Industry 5.0: Theoretical Foundations for Enabling Technologies and Applications in Manufacturing Context

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Abstract

Industry 4.0, also known as the fourth industrial revolution, is a concept that refers to an increased degree of automation with the purpose of increasing operational productivity and efficiency in an industry by integrating the virtual and physical worlds. As a result of the inability of Industry 4.0 to answer and fulfill the rising demand for personalization, the phrase "Industry 5.0" was established to address personalized production and to empower individuals in the manufacturing process. The introduction of the phrase "Industry 5.0" has been met with various perspectives about how it should be defined and what aspects of coexistence between people and robots should be prioritized. This acts as the impetus for this work in identifying and analyzing the many topics and research trends of what Industry 5.0 is employing text mining tools and methodologies. In this article, a comprehensive discussion of the possible applications of Industry 5.0, including intelligent healthcare, cloud manufacturing, supply chain management, and production in the manufacturing industry, is presented. After that, we will talk about some of the enabling technologies for Industry 5.0, such as edge computing, digital twins, collaborative robots, the Internet of Everything (IoE), blockchain, and networks that are 6G and beyond. In conclusion, we discuss a number of research obstacles and unresolved questions that need to be further investigated in order to realize the potential of Industry 5.0. In recent years, it has come to the attention of the scientific community that the concept of Industry 5.0 as a doorway leading to the connectedness and co-existence of humans and machines has been garnering a growing amount of interest.

Keywords: Industry 5.0; Supporting technologies; Manufacturing context; Artificial intelligence; Edge computing.

1. Introduction

The advent of rapidly developing digital technology and Artificial Intelligence (AI)-based solutions has resulted in a rapid shift that is now being experienced in the industrial business of today. The difficulty that faces manufacturers in manufacturing sectors everywhere in the globe is how to boost efficiency while still maintaining a human presence in such businesses. This undertaking becomes much more challenging when new technologies, such as brain-machine interfaces and advancements in AI, make robots a more important part of the production process. The next industrial revolution, often known as Industry 5.0, has the potential to provide solutions to these problems. The idea behind Industry 5.0 may be summed up as people and machines working together to solve problems rather than competing against one another [1]. The preceding revolutions in the industry were called Industry 1.0, Industry 2.0, Industry 3.0, and Industry 4.0, respectively as presented in Figure 1.

Textiles, steam power, iron, tools, cement, chemicals, gas, lighting, glass, paper, mining, agriculture, and transportation were the primary areas of concentration in Industry 1.0, which emerged in the 18th century and centred on these areas of production. Employment opportunities, improved agricultural practices, improved transportation, and continuous economic expansion are all results of this revolution. Pollution and the lengthy amount of time necessary to execute the required techniques are two of the main problems connected with Industry 1.0. Linear programming and geometry were two

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of the mathematical methods that were used in Industry 1.0. The 19th century saw the beginning of Industry 2.0, which was primarily concerned with areas such as iron, steel, rail, electricity, machine tools, paper, petroleum, chemical, marine technology, rubber, bicycles, vehicles, applied science, fertilizer, engines, turbines, telecommunications, and modern company management. The development of the electrical power grid, telephones, the telegraph, and internal combustion engines are all examples of the accomplishments that resulted from this revolution. The high cost of the electrical power that is used is the most significant disadvantage of Industry 2.0. Differential equations, linear equations, and geometric concepts were used in Industry 2.0's application of mathematical tools. The 20th century saw the beginning of Industry 3.0, and its primary areas of concentration were the semiconductor industry, digital circuits, programmable integrated circuits, telecommunications, wireless communication, the renewable energy sector, and automation.

The invention of the telephone, the discovery of renewable sources of energy, the computerization of manufacturing processes, and the creation of robots are all products of this revolution. The fact that certain automated systems won't function in specific contexts is the most significant disadvantage of Industry 3.0. For instance, the implementation of Flexible Manufacturing Systems (FMS) was one of the most important parts of the Industry 3.0 initiative. However, these systems are quite complicated, which resulted in additional operating expenses that some organizations just could not afford to bear. Many businesses were put off by the difficulty of the process as well as the additional fees. Differential equations, linear programming, and logical controllers were some of the mathematical instruments that were used in Industry 3.0. The fourth industrial revolution, often known as Industry 4.0, emerged in the 21st century and centred on the implementation of intelligent systems throughout all sectors of the economy. The successes of this revolution include completely automated systems and artificially intelligent systems that function in unpredictable settings. Machine learning has a favourable impact on the fourth industrial revolution, which is a good development. The fact that not all of the data stored in the cloud can possibly be protected and those completely expert systems are not yet established for companies are two of the disadvantages of Industry 4.0, techniques for optimization and network theory are examples of the mathematical instruments that are used by Industry 4.0.

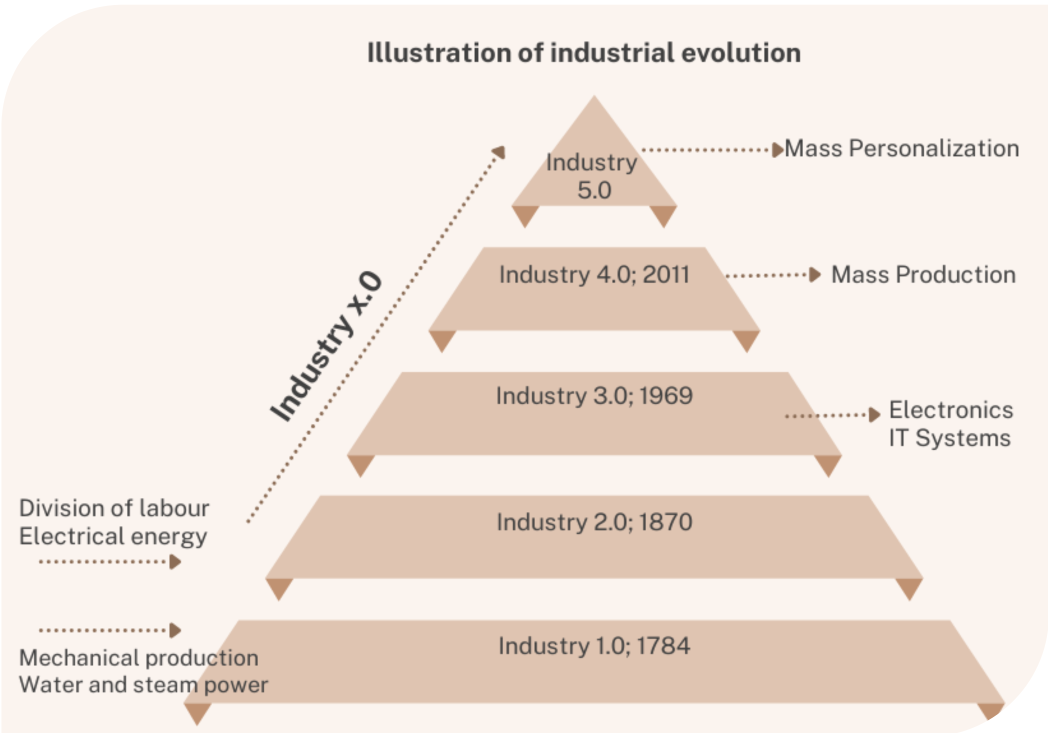

Figure 1: An illustration of the development of the industry.

Michael Rada is the one who came up with the name "Industry 5.0" [2]. The use of risk-reducing collaborative robots is one of the essential components that is required for Industry 5.0 to function properly. These robots are capable of recognizing, comprehending, and sensing the human operator, as well as the objectives and requirements for the activities that are being carried out. These robots will, according to the plan, first observe and then learn how a person conducts work, after which they

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will assist human operators in completing the operation. In addition, the incorporation of AI into human life is a key component of Industry 5.0, with the end goal of increasing manpower. Sophisticated information technology (IT) technologies, the Internet of Things (IoT), robotics, AI, and augmented reality (AR) are actively applied in the industry in Industry 5.0 for the benefit and convenience of human employees.

Industry 5.0 acknowledges the ability of the industry to satisfy societal goals that go beyond employment and growth, such as being a sustainable source of development [3]. This may be accomplished by ensuring that manufacturing takes into account the constraints of our planet and places the health of workers as the top priority. Industry 5.0 makes a contribution to the necessary technological update that the industry needs in order to fulfill its potential as a reliable system for people looking for fulfilling and healthy careers. It gives a high level of importance to the well-being of workers and makes use of emerging technologies in order to generate wealth that goes beyond employment and growth while still taking into account the limitations of the earth. It gives employees more autonomy and satisfies their ever-evolving demands for skill and education. It improves the industry's competitiveness and makes it more appealing to skilled workers. A "European Green Deal," "an economy that works for people," and "a Europe fit for the digital age" are the three aims that the Commission has in mind when it comes to the implementation of Industry 5.0. As a result, the foundation of Industry 5.0 is not technology but rather concepts like human-centricity, environmental stewardship, and social benefit. This reorientation is centered in the idea that technology can be adapted to promote values and that technical innovation can be built on ethical aims, rather than the other way around. Specifically, this reorientation is based on the idea that technology may be tailored to support values.

To put it succinctly, the following is a rundown of the contributions that our work has made: In the first part of this article, we will examine a variety of extra characteristics of Industry 5.0 in comparison to earlier iterations of industrial development. In light of this, an in-depth discussion is provided on the characteristics of smart additive manufacturing, predictive maintenance, hyper customization, and cyber-physical cognitive systems. In addition to this, we examine the most recent developments in terms of initiatives, products, and organizations working on standardization in relation to Industry 5.0. In the second part of this article, we talk about the most promising applications that will be created and enabled by Industry 5.0. Some examples of these applications include intelligent healthcare, cloud manufacturing, supply chain management, manufacturing production, and a variety of other applications. Despite the various research and development projects that have been carried out, Industry 5.0 still faces a great deal of difficulty and problems. We are eventually going to discuss these challenges in terms of security, privacy, cooperation activities between humans and robots in manufacturing, scalability, and trained personnel. In addition to this, we identify interesting research avenues that might help bring Industry 5.0 into existence.

2. Applications related to Industry 5.0

In the following paragraphs, we will talk about some of the possible uses of Industry 5.0, as presented in Figure 2.

2.1 Cloud manufacturing

Computing in the cloud refers to a kind of computer technology that combines high performance and cheap cost. Sharing of resources, flexible extension, and dynamic allocation are only three of the many benefits that virtualization technology brings to the field of cloud computing. The ability to transfer a significant amount of data to a cloud computing center, where it can be stored and processed, makes manufacturing and production much easier. Cloud-based manufacturing is an emerging technology that has the potential to make a significant contribution to the realization of Industry 5.0 [4]. Industry 5.0 paves the way for modularization and service orientation in the context of manufacturing, both of which are important considerations in an environment where systems orchestration and the sharing of services and components are important. The functioning of a contemporary business entails a significant number of decision-making tasks, each of which calls for a substantial quantity of information and extensive computational effort. At one time, industrial companies needed many computer resources, such as servers for their databases and machines that made decisions. This resulted in ineffective data interchange and sharing, decreased productivity, and a less-than-ideal utilization of the resources available for manufacture. Computing in the cloud offers an efficient

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remedy for these kinds of issues. As a result of the fact that complicated decision-making processes may be facilitated by cloud computing, all data can be kept on either private or public cloud servers.

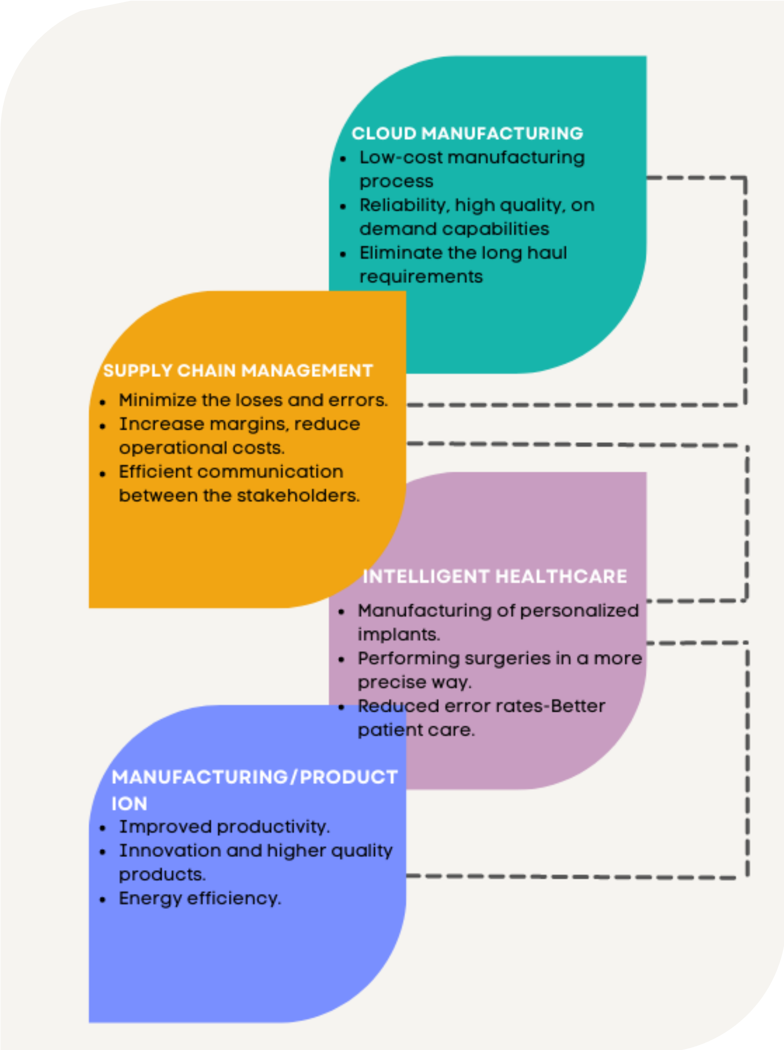

Figure 2: An illustration of the development of the industry.

2.2 Intelligent healthcare

These days, medical professionals often rely on machine learning models to assist them in correctly detecting patients' illnesses. This contributes to an increase in the accuracy of illness diagnosis, which, in turn, helps patients save a significant amount of time and resources. However, in light of the present circumstances, this is not sufficient. A technology that can monitor a patient's blood pressure, sugar levels, and other factors, as well as provide personalized therapy to patients with the help of their attending physicians, is desperately needed in today's healthcare system. This is something that might be made feasible by Industry 5.0 [5]. Wearable computing devices with intelligence, such as smartwatches and intelligent sensors, are able to continuously record a patient's health care data in real-time, and this information may be saved in the cloud. After that, machine learning algorithms might be used in order to diagnose the patients' medical conditions. These intelligent gadgets are able to interact with one another, and in the event that a doctor's attention is necessary, these devices will be able to feed the present state of the patient to the physicians and notify them to treat the patient. The use of collaborative robots (cobots) allows surgeons to collaborate with robots that can talk to each other in order to provide better care for their patients during surgical procedures. These are just a few instances of how the healthcare business might be completely transformed by Industry 5.0.

2.3 Supply chain management

The disruptive technologies that allow Industry 5.0, such as digital twins (DT), cobots, 5G and beyond, machine learning, IoT, and edge computing (EC), when matched with the smartness and ingenuity of people, may help companies satisfy demand and offer personalized and customized goods at a quicker

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speed. This makes it easier for supply chain management (SCM), which is an important idea in Industry 5.0, to integrate mass customization into their manufacturing processes. A digital representation of the SCM, including all of its warehouses, inventory locations, assets, and logistics, may be produced with the help of DT. The DT includes client locations, transportation routes, distribution facilities, and distribution facilities in addition to factories, suppliers, and contract manufacturers. DT provides assistance throughout the whole of the SCM's life cycle, beginning with the design phase and continuing through building, commissioning, and operations.

2.4 Manufacturing/Production

It is commonly known that throughout previous periods of technological revolutions, the advent of robotics and automation ushered in a period of paradigm shifts in the industrial sector all across the world. In the past, robots have been used in production settings to do dangerous, monotonous, or physically difficult labour, such as welding and painting in automobile factories, loading and unloading big consignments in warehouses, and other similar tasks. As robots in the workplace become smarter and more connected, the goal of Industry 5.0 is to facilitate collaborative operations that combine cognitive computing abilities with human intellect and ingenuity. Because of this, it is not inconceivable that the fifth industrial revolution would bring about adjustments in conventions and create significant changes in the way that we think about industry and production.

2.5 Other applications

- Education is widely regarded as an important component of modernization efforts and a prerequisite for any nation. The evolution of education is a response to changes in both culture and business, and it results in the production of significant intellectual resources that are essential to the success of enterprises in the future. Education in Industry 4.0 was primarily focused on technology, which meant minimizing human participation and giving emphasis to machines. However, with Industry 5.0, the goal is to develop a synergy between people and autonomous machines.
- Management of disasters: A catastrophe is defined as an unexpected, catastrophic occurrence that results in loss of life or property, and the techniques that are used in its prevention and management are the methods that enable us to lessen the impact of the disaster. The provision of disaster assistance is an essential component of any business strategy; however, this plan is primarily concerned with the immediate future. As a result of the COVID-19 pandemic, some disaster recovery plans have been changed, which may result in the introduction of long-term resilience as a policy that replaces disaster recovery techniques.

3. Supporting Technologies

Cognitive abilities and creativity, when combined with a number of supporting technical advancements such as EC, DT, IoE, big data analytics, cobots, 6G, and blockchain, may help enterprises enhance productivity and offer customised goods more rapidly. Industry 5.0 is an enhanced production model that places an emphasis on the interaction between machines and people. This model was made possible by the technologies that enable it. Smart machines are intended to work together with people, and this cooperative work makes it possible for human skills to be more productive and incredibly simple to automate for individuals and small enterprises than it has ever been before. In this part, we will have a quick conversation about a few of the technologies that will make Industry 5.0 possible.

3.1 Edge computing

EC is a new conception that has emerged as a result of the fast expansion of the IoT and the supply of a large number of cloud services. This new conceptualization makes it possible to process data at the network's edge. Not just in the future Industry 5.0, but even in the process of transitioning to Industry 4.0, EC has the potential to give tremendous value. EC is able to satisfy the standards that have been set for latency costs, battery life limits, reaction time requirements, and data security and privacy. EC reduces the amount of time spent communicating and ensures that applications continue to function well even when deployed in faraway locations. In addition, EC is able to process data without sending it to a public cloud, which helps to reduce the number of potential vulnerabilities that might arise during the important events that are part of Industry 5.0. EC is able to carry out a variety of helpful tasks, including the processing of data, maintaining the coherency of caches, offloading computation, and transporting and delivering requests.

3.2 Cobots

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Recent developments in robotics and automation have made it more necessary for humans to collaborate with robots in the workplace. It is evident that all gadgets that possess computational capabilities have gotten more intelligent and have introduced a new technology that is referred to as cobots as a result of the large quick developments that have occurred in AI and smart technology. Cobots are robots that are meant to operate in partnership with people. This collaboration helps to make human skills more effective and incredibly simple to automate for individuals and small enterprises than they have ever been before. Edward Colgate, a professor at Northwestern University, and Michael Peshkin, a computer science student there, are credited with developing the first cobots in 1996. The initial generation of cobots did not have any engines, operated in a fairly passive manner, and were equipped with brakes at all times when they were in use. Although contemporary cobots are quite different from classic industrial robots, they are nevertheless capable of working alongside people and do not need enclosed workspaces. Cobots are often equipped with sensors and have a high level of sensitivity to the detection of unpredicted impact. As a result, they have the capability to cease operating on their own if human employees identify any things that have been accidentally put in their path. When compared to conventional industrial robots, this characteristic lends them an increased degree of dependability in terms of workplace safety.

3.3 6G and beyond

In the future, 6G will be able to provide major value-added services to the 5.0 version of Industry. It is difficult to build a radio infrastructure that consists of a highly dense network of hundreds of millions of sensors, hardware parts, and robots. It will not be able to satisfy the fast growing demand for bandwidth with the existing networks (such as 4G and 5G networks), given the rapid expansion of intelligent infrastructure and the potential applications it may support. In the revolution known as Industry 5.0, the adoption of technologies beyond 6G makes it feasible to supply improved latency, support high-quality services, as well as vast internet of things infrastructure and integrated artificial intelligence capabilities. 6G networks help increase application performance in Industry 5.0 apps by enabling smart spectrum management, AI-powered mobile EC, and smart mobility. This helps improve application performance in an efficient and effective manner.

3.4 Other technologies

In this regard, a number of the already available technologies, such as Blockchain, extended Reality (XR), big data analytics, IoE, DT, and Private Mobile Network (PMN), play an essential part in making Industry 5.0 and the applications it enables possible. All technologies are presented in Figure 3.

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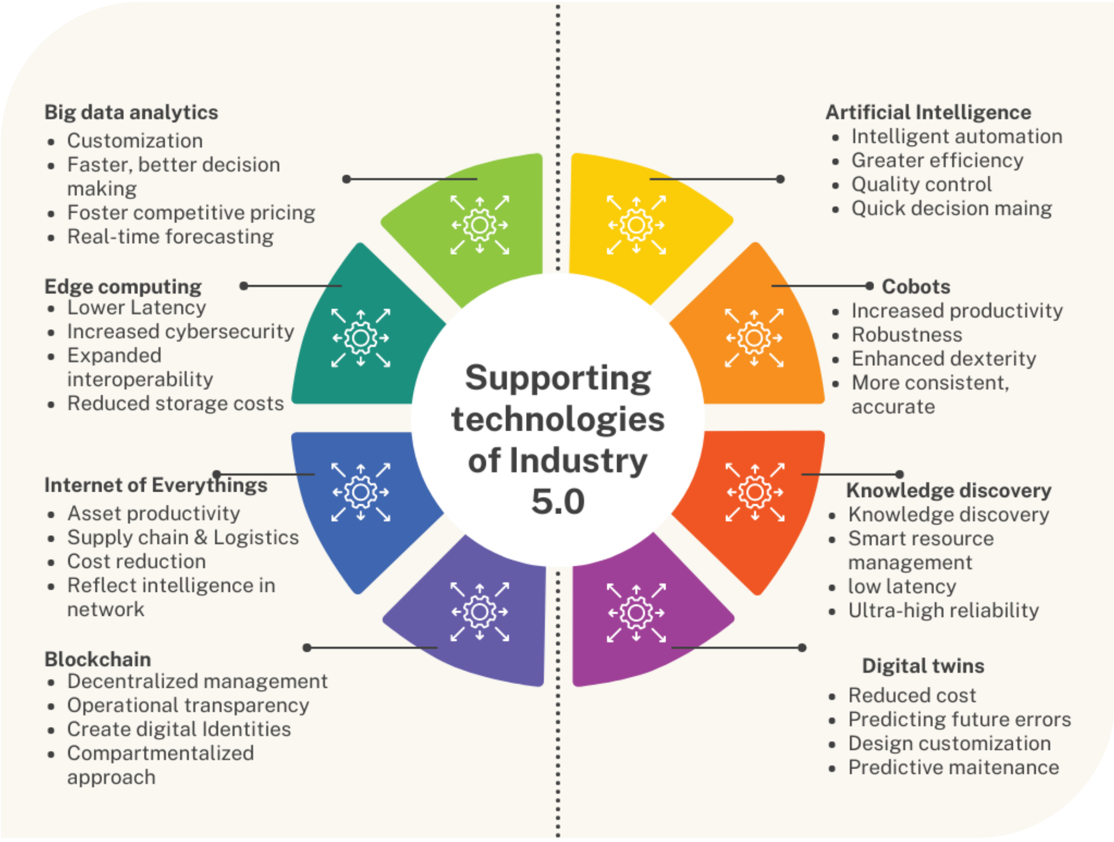

Figure 3: Supporting technologies in Industry 5.0.

4. Industry 5.0

Building on the innovations of Industry 4.0 (also known as the Fourth Industrial Revolution), the term "Industry 5.0" describes the next stage of industrial growth. This concept is meant to portray a future in which people and cutting-edge technology collaborate to promote creativity, efficiency, and long-term prosperity[6], [7].

Industry 5.0 seeks to blend human talents and knowledge with modern technology like AI, robots, and the Internet of Things (IoT), while Industry 4.0 emphasises automation, connectivity, and data-driven decision-making. It values the individuality of each person and looks for ways to put their talents to use in tandem with those of smart equipment.

Intuition, sophisticated problem-solving, creativity, emotional intelligence, and ethical decision-making are all crucial in Industry 5.0 roles for people to play. They collaborate with machines, using the machines' accuracy, efficiency, and processing capacity while also utilizing their own cognitive talents[7], [8].

Industry 5.0 aims to solve the social and ethical problems caused by automation and digitization. The value of people's happiness, new jobs, and acceptance in society are all acknowledged. The goal of Industry 5.0 is to strike a balance between technical progress and human-cantered ideals, with the latter taking precedence so that technology is used to better people's lives and foster sustainable development.

Adaptive business models, team-based workplaces, and individualized manufacturing are all possible within the context of the new industrial paradigm. In doing so, it promotes the creation of tools that help people continue learning throughout their lives and cultivate an innovative mind-set[9], [10].

Manufacturing, healthcare, transportation, agriculture, and services are just some of the sectors that might benefit from the innovations brought about by Industry 5.0. In the manufacturing industry, for instance, human-machine cooperation may result in more malleable production methods, unique final

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products, and better quality assurance. In healthcare, cutting-edge robots and AI may facilitate diagnosis, treatment, and aftercare.

Industry 5.0 has many potential advantages, but it also has several problems that must be addressed. These include ensuring technology is used ethically, training workers to take up new jobs, addressing fears about automation, and giving people in all parts of the world and all socioeconomic classes access to the advantages of technology.

To sum up, the concept of Industry 5.0 is a future outlook for the manufacturing sector that places an emphasis on human and technological cooperation. The goal is to use their complementary strengths to boost creativity, efficiency, and the common good. Industry 5.0 has the ability to design a future that is more sustainable, inclusive, and human-centric by merging the power of technology with human creativity, intuition, and ethical decision-making[11], [12].

There are several ways in which Industry 5.0 might encourage lifelong learning and new forms of creativity.

Continuous learning and training are essential in Industry 5.0 as they allow workers to keep up with rapidly emerging technology and workplace demands. Workers may be equipped with the expertise required to operate productively with cutting-edge technology via the implementation of lifelong learning programmes. Data analytics, AI, robotics, and HMI are just few of the areas where education is provided.

Humans and robots are encouraged to work together as equals under Industry 5.0's concept of "collaborative work environments." This encourages a mindset that values education, growth, and creativity. Workers may engage with machines to learn how to optimise workflows, boost productivity, and discover new possibilities. This method of working together fosters a culture of lifelong learning and inspires employees to proactively seek out novel approaches to problems.

Industry 5.0 might encourage the growth of prototyping spaces, such as innovation centres and incubators, where employees can test out novel approaches to business and technology. These centres foster innovation, experimentation, and the cultivation of entrepreneurial spirit by providing a safe space for all three. Industry 5.0 encourages employees to adopt a growth attitude by promoting a culture of innovation[13], [14].

Industry 5.0 encourages interdisciplinary work by connecting experts in sectors as varied as engineering, design, data analytics, and the social sciences. Working together allows for the dissemination of information and the development of fresh methods of approaching problems. Industry 5.0 improves education and fosters creativity by fostering cooperation across disciplines.\

Learning and growth are aided by technological advancements in the context of Industry 5.0. Learning environments that are both interactive and immersive may be created via the use of online platforms, VR/AR, and simulations. These tools allow employees to absorb new information, hone their abilities, and test out various situations in a risk-free setting, all of which contributes to an atmosphere of constant improvement and fresh ideas[15], [16].

Industry 5.0 encourages and rewards originality, analysis, and problem-solving skills in its workforce. The combination of human potential with cutting-edge technology fosters an environment where employees are inspired to use their imaginations, question norms, and develop novel approaches to problems. This focus on people-oriented abilities fosters an environment where employees are encouraged to think creatively and acquire new talents.

Data-driven decision making and feedback loops are highly valued in the 5.0 version of Industry. With access to real-time data and analytics, employees may better understand their performance, pinpoint opportunities for growth, and inspire new ideas. Employees may improve processes and results via continual learning, method adjustment, and creative problem solving with the use of data and feedback.

Industry 5.0 facilitates learning from data and feedback, encourages cross-disciplinary collaboration, leverages technology-assisted learning, empowers creativity and critical thinking, and creates environments that encourage lifelong learning and innovation. Industry 5.0 incorporates these features

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to foster an atmosphere where employees are encouraged to learn, change, and innovate in response to new technologies[17], [18].

5. Future Challenges and Potentials of Industry 5.0

- Through a cognitively empowered production process, Industry 5.0 has the potential to allow the delivery of highly individualized services to customers. In order to provide seamless services, it is necessary to overcome some of the possible implementation problems that are highlighted in this section. The issue of security is one of the possible obstacles. As we progress towards a more digitized form of computing, the security vulnerabilities that are present in the processing of heterogeneous data and the use of cloud services for the administration of a variety of user and industrial data will need to be cross-checked. While considering how to provide the client with individualized and more predictive services, one must also take into consideration ethical concerns, data transactions that do not compromise privacy, data collection that does not compromise privacy, and so on. Bringing back human labour to the factory floor could be a beneficial strategy, but in order to address the practical concerns and comply with regulations, sufficient training has to be provided to both the humans and the machines that will be working side by side. In order to provide individualized customer care via collaborative efforts between humans and robots, it is necessary to address the challenges associated with increasing the number of users and the number of production processes. In addition, one must take into consideration the ethical problems that are raised by the implementation of AI in order to steer clear of possible setbacks and adverse effects on society brought on by its success.
- An investigation on Industry 5.0, including its combination with AI, Big Data, and the Internet of Things, was given in. They propose constructing safer and more intricate hyper-connected networks, which have the potential to be the future of many other fields, such as digital pharmaceuticals to monitor actual medication adherence. AI, IoT, and Industry 5.0 will also be beneficial to the acquisition of large amounts of data in a variety of digital contexts. Additionally, a presentation was given on the potential uses of Industry 5.0 in COVID for the purpose of providing patients with personalized therapies and diagnoses. They have used technology from Industry 5.0 in order to assist the COVID epidemic. They proposed the substantial difficulties that may be undertaken by Industry 5.0 in the process of finding solutions to the issues relating to the consequences of the COVID epidemic. In addition, in the period that follows COVID, the development of cobots may be used for making contactless payments, tracing kidnappers, monitoring patients, and providing medical treatment to them.

6. Conclusion

In this study, we delivered a survey-based tutorial on Industry 5.0's possible uses as well as the technology that would enable it. We began our study by presenting a description of several ideas associated with Industry 5.0 from the point of view of the academic community in addition to the industry community. Later on, we spoke about some of the possible applications of Industry 5.0, such as intelligent healthcare, cloud manufacturing, supply chain management, manufacturing production, and so on. After that, we talked about some of the major enabling technologies of Industry 5.0. This correlates with the notion that Artificial Intelligence and Machine Learning technologies would be used by Industry 5.0 in order to simplify the completion of repetitive activities while simultaneously providing cognitive assistance to human workers. In addition, it is anticipated that the combination of big data and digital transformation would result in the creation of an information environment that is abundant with data that can be utilized for real-time resource planning and management. The method of topic analysis was used in order to determine the topical characteristics of the articles that were released addressing Industry 5.0. The landscape may be broken down into five distinct thematic themes, the majority of which are related to intelligent and environmentally friendly production, followed by human-machine interaction and co-existence. More precisely, the concept of Industry 5.0 as a doorway to the connectedness and co-existence of humans and machines is seen to garner a lot of attention among members of the scientific community.

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