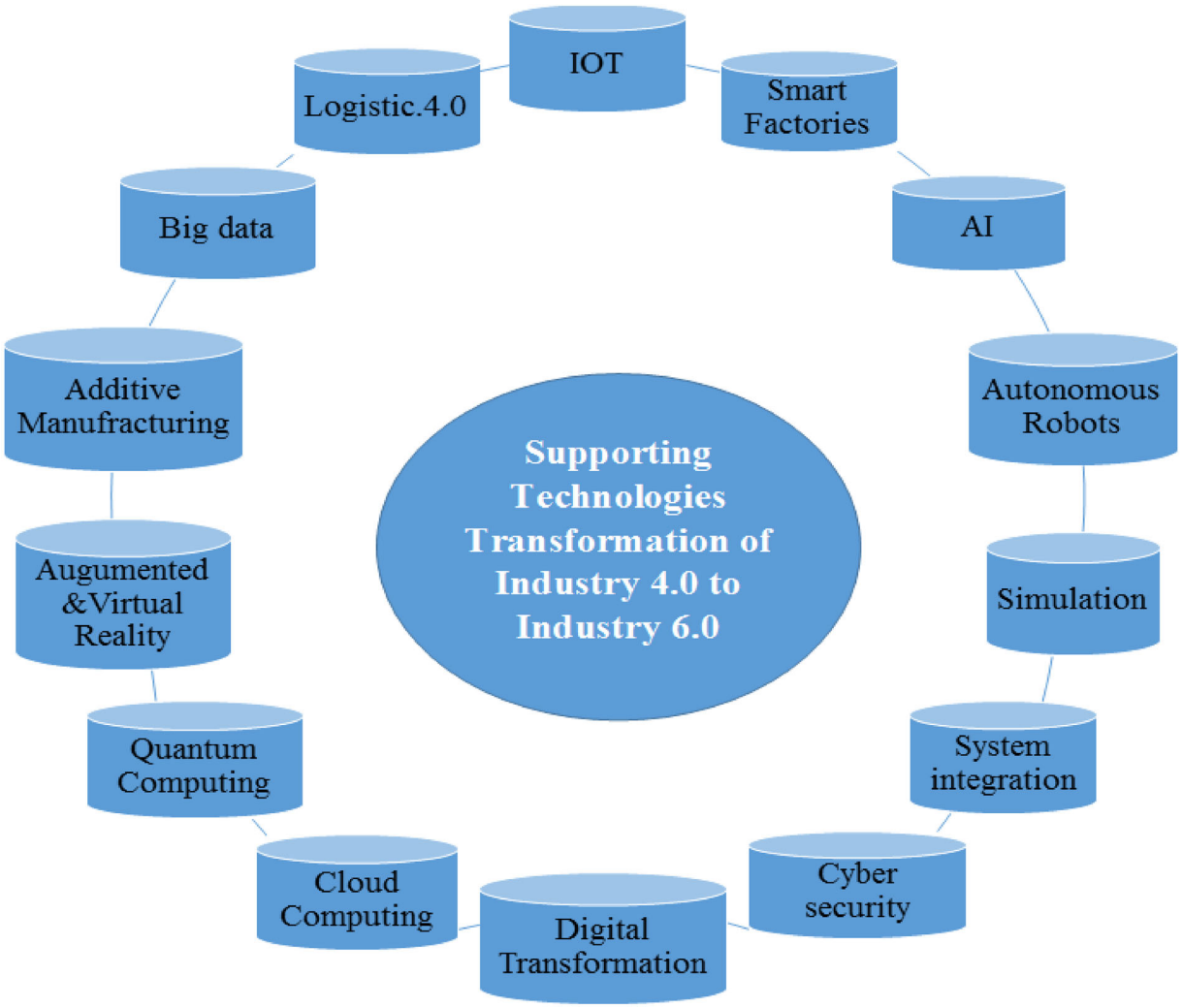

Fig. 3 The vital assisting technologies in the evolution from industry 4.0 to industry 6.0

technologies, which can be applied worldwide and deliver wealth, prosperity away from the job and growth to nation across all planetary boundaries and keep a man in the center and machines around him. Industry 6.0 is the compliments to future industry 5.0. This revolution would bring flexibility in the manufacturing world highly as per the requirement of customers, stakeholders, shareholders, organizations with the help of various digital technologies, quantum computing, automatic robotic industries, which would be controlled by quantum radar, quantum electricity, cloud electricity, planet thermal energy, etc. This paper revolves around some research questions.

Question 1 To study the need for industry 6.0.
Question 2 To find out the techniques which can support industry 6.0
Question 3 To study advantages and challenges of industry 6.0

6. Need of Industry 6.0

In the present era of COVID-19, the entire world was facing difficulties meeting customers' demand regarding supplying goods services, manufacturing, and other daily need items. This global crisis has forced manufacturers, organizations, and service providers to rethink the current production strategy, delivering services to customers, customer interaction, supply chain network, circular economy, integration of products, green transition, and digitalization. Throughout the industrial revolution history, it has been seen that industries have the caliber and proven their capability to the prime transformation. In addition, enterprises will always be ready to accept this transformation toward the weather change impartiality and change in digital governance in a flexible and foreseeable world. This revolution would eternally connect the planet affected by weather change and ecosystem calamities, so there are some counsels to reduce the risk of exposure against the

Table 2 Assisting technologies of industry 4.0 to industry 6.0

Technologies	Descriptions	References
Additive manufacturing (3D printing)	In this technique, layer by layer material is deposited to produce the desired parts with the help of input of data of CAD models	[18, 19]
	By use of this technology, personalized products can be made with the help of 3D printer technology	
Artificial intelligence	This technology provides human-like intelligence capability to machines with the help of algorithms and software	[20, 21]
	This technology is a combination of several other technologies such as augmented reality or virtual reality to provide significant virtual support to the manufacturer	
	By use of this technology, future trends of markets can be forecasted	
Autonomous robots	Autonomous robots could bring new advancements in manufacturing where intelligent robots will perform the tasks and operate self-reliantly, without the help of human control or involvement	[22]
	These are employed to craft innovation in the manufacturing industries and several other fields, exclusively to execute a challenging task and help humans	[23]
Quantum computing	This technology develops advanced products and provides services that interrupt and redefine the old manufacturing process	[24, 25]
	It assists in the finite-difference analysis of design, structural analysis, aerodynamics SCM, machine learning, cryptography, simulation, etc	
	It provides high-performance computing, efficiently assessing data that replaces old classical computers	
Internet of things	Internet of things allows the manufacturing system to connect with other industries and appropriately pass information	[26]
Augmented and virtual reality	This technology helps the industries to improve safety and speed up productivity	[27]
	It helps manufacturers perform predictive analysis, creating a virtual environment of Production to analyze or detect the bottleneck portion that requires improvement	
	It provides excellent support information of staff during the emergency procedures	
Digital transformation	This technology is the amalgamation of all the digital technologies such as IoT, big data, artificial intelligence, Data Mining, etc	[28]
	This technology improves efficiency, capital cost reduction, innovation, and generates new ways of revenue generation	
	This technology modifies existing business models, working culture, customer satisfaction, and market demand	
Cyber security	This technology gives Security to software, hardware, important information, and data from the stealing by employing a computer network	[29, 30]
	It protects all the data regarding manufacturing, purchasing, design database, etc., to gain good results and reduce the risk of stealing and illegal access	
System integration	This technology connects different subsystems and various components on the bulky system using multiple techniques such as computer networking and EAI (enterprise application integration)	[28]
	Industries can improve productivity, quality, and operational services using this technology	
Simulation	It is an essential set of several tools required to implement digital manufacturing successfully	[31]
	It provides facilities for experimentation and validates the product design, system design, and alignment	
Smart factories	It is the main foundation of industry 4.0, where the entire cyber-physical system observes all the physical processes, which take place inside the industries, and develops a virtual or prototype copy of the physical-design and style decentralized decisions	[32, 33]
	It provides flexible and adaptive production process solutions for critical and dynamic problems	
Cyber-physical systems	The cyber-physical systems integrate physical (hardware) and software systems to perform the earlier defined tasks	[34]
Big Data	This technology stores many complex data using IoT devices and provides manufacturers and service providers significant services	[28, 31]
	It helps the manufacturing industries to visualize the several manufacturing processes	
	It helps the industries to eliminate bottlenecks, predictive demands, predictive maintenance, and improve business strategy improvement of warehouses processes	

Table 2 continued

Technologies	Descriptions	References
Cloud computing	This technology uses a network from the outskirts, or remote servers compared to the internet to stockpile, manage, and process the data, rather than in-house, personal or local servers This technology can access the program from remote locations or in an organization, refining management capabilities The cloud-based applications help the manufacturing industries record the production data details such as when the demand changes, raw material requirements, and supply chain information. The use of software makes the manufacturing task easy to meet future needs	[35]

global threat in the forthcoming time. If all desire to be ready for future shudders, all must emphasize robustness, safety, sustainability, resilience, and antifragility concepts. This revolution would bring novel ideas and innovative technologies that would craft new growth and welfare for humanity [11, 12].

7. Supporting Techniques for Industry 4.0 to 6.0

It has to be speculated that the past industrial revolutions were based on mass production, automation, personalized customer demands, and substantial production runs where machines are engaged with humans and enabled with AI algorithms to manufacture the products and provide services to customers their requirements. 3D printing technology is spreading its wings toward a new degree of freedom in the new revolution by adding a more comprehensive range of materials, biomaterials, chemicals for lithography control release medicine [13]. These 3D printed, AI, machine learning-enabled technology used in medicine could reduce the chances of infections during the human touch in OPD services. In the present time of pandemic where daily new viruses are ready to attack humanity, these robotics-based medical systems could ensure the safety of humans with less risk [14]. In 2005, Mitsubishi (wakamaru) imagined the dream of home front assisting robots, now in the sixth industrial revolution, it is the postulate that would assist aging people [15]. For the EEG, this would provide a significant advancement to humans where it would have the potential to add simulated pain receptors, which would tend to fix natural skin on body parts by using synthetic or artificial materials [16]. Quantum computing can transform the shape of business, industries, healthcare systems, finance, and material science by solving complex problems that traditional computers cannot solve [17]. Quantum computing has great potential to change the supply chain, value chain and expand AI. Industry 6.0 is the amalgamation of industry 4.0 and industry 5.0 with innovative convergence ideas. In industry 6.0, humans, robots, advanced technologies, quantum computing, antifragile manufacturing, digital twins, dynamic supply chain concept, multidimensional printing technique, home assisting robots, robot-based medics and deep plunge electroencephalogram (EEG), etc., would work together to make human work more accessible and provide zero defects services to customers. These technologies would enhance human capabilities and skills in manufacturing and other areas by providing them significant opportunities to learn and assess in the R D. Figure 3 and Table 2 shows the key assisting technologies in evolving from industry 4.0 to industry 6.0 [1].

8. Benefits of Industry 6.0

Industry 6.0 would support hyper-connected industries, provide dynamic value networks, dynamic supply chain, transparency in information flow all over the administrations either internally or externally throughout the world. It would be the way of life with keeping the proper balance or mastering the economics of learnings. It promotes the human virtual digital twin where all can simultaneously see physical goods and virtual product information, connect the manufacturing industries globally, and provide superior technical help, better understanding, and decision-making. Antifragile manufacturing will be the predicted concept for this revolution, where antifragility can be obtained through systems flexible design. It depends on non-functional requirements where software systems are judged based on openness, usability, safety, movability, and other functions that create hurdles in attaining a software system [36]. In the coming years, this revolution would provide creative thinking, unique and innovative ideas in manufacturing and other fields and enhance the protagonist characteristics of humans and machines.

9. Limitations of Industry 5.0 and Assisting Technologies of Industry 6.0

Industry 4.0 was based on mass production and smart production, whereas achieving sustainability resilience [37] and collaborations of man and machine [38]. It was the

concept of industry 5.0 [4], and the futuristic concept of industry 6.0 advocates antifragile manufacturing, ubiquitous, human digital twin and customer that connects manufacturing, hyper-connected industries and customer needs are on high priority with use of sustainable resources. For a few years only, researchers, industrialists, policymakers, and future visionaries started to think beyond industry 4.0 and industry 5.0. Additionally, some futuristic have also pointed out the inadequacy of both industries. According to the view of Johansson et al. that industry 4.0 may have a low tendency to integrate digital connectivity and man–machine alliance [38]. It had already well known that artificial intelligence and robotics engineering is one of the essential supporting columns in the fourth industrial revolution, only the primer of the machine and human collaboration is not enough to start the new revolution. According to the Hirsch-Kreinsen et al. [39], the cost for implementing digital technologies such as IoT, AI, big data, and robotics in the industrial revolution 4.0 and industrial revolution 5.0 has required a large amount of cost and extraordinary skill, which could be the reason of un-satisfaction amongst the industries and social perspective. Industry 5.0 represents some exclusive limitations and responses such as high price responsibilities in manufacturing policies, standardization, and legalization in all policies to preclude any thoughtful problem among the digital technology, society perspective, and business [40]. The probabilities of social heterogeneity among the society in relations of values and adapting the new technologies of a new revolution, measurement of ecological balance and social values, significant investment and integration of all the customers from high business to SMEs, and environment based new policies with agility, outcome-based [41], and greater dependency on technologies [42]. As a noble initiative by business, Finland in "From industry X to industry 6.0" was sketched a series of predictive implementation strategies, policies, investment, business landscape, Research and development, and manufacturing ecosystem and future path dimensions to promote industry 6.0 [1]. Additionally, government, agencies, and industries responses are being limited for some time. Still, academia is peerlessly embracing the critical discussion on industry 6.0, as MDPI journals, Journal of manufacturing systems, World Conference on Technology, Innovation and Entrepreneurship, and IET (The institution of engineering and technology).

10. Challenges in Implementing Industry 6.0

The dream of industrial revolution 6.0 can only be attained by doing systematic work and collaborative effort of government and manufacturers toward the welfare of society. This revolution wants the long-term commitment from the manufacturers, policymakers, stakeholders, and government to implement sustainable industry 6.0 in the organization. The implementation of this holistic approach can be geared with proper research and development to positioning in the revitalization of Industrial Production. During the execution of industry 6.0 could face many challenges such as digital transformation, difficulty in adopting new and advanced technologies, allocation of resources, industry-relevant technology, internationalization, industry collaboration, freedom to research in development, capital cost (needed funding) involved in developing and implementation of new technologies, reskilling costs and adoption of 5G /6G technologies.

11. Conclusions

Industry 6.0 has been the theoretical concept; it will change the manufacturing world's entire scenario if it applies to industries. Numerous people have been scared of losing their jobs due to complete automation in industries, so it is required while introducing any new industrial revolution that the number of jobs should always be more than the job loss. Otherwise, social un-satisfaction and negative impressions could engender in society. This revolution focuses on providing virtualized antifragile manufacturing and antifragile services. It would concentrate on customer-centric, customer-focused ethos, super-connected industries with vibrant supply chain, automated flexibility, internal value networks where proper interactions within the organization or outside across the various nations and its administrative areas.

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