JOURNAL OF MECHANICAL ENGINEERING AND SCIENCES
ISSN: 2289-4659 e-ISSN: 2231-8380
VOLUME 18, ISSUE 4, 2024, 10303 - 10329
DOI: https://doi.org/10.15282/jmes.18.4.2024.7.0813

REVIEW ARTICLE

Advancement of human-machine collaboration in manufacturing: A review on industry 1.0 - 6.0

I. O. Oladele[1], C. J. Okoro[1], S. O. Falana[1]*, F. O. Olajesu[1,2], S. O. Adelani[1, 3], L. N. Onuh[1,4]

[1] Department of Metallurgical and Materials Engineering, Federal University of Technology, Akure, PMB 704, Nigeria
[2] Department of Materials Science and Engineering, Iowa State University, Ames, IA, United States
[3] Materials Science and Engineering Program, University of Colorado Boulder, 80303, Colorado, United States
[4] Faculty of Materials and Chemical Engineering, University of Miskolc, Miskolc, Egyetem ut 1, 3515 Hungary

ABSTRACT – The industrial revolutions have significantly influenced recent global production and manufacturing strategies. This was made possible due to the pivotal function of emerging technologies such as cyber-physical systems, artificial intelligence, machine learning, and the internet of things. Integrating these technologies in Industry 4.0 facilitates the establishment of smart factories, distinguished by enhanced connection, automation, and data-driven decision-making. These systems have applied cyber-physical systems in real-time interaction between physical and computer processes, while artificial intelligence and machine learning enhanced production via intelligent automation and predictive maintenance. Hence, this review offers a comprehensive examination of the conceptualization of historical revolutions from Industry 1.0 to 5.0 and a futuristic outlook for Industry 6.0. The findings indicate a transformative path in human-machine interaction that showcases seamless collaboration between humans and intelligent machines. The review revealed a progression that advanced unparalleled efficiency, adaptability and customization in manufacturing processes. Thus, the review highlights the transformation from automation-centric models to a human-centric approach. The possible present and future benefits for researchers, practitioners, and policymakers in advancing technology and manufacturing and future outlooks were enumerated. Hence, the socio-economic impact of these trends in revolution cannot be overemphasized and, therefore, require more attention. Conclusively, available and needed materials were considered part of the driving force for the Industrial Revolution in agreement with trends in material ages.

ARTICLE HISTORY
Received : 24th July 2024
Revised : 16th Oct. 2024
Accepted : 14th Nov. 2024
Published : 30th Dec. 2024

KEYWORDS
Industrial revolution
Industry 1.0-6.0
Cyber-Physical Systems
Artificial Intelligence
Machine Learning

1. INTRODUCTION

The demand for advanced materials for high-tech applications in all areas of human endeavor has necessitated advanced human-machine collaborations [1-3]. Also, the concern for the environment and sustainability of materials and processes has contributed to the increase in the desire to change manufacturing processes [4-8]. Thus, technological advancement in modern days is highly supported by smart manufacturing processes. On July 2nd and 9th, 2020, the Directorate-General for Research and Innovation hosted virtual sessions where these conversations arose. Thus, the beginning of the Fifth Industrial Revolution, also known as Industry 5.0, was formally adopted by the European Commission in 2021 after reaching a consensus among participants from research institutions, tech companies, and funding organizations around Europe [9-11]. This important development was officially announced with the publication of "Industry 5.0: Towards a Sustainable, Human-centric, and Resilient European Industry" on January 4, 2021. This is comparable to the German government's top-down implementation of Industry 4.0 in 2011 in response to the shifting geopolitical and sociological landscape [12]. The current drive in the manufacturing world is a growing consensus that manufacturing should put its employees' welfare first in the era of Industry 5.0. This has resulted in a paradigm shift towards ensuring the employees' well-being, sustainability, and resilience. The focus is now on manufacturing as a human-centric rather than purely system-centric process driven by efficiency, quality improvement, and cost reduction. This shift stems from the inability to accurately correlate the total standard of living and well-being with the gross domestic product per capita as a gauge of societal success. Therefore, the Organization for Economic Co-operation and Development introduced the idea of a "Well-being economy," often referred to as the "Economy of Well-being," in 2019 as a framework to support the simultaneous progress of personal well-being and sustainable economic growth [13]. Thus, this change has redirected the focus of many in the academic and industrial settings.

Industrial revolutions are mainly targeted towards enhancing man's work, traced back to the First industrial revolution in the late 1780s, which saw the evolutionary innovation of the generation of mechanical power from fossil fuels, water, and steam. The second industrial revolution in the late 1870s saw the expansion of mass production utilizing various electronic and information technologies. In comparison, the third industrial revolution in the 1970s led to the introduction of automation in the production industry. The fourth industrial revolution, Industrial 4.0, was the internet of things (IoT)

***CORRESPONDING AUTHOR | S. O. Falana** | ✉ iooladele@futa.edu.ng; olumide706@gmail.com

and cloud computing. They establish a real-time connection between virtual and physical worlds or "cyber-physical systems.

Industry 4.0, sometimes known as the fourth industrial revolution, is a significant change marked by the digitalization and automation of industrial operations. This revolutionary period in manufacturing closely relates to the future growth of the IoT. Industrial processes are changing due to technologies like robotics, 3D printing, machine learning, networking, and data analytics, which lessen the need for human labor and judgment. Industry 4.0 uses data processing, also known as big data analysis, to describe various applications such as digital engineering, feedback loops, trend prediction, probabilistic life modeling, predictive maintenance, behavioural analytics, risk modeling, and reliability engineering. These solutions use data-driven insights to improve design, production, and maintenance [14]. To achieve this, we must convert data from sources such as databases, computer systems, industrial IoT, digital twins, and digital threads into useful information. Semantic interoperability makes this conversion easier, and statistical analysis, or artificial intelligence (AI), can further refine it into knowledge. By integrating digital developments, this manufacturing era reduced human error, sped up time to market, and improved the flexibility of industrial processes in reaction to new information. Industry 4.0, which represents the fusion of operational and information technologies, exemplifies the real-time synergy between processes and data. Industry 4.0 transformed how companies create, enhance, and deliver their products. Manufacturers incorporate modern technologies like cloud computing, analytics, the IoT, AI, and machine learning (ML) into their manufacturing operations [15]. The Industry 4.0 idea anticipated more human participation as a remedy, which resulted in the need for Industry 5.0. Industry 5.0, in contrast to Industry 4.0, attempts to address new resilience-related challenges by reintegrating humans into the industrial process control loop [16].

According to Grabowska et al. [17], the European Commission stated that Industry 5.0's core principles go beyond purely economic goals. It is a societal aspiration to acknowledge the planet's limited resources while aspiring for resilience and prosperity. This approach focuses on coordinating production methods with environmental sustainability and prioritizing industrial workers' well-being. This viewpoint prioritizes human happiness as the primary goal of the manufacturing process, highlighting the transition to a more comprehensive and ethical industrial paradigm shift. The paradigm shift is necessary because the ensuing humanitarian and refugee crises have had a significant negative impact on global industry and the economy. There is an urgent need for increased process resilience, sustainable output, and higher-quality decision-making in response to these difficulties. Even though industrial 4.0 is still an ongoing project, futuristic researchers are already considering a loop of autonomous manufacturing with human intelligence in the Fifth Industrial Revolution [11, 18]. Although significant research has been done to improve operators' physical and mental health, there is still a lack of consensus over what human-centric manufacturing entails, and the degree to which automation diffusion in our lives largely depends on the technological level and acceptance of a collaboration between humans and machines. The interactions between humans and robots, their impact on the manufacturing industry, their potential applications, and the benefits they offer have sparked significant interest [11].

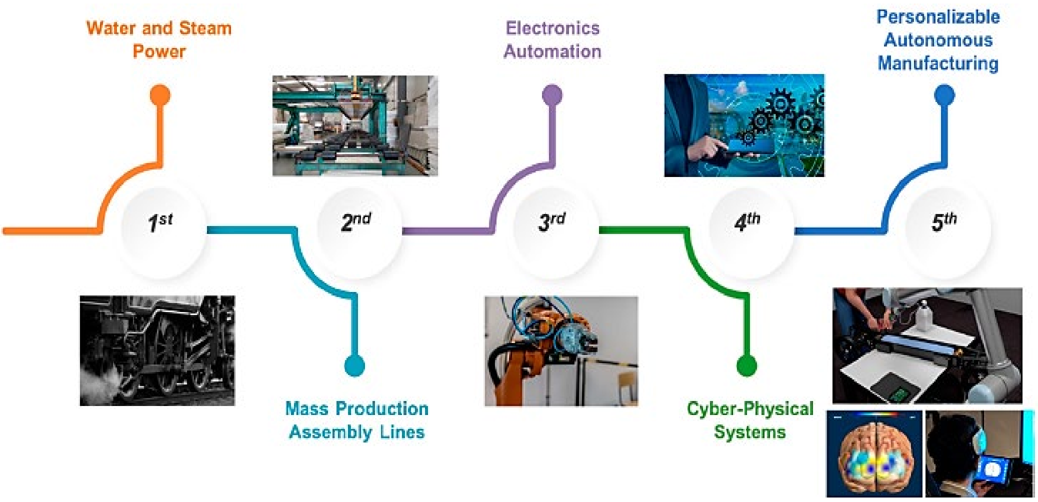

Figure 1. Industrial revolutions [24]

Human-centric manufacturing is still an emerging and contentious idea, and in-depth debates are required to clarify its research goal. It is crucial to note that system-centric automation environments have incorporated earlier research projects in disciplines like ergonomics [10, 19], Operator 4.0 [20–21], and human-robot collaboration [22]. While partially demonstrating a focus on human factors, these studies warrant a reassessment within the context of human-centric manufacturing. In the past decade, the collaboration between humans and machines has evolved, with many researchers and scientists intensifying their research focus on collaborative robots (Cobots) that safely share the workspace with the operator. This is because collaborative robot applications are more robust and complex than traditional industrial robot applications; as a result, they are an area of major research interest. Maurizio and Yuval [23] noted that for this human-machine relationship to coexist in achieving any meaningful task, the robots/machines must possess some moving and manipulating intelligence to avoid collision and remain efficient. Many of these cobots deal with precision, safety measures, collision avoidance, and smart manipulations. Another factor required to attain a collaborative environment between humans and machines is the ability of the cobots to behave intelligently and understand situations with ease in communication management, like human-human communication. Thus, this review paper analyzed the impact of collaborative work between humans and machines, its contemporary applications in the manufacturing sector, its socio-cultural impacts, and the paradigm shift in knowledge and technology. Figure 1 shows an image representation of the industrial revolution. The study was carried out through an extensive review of relevant research reports, where a thorough analysis of recent research journals and publications was conducted, and specific data relevant to human-machine collaboration was gathered. A brief comparison of the core values of Industry 4.0 and 5.0 were evaluated. The existing areas of applications, including technology and infrastructure, were noted after extensive analysis. Also, the limitations and challenges of human-machine collaboration were underscored, thereby looking forward to the emergence of Industry 6.0.

2. PERCEPTION OF INDUSTRIAL REVOLUTIONS

The operational paradigm of the globe has changed significantly for the fifth time in recorded history. This tendency reflects the changes during Industry 1.0, 2.0, 3.0, and 4.0 [25]. These revolutions have significantly impacted how people live, work, and have fun and corporate operations. Parallel to this, there have been four major revolutions in the retail industry: Industry 1.0, Industry 2.0, Industry 3.0, Industry 4.0, and Industry 5.0 [26]. The conceptualization of industrial revolutions encompasses four pivotal periods, each signifying a radical shift in industry and manufacturing techniques [27]. The First Industrial Revolution, which began in the 18th century, introduced mechanical processes powered by water and steam, leading to the emergence of factory systems. The Second Industrial Revolution, occurring in the late 19th and early 20th centuries, witnessed the advent of mass manufacturing and assembly lines, propelled by electricity and advancements such as the telegraph and telephone. The Third Industrial Revolution, often known as the digital revolution, transpired in the mid-20th century with the emergence of electronics, computers, and information technology, resulting in increased automation in production. Industry 4.0, the Fourth Industrial Revolution, is defined by the amalgamation of sophisticated technologies, including cyber-physical systems (CPS), artificial intelligence, machine learning, and the IoT [28, 29]. These technologies facilitate intelligent manufacturing and autonomous decision-making systems powered by real-time data from interconnected machinery and gadgets. CPS is the foundation of Industry 4.0 by connecting physical systems with computer models. In contrast, artificial intelligence and machine learning (ML) facilitate the processing of extensive data, operation optimization, and predictive maintenance implementation [30]. The IoT augments connectivity by enabling objects to interact and collaborate inside industrial settings. This revolution is altering manufacturing and commercial paradigms, highlighting enhanced efficiency, adaptability, and the creation of intelligent, autonomous systems that can redefine future industrial operations [31].

Industry 5.0 emphasizes human-machine collaboration while moving away from Industry 4.0's emphasis on fully automated systems and toward something more human-centric [32]. Cutting-edge technology that helps humans with jobs, such as AI and collaborative robots, improve productivity and customization. This revolution emphasizes customized solutions, shifting industrial methods from mass production to more adaptable and flexible ones. Furthermore, when robots take over monotonous activities, human abilities are rewarded for creativity and problem-solving, leading to a more harmonious relationship between technology and the workforce [33]. Industry 5.0 strongly focuses on resource efficiency and environmentally conscientious production, with sustainability and resilience as its main pillars. The industrial carbon footprint is to be decreased by applying green technology, renewable energy, and circular economy concepts. Decentralized production methods also improve resilience, making it possible to respond to global issues like supply chain interruptions and climate change in a more adaptable and flexible manner. In addition, the sector prioritizes social responsibility and ethical issues, ensuring that automation and AI developments meet societal demands and encourage the creation of jobs through upskilling and reskilling [34-38].

2.1 Industry 1.0

Industry 1.0, which took place between 1760 and 1840, was the start of the Industrial Revolution and brought about significant changes in the manufacturing and industrial processes [39]. The widespread use of steam power, which replaced water-powered machinery and human and animal labor, was the driving force behind this revolution. James Watt's ground-breaking discovery of the steam engine transformed companies [40]. It allowed them to shift from riverbanks, where they had been reliant on waterpower, to urban areas. Automation transitioned significantly from manual labor using breakthroughs like steam and waterpower. Several industries, including iron, coal, transportation, and textiles, transformed thanks to automation [41]. The textile industry saw a significant rise in productivity with the development of mechanical manufacturing processes, such as James Hargreaves' spinning jenny, which produced eight times more thread than manual labor [42]. With steamships and locomotives, steam power also transformed transportation, cutting travel times significantly and accelerating trade and communication over great distances. These developments had a tremendous impact on world economies, resulting in urbanization, social transformations, and labor market changes. Industry 1.0 brought faster transit, more industrial production, improved infrastructures, and more effective textile manufacturing [43-44].

Industry 1.0 has a profoundly negative social and economic impact, radically changing how society is organized [45]. People moved from rural regions to urban centres, causing a fast rise of industrial cities and an acceleration of urbanization as they flocked to cities in pursuit of manufacturing work [46]. The middle class grew, and a new industrial working class was formed due to this movement. Nevertheless, the advantages of higher output and economic expansion were accompanied by formidable obstacles [47-48]. Child labor was commonplace, and working conditions in factories were frequently unfavourable, with extended hours and dangerous surroundings [49]. The environmental effects of coal-powered machinery also became noticeable when pollution levels in industrial cities increased. These societal issues ultimately sparked movements for worker protection, the resolution of industrialization's detrimental environmental effects, and labor reforms, including reduced working hours and tightened safety standards [50]. Notwithstanding these drawbacks, Industry 1.0's innovations paved the way for subsequent industrialization and shaped the contemporary world by fostering ongoing technical innovation and industrial expansion [51]. Economic expansion sparked migration, reconstruction initiatives, and an increased labor force, setting the foundation for succeeding industrial revolutions [52].

2.2 Industry 2.0

The second stage of the industry, Industry 2.0, took place between 1870 and 1914 and was marked by the development of electrical power sources, telephones, automobiles, and mass industrial output. This creation orchestrated the use of cutting-edge equipment and the removal of steam engines. Henry Ford transformed the auto industry by stealing the concept of assembly lines from Chicago slaughterhouses, which increased output while cutting expenses. Appliances became more cost-effective and efficient when electricity replaced steam and water as primary energy sources. Assembly line integration became commonplace in mass production, significantly increasing manufacturing output and creating unemployment as machines replaced numerous positions [53].

The use of open-hearth furnaces for large steel production led to rapid growth in the infrastructure. Industry 2.0 evolved partly due to the invention of the assembly line and electric power. It made mass production possible and ushered in the age of automation. The other ideas of the Second Industrial Revolution enhanced efficiency, uniformity, and a methodical workflow from the created notion of scientific management. The second stage laid the groundwork for the third industrial stage's advancements in electronics, aviation, and other fields of industry [54]. The globe underwent a significant change due to the second industrial revolution, the technological revolution. This period saw revolutionary developments introducing new energy sources, including electricity, gas, and oil. These discoveries sped up the creation of combustion engines, which enabled efficient use of these energy sources. Due to rising steel demand, the steel sector saw substantial growth, and synthetic fabrics, dyes, and fertilizers were produced thanks to chemical synthesis [55-59].

The development of the telegraph and telephone revolutionized communication techniques and altered how people interacted. The invention of the automobile and airplane flight marked the beginning of the 20th century and the revolution in transportation systems [60]. These revolutionary discoveries were made possible by centralized research and funding, managed according to an economic structure based on new, massive industries. In this era, developing artificial materials like disinfectant antiseptics (especially phenol and bromine) and comprehending the role of bacteria in wound infections chemistry played a significant role. Electric systems also made important advancements by introducing electric generators, vacuum pumps, gas lighting systems, and transformers. Electricity has become a means of transmitting energy to all places [55]. Also, faster railways and diesel engines were created, and clipper ships made their imprint on the world of transportation. Steel implements, drainage and irrigation pipelines, steam-operated threshers, seed drills, and automated reapers were only a few of the advances that helped agriculture. The relationship between our perception of nature and its influence on technical practices was radically transformed during this time, permanently altering the technological change process itself.

2.3 Industry 3.0

The Third Industrial Revolution, also known as Industry 3.0, was greatly influenced by World Wars I and II, significantly impacting world growth and economics. The second industrial revolution ended with the Second World War, while the third industrial revolution began in the years following 1969. Industrial automation transitioned from electromechanical systems to computer-based control systems, ushering in inventions like Programmable Logic Controllers (PLC) and industrial robots. Nuclear energy, a new energy source introduced by the third industrial revolution, has more significant potential than its forerunners. Transistors and microprocessors experienced a substantial rise during this time, along with the development of computers and telecommunications. These technical developments made manufacturing materials on a smaller scale possible, providing opportunities for biotechnology and space research. The revolution automated industrial processes using electronics and information technology, which resulted in substantial breakthroughs across many industries [55, 61].

Industry 3.0 production divisions are organized according to principles based on the integration of Computer Numerical Control (CNC) technology, which functions via interfaces between humans and machines [62]. The movement of materials (blanks) and machining tools within the work chamber is guided by programs created by specialists utilizing 3D models, schematics, and construction documentation on CNC machines and semi-automated systems controlled by specialized software [63]. These devices use servo motors and controllers to synchronize the movement of the material base and tool base to process a wide range of materials, including metals, polymers, and organic glass. The subtractive technology-based manufacturing process happens automatically as the tools gradually shape the material into the desired result [64]. Operators of CNC machines manually program the machines by following technical instructions and using integrated control panels. Technical requirements specify each machine's capabilities, tailored to specific technological tasks and material kinds. Depending on how well their manufacturing processes mesh, many CNC machines in a production setting can be combined into a single segment, streamlining the entire process. The great accuracy and reproducibility of the produced goods are two essential benefits of CNC-based production. CNC software may make similar things once repeatedly produced and verified. Manufacturers do not need to modify fundamental manufacturing processes when introducing new goods; they only need to update the software to support new designs [65]. Complex designs that are impossible to manufacture manually may be handled quickly and effectively by CNC machines [62].

Businesses increasingly use 3D printers, which employ additive manufacturing to manufacture complicated objects, to modernize Industry 3.0 production further [66]. By integrating 3D printing technology with conventional CNC machining, enterprises may manufacture elaborate and superior items using various materials [62]. Both systems use similar programming concepts, so CNC operators may quickly transition to working with 3D printers with more training. Industry 3.0 firms employ sophisticated measurement tools like X-ray machines and optical stations to provide quality control. Integrated measurement instruments within the machine are also used for real-time monitoring of CNC operations.

2.4 Industry 4.0

The term Industry 4.0 was first introduced in 2011 at the Hannover Fair. It was an initiative created from a project under the German government's high-tech strategy. It expands the conceptualization of CPS into Cyber-Physical Production Systems (CPPS) with the smart factory as one of the key associated initiatives [67, 68]. Production systems, such as CPPS, can make intelligent decisions in the Industry 4.0 era. They enable real-time communication and collaboration between manufacturing and things [69], enabling flexible manufacturing of high-quality specific products at mass precision and efficiency. Industry 4.0 has made it easier for companies to adopt cutting-edge technologies and improve their competitive edge in domestic and international markets. It organizes production processes under decentralization, real-time data analysis, service orientation, modularity, and interoperability between physical and digital systems [70, 71]. As a result, the principles and techniques enable seamless integration of business systems and promote cooperation along the whole value chain. Throughout the entire product lifetime, it is crucial to maintain constant real-time communication and collaboration between all engaged stakeholders. This can be accomplished by utilizing a digital platform. It allows manufacturing systems to adjust quickly and automatically to changing client demands.

The efficiency of partnerships within manufacturing supply chains is significantly improved using technologies and application models [72-74]. The model includes the Join Industries 4.0 platform, established by professional organizations (VDMA, BITKOM, and ZVEI) to develop the initiative and guarantee a coordinated and cross-sectoral approach [20]. Similar strategic initiatives have been developed in various countries across the globe. Examples include the United States' Industrial Internet Consortium, Industria 4.0 (Italy), Sweden's Produktion 2030, Made in China 2025, and Society 5.0 by Japan. Industry 4.0, often known as smart manufacturing, seamlessly blends intelligent digital technologies like big data and ML with physical production and operations. Through this integration, a vast and integrated corporate ecosystem is created. To accomplish this convergence, the manufacturing process must be reorganized with an architecture capable of processing the massive volumes of real-time data generated by IoT sensors and other devices. It should also make millisecond-level precision control of the entire environment possible. Cyber-physical systems, which stand for continual improvement and integration of functions, represent the progress of Industry 4.0. Autonomous and semi-autonomous decision-making processes are essential in this paradigm. To make these developments possible, Industry 4.0 integrates necessary components, including the IoT, AI, newly integrated systems, improved analytics, and several other technologies [15]. Figure 2 shows the Industrial Revolution from Industry 1.0 to 4.0.

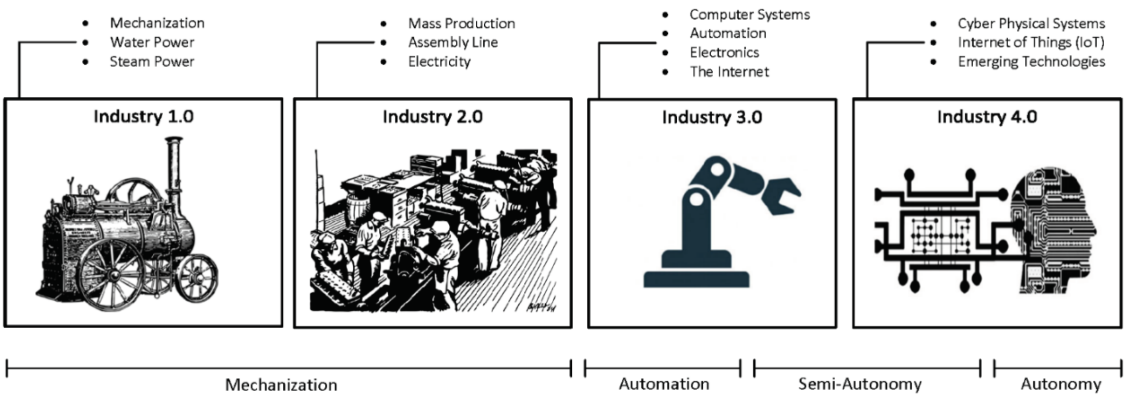

Figure 2. Industrial revolution from industry 1.0 to 4.0 [54]

2.4.1 Cyber-Physical System in Industry 4.0

A typical CPS-embedded process for Industry 4.0 is shown in Figure 3. According to Javaid et al. [15], Cyber-Physical Systems have numerous significant applications in Industry 4.0. Among these applications are:

- *Physical Process Regulation and Interaction*: CPS makes it possible to regulate and engage with various industrial processes precisely. Industries can quickly adapt to market demands and ensure effective manufacturing procedures. CPS encourages innovation by offering a platform for creating cutting-edge technologies [15, 75].
- *Productivity Boosting*: Simplified operations and improved processes boost industrial productivity. Increasing Production Capabilities: By utilizing CPS technology, industries can increase their production capacities [76].
- *Enhancing Workflow*: CPS supports the efficient flow of tasks and resources. This enhances workflow effectiveness [77].
- *Quality Improvement*: Real-time monitoring and modifications ensure the manufacturing of high-quality goods [78].
- *Intelligent Networking*: CPS allows multiple systems and devices to network, improving overall connection intelligently. Intelligent decision-making processes are automated, resulting in more effective operations [79].
- *Design and Development of Goods*: CPS supports the design and development of goods by offering insightful information and simulations [80].
- *Remote Control*: Monitoring and managing industrial operations remotely are now possible, eliminating the requirement for on-site presence. [81]
- *Reducing Dependency*: CPS lessens reliance on manual intervention, resulting in more dependable systems. Information Transparency: It guarantees that information and data sharing throughout the organization is transparent.
- *Safe Workplace*: By automating risky jobs, CPS helps to create safer work environments. Utilizing production resources effectively means using energy, raw materials, and other resources while minimizing waste.
- *Equipment Linkage*: A smooth connection between several pieces of machinery and equipment improves coordination and productivity [15, 77]
- *New Product Opportunities*: CPS creates doors for developing cutting-edge goods with cutting-edge functionality. Handling prospective Issues: It enables proactively identifying and handling prospective problems, reducing downtime.
- *Predictive Repair*: CPS foresees the need for equipment repair, enabling quick responses to avert breakdowns.
- *Better Supply Chain Insight*: It offers thorough insights into the supply chain, allowing for well-informed decision-making.
- *Lean Manufacturing*: CPS promotes lean manufacturing concepts by eliminating waste and inefficiency.
- *Maximizing Machine Utilization*: Production schedules are optimized by using the best machinery.
- *Monitoring the Factory Floor*: Continuous monitoring of the factory floor guarantees efficient operations.
- *Data Gathering and Analysis*: CPS gathers and examines enormous amounts of data to gain useful insights and make changes.
- *Resource Optimization*: Manpower and material costs are considered while allocating resources.
- *Software Management*: Smooth integration and operation of software systems are guaranteed by effective management [15].

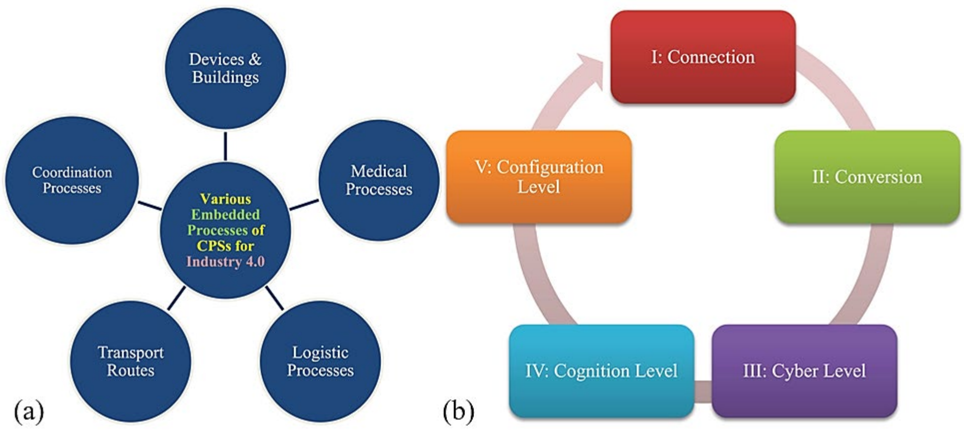

Figure 3. (a) Typical CPS with embedded processes and (b) Architecture of CPS for Industry 4.0 [15]

Apart from CPS, industries utilize other platforms. Liu et al. [70] surveyed and made a comparative analysis list of platforms used in Industry 4.0, shown in Table 1. At the same time, most of the platforms are utilized by large corporations. Liu et al. [70] considered a platform for small-medium enterprises (SMEs) by using semantic technologies to provide context to machine-to-machine communications; semantic technologies play a critical role in making the creation of SME clusters easier. They accomplish this by supervising and controlling rules and regulations that are computer-based or machine-readable, enabling the digital administration of the entire platform ecosystem. The architectural issues observed in the research are the layered architecture style and event-driven style. Industry 4.0 ensures the manufacturing sector's competitiveness in the future by empowering businesses to respond effectively and quickly to market disruptions and product changes. This paradigm situates the Industry 4.0 environment's inherent value proposition-creation-capture cycle within the context of a manufacturing organization's customer-product-process-resources perspectives. The framework creates a system dynamics model of the mass customization paradigm to show the framework's usefulness [82].

Table1. Comparative survey of Industry 4.0 platforms [70]

Platform Name	Industry Sectors Supported	Architecture Style/Type	Communication	Knowledge Protection and Sharing Mechanisms	Platform Service Extensibility Approach	Implementation Technologies
NIMBLE	Yes	Microservice infrastructure	Service-oriented	Data sharing service and product ontology	Hardcoded	Web interface, cloud-based microservice
IDARTS	Yes	General layered architecture		Knowledge Management Component: Data workflow	N/A	Java Agent Development Framework (JADE)
IoT energy platform	No	General layered architecture		UML class-based information model; data workflow	Hardcoded	Nimbits
RTMIIS	Yes	SOA	Service-oriented	N/A	Hardcoded	Cloud-based micro-service
Government affairs service platform	No	SOA	Service-oriented	User service	Hardcoded	Web VRGIS engine, cloud-based microservice
A collaborative knowledge transfer platform	No	General layered architecture	RESTful API	Database	Hardcoded	PHP, JavaScript, MySQL
Middleware for Intelligent Automation Platform	Yes	Specialized middleware in general layered architecture	OPC UA Standard over Time Sensitive Networks	Cloud service and database warehousing	Hardcoded	Cloud-based microservice
Fog-of-Things platform	No	Platform-as-a-Service	Message routing	Cloud service	Hardcoded	Cloud-based microservice
An automated flow-shop manufacturing system	Yes	General layered architecture	OPC UA with database	Multi-view synchronization	Hardcoded	J2EE and Unity3D
SCM system with a blockchain-enabled architecture	Yes	General layered architecture	Peer-to-peer blockchain network	Blockchain database; Traceability and visibility service	N/A	Validated by experts in SCM
Simulation Platform for Virtual Manufacturing Systems	Yes	SOA	Service-oriented	Cloud service and data store model	Service-oriented integration	Cloud-based microservice
DIGICOR (present study)	Yes	Specialized EDSOA	Event-based	Authentication service and ontology layered architecture	App-store based	Angular 4 front-end, cloud-based back end, Kubernetes

2.4.2 Artificial intelligence and Industry 4.0

Artificial intelligence development offers a chance to harmonize AI technology with the ideas behind Industry 4.0. Artificial intelligence integration can drastically improve product quality and production efficiency. Security, autonomous configuration, planning, control, monitoring, prediction, and decision-making are just a few of the industrial uses of AI. These programs make handling errors, optimizing processes, and simulating scenarios easier [77, 83]. Simulations powered by AI aid in parameter optimization and improve system efficiency. AI also makes it possible to recognize patterns and forecast the future, enhancing system administration, cutting expenses, and effectively using resources. In more precise terms, AI is the process of building intelligent robots that mimic human cognitive functions like learning and problem-solving. Algorithms which are compiled sets of instructions that direct machines to behave intelligently. In large and varied datasets, AI systems excel at finding patterns and relationships. They can do intentional and adaptive behaviors because they can anticipate obstacles, deal with them, and intelligently adapt [84].

Many researchers have concentrated on how Industry 4.0 and AI can be integrated to discover the potential of AI in data management, production efficiency, quality, safety, and sustainability. Studies have also focused on quality assurance, with a strong emphasis on cycle monitoring and control. These initiatives seek to raise customer happiness and product quality. For instance, research on data management across product life cycles has focused on how AI may optimize different stages [85-86]. The potential of AI and big data applications to improve productivity and sustainability in manufacturing and industrial applications has also been investigated in the context of Industry 4.0 technology [77]. Figure 4 shows the Applications of AI in the marketing industry.

Figure 4. Applications of AI in the marketing industry [87]

Researchers such as Haleem et al. [87] and Verma et al. [88] discussed the influence of AI in the marketing domain. Their research encompasses Location management, pricing strategies, target audience identification, strategic planning, product management, real-time pricing adjustments in response to demand fluctuations, promotional activity management, and the creation of products that are specifically catered to customer needs are all areas of focus in the field of AI marketing. Table 2 shows the areas of application and advantages of using AI within the concept of Industry 4.0. Figures 5 and 6 and Table 3 show the framework for AI decision-making in the marketing domain.

- *Strategy and Planning*: AI is a critical component of strategy and activity planning for marketers, especially in segmentation, targeting, and positioning (STP). AI helps marketers influence a company's strategic direction in addition to STP. Different industries, including banking, finance, art marketing, retail, and tourism, can find lucrative consumer categories using text mining and machine learning algorithms. Target clients can be precisely identified by combining data optimization methods and machine learning [89, 90].
- *Product Design*: AI-powered tools in marketing analytics can evaluate whether a product's design meets client needs, increasing overall customer happiness state. Notably, AI increases system capabilities and supports innovation and design processes by assigning preference weights to product qualities in searches, helping marketers comprehend product recommender systems, enabling customized marketing tactics and efficient product management. Deep learning makes it possible to provide customized point-of-interest recommendations and makes it easier to explore new locations. AI allows companies to tailor their goods and precisely match them to client wants [88, 91].
- *Price Management*: Calculating the final pricing is complicated and requires considering various variables. The task is considerably more challenging when demand fluctuations necessitate real-time pricing modifications. With algorithms like the multi-armed bandit that dynamically change pricing in real-time scenarios, artificial intelligence is at work [88]. Machine learning algorithms applying Bayesian inference can quickly align price points with rivals in pricing environments that are undergoing rapid change, such as e-commerce claims that to optimize dynamic pricing strategies, advanced pricing algorithms, such as best response pricing, considering customer preferences, rival strategy, and supply networks [92, 93].
- *Strategic Placement*: Making sure products are accessible and readily available is an essential part of the marketing mix that significantly improves client happiness. The logistics, inventory control, warehousing, and transportation activities that support the delivery of goods are frequently mechanical and repetitive. Collaborative robots for packing, drones for delivery, and the internet of things for order tracking and replenishment are all examples of how artificial intelligence offers an excellent answer for location management. The distribution process can be more convenient for suppliers and customers by standardizing and automating it [93-94]. Beyond its use in distribution management, AI also fosters consumer involvement in the context of services. Service robots given emotional AI programming are useful for surface acting. These embodied robots can greet and interact with clients to achieve customer satisfaction; including human components in the service environment is crucial. AI-powered automation of service procedures opens new possibilities for improving productivity and performance [95, 96].

- *Promotion Management*: Marketing campaign management includes several facets, including search engine optimization, media scheduling, and planning. These marketing strategies are transitioning from physical to "phygital," synthesizing digital and analog experiences. Global digital transformation has led to an increase in social media marketing and advertising. Customers significantly influence the nature, location, and timing of promotions in the current technological environment. AI is essential in this new advertising environment. Based on client profiles and preferences, AI enables the personalization and customization of messages. By using content analytics, messages can be made more valuable and effective. Emotive AI systems make real-time tracking of customer preferences and dislikes possible [88, 95].

Table 2. The descriptive applications of AI [87]

S/N	Applications	Description
1	Digital Marketing	Digital marketers can better understand customer behavior and target the appropriate audience with the help of AI, which significantly impacts the industry. AI enables marketers to engage in meaningful relationships and benefit business outcomes by processing enormous amounts of data from social media, emails, and the web. When used with marketing automation systems, it enables data collecting, consumer insights, action prediction from customers, and automated marketing decisions.
2	Reduction of human mistakes	Particularly in crucial areas, AI has drastically decreased human errors. It can also enhance email content to make it more pertinent and enticing to readers. Learning and adjusting to an organization's cybersecurity requirements prevents human errors and addresses data security concerns. Additionally, employing numerous conventional resources for implementing marketing strategies is no longer necessary, thanks to AI.
3	Connect business process	AI uses information technologies to improve consumer experiences by streamlining entire company operations. Utilizing tailored and human-centred marketing methods, marketers who use AI achieve superior marketing results. Customers are captivated by AI-driven marketing strategies, becoming fervent brand advocates. Enhancements to interaction designs provide consumers more influence over their micro-moments. AI's expanding benefits are altering businesses and improving marketing campaigns.
4	Analyze massive amounts of market data	AI examines market data, forecasts user behavior, and determines to buy intent from search searches. It identifies flaws and makes it easier to take corrective action, radically changing how businesses operate. Efficiency is significantly increased by AI and ML, virtually tripling company effectiveness.
5	Deliver valuable information	Data analysis is streamlined by AI technologies, which provide clients with information specifically suited to their needs. It is a tactical tool for marketing initiatives, fusing technological advancement with human intelligence to provide highly tailored content. Ad content is changed in real-time due to algorithms analyzing visitor behavior. Future content is improved via ongoing data collection. AI helps merchants concentrate on outcomes and better understand client decisions using personal and behavioral data. Psychographics provide an in-depth understanding of client goals and purchase trends, improving the selection of goods and services.
6	Enable convenient customer support	AI improves customer service, resulting in smooth interaction. Artificial intelligence is essential for marketing automation, which depends on repetitive processes. Real-time client data is collected by AI, which also helps organize data by applying ML insights on a massive scale. AI-powered automation solutions are revolutionizing methods, answering new demands for hyper-personalized offerings, and promising improved marketing techniques.
7	Better marketing automation tool	Marketing automation technologies with AI integration help companies find eligible prospects, improve lead nurturing plans, and produce pertinent content. Dynamic content emails, specially tailored ones, are very successful at ensuring relevance and engagement by customizing messages to subscribers' interests, geographies, psychographics, and behavior.
8	Ease workload	Predictive analytics is a special application of AI in marketing that provides a fast and effective way to extract insightful information from complex data. Predictive lead scoring benefits greatly from predictive analysis, which is powered by AI and maximizes the value of existing data. Marketers increasingly use this predictive algorithms-based strategy to filter efficiently and rate leads.
9	Speeds up data processing	AI expedites data processing while guaranteeing security and accuracy, allowing marketers to concentrate on strategic objectives for successful campaigns. It collects real-time tactical data, enabling quick decision-making based on data-driven reporting. AI automates routine tasks, cutting down on time and mistakes, maximizing the use of human resources, and freeing up talent to concentrate on crucial work while lowering hiring costs.
10	Make customer-centered choices	Organizations may make more customer-focused decisions thanks to AI's ability to collect useful consumer insights. It examines massive online content, including blogs and social media. It aids marketers in building complete consumer personas based on various data points, including on-site interactions, regional preferences, spending patterns, prior interactions, referral sources, and more.

Table 2. (cont.)

S/N	Applications	Description
11	Examine data about customer	To establish the best contact times, frequency, desired content, and efficient email themes and headers, machine learning analyzes a large amount of consumer data. Based on thousands of data points collected about each user, advanced algorithms offer tailored website experiences. By analyzing massive data, AI customizes offers and information for different user types. Marketing predictive models estimate conversion costs, identify customers likely to make multiple purchases, and forecast prospects becoming clients.
12	Improve stock control	AI improves stock control during strong demand by avoiding irrational purchases and maximizing income. For addressing specific dynamic pricing and demand forecasting requirements based on products and client segments, tailored solutions, either internally produced or created by external experts, are crucial.
13	Customize shopping processes	AI improves shopping experiences using simulation models and machine learning-based suggestions, frequently in conjunction with virtual assistants. Companies like Amazon use AI to provide purchase recommendations based on past behavior, and if these technologies advance, they may eventually outperform human abilities in some fields. AI is excellent at spotting marketing trends, utilizing in-depth knowledge and data analysis to forecast consumer behavior, enhance user experience, and meet real-world customer needs.
14	Digital advertising	To optimize ad campaigns based on user information like gender, age, and hobbies, AI is widely utilized in digital advertising on sites like Facebook, Google, and Instagram. It supports strategic decisions by assisting marketers in recognizing microtrends and predicting broader trends. With the use of this technology, digital advertising waste is reduced, increasing investment returns. Additionally, the future of digital marketing is changing due to AI's integration with IoT and connected gadgets.
15	Better customer experience	Businesses are adopting intelligent technology solutions to improve customer satisfaction and operational effectiveness. These platforms enable marketers to gather in-depth customer data that help them increase conversion rates and lighten the workload of their marketing teams.
16	Assisting marketers	By bridging the gap between massive amounts of customer data and potential future behaviors, AI enables marketers to interact with customers successfully. Big data from digital media can analyze campaigns in depth and transfer value seamlessly between channels. Marketers who use AI-powered solutions have access to centralized platforms that can effectively manage massive amounts of data.
17	Increased customer satisfaction and revenue	AI in marketing has several advantages, including enhanced customer happiness, faster processing times, less risk, and revenue growth. Through rapid budget allocation decisions across various channels made possible by AI platforms, clients are consistently engaged, and campaign value is maximized. Marketing professionals can improve their plans, replicate effective methods, and allocate resources efficiently with the help of personalized messaging, the identification of at-risk clients, and detailed analytics provided by dashboards driven by AI.
18	Development of a predictive model	Data collection, the creation of prediction models, and their testing on actual clients are all made easier by AI-powered solutions. They allow for targeted email delivery and assist in identifying groups of disengaged customers, hence identifying possible churn. AI-driven churn prediction examines omnichannel data, spots dwindling consumer interest, and sends pertinent offers to keep users interested. Customer engagement, lifetime value, and income increase when personalized content production and AI-powered churn prediction combine.
19	Learning about customer preferences	Data collection, the creation of prediction models, and their testing on actual clients are all made easier by AI-powered solutions. They allow for targeted email delivery and assist in identifying groups of disengaged customers, hence identifying possible churn. AI-driven churn prediction examines omnichannel data, spots dwindling consumer interest, and sends pertinent offers to keep users interested. Customer engagement, lifetime value, and income increase when personalized content production and AI-powered churn prediction combine.
20	Make better decisions	AI analysis of qualitative and quantitative data offers insightful data that helps people make better decisions. AI in Google Ads enables marketers to concentrate on more strategic decisions like campaign planning. Deep learning, a highly developed branch of ML, analyzes massive and complex data to comprehend consumer interactions, enabling tailored advertising and higher returns on investment. Agencies may evaluate data, forecast trends, and improve brand quality as AI becomes more widely available. Businesses may produce creative, targeted adverts using AI when using digital marketing techniques, which increases sales and reduces expenses.

Table 2. (cont.)

S/N	Applications	Description
21	Target audience	AI marketing improves conversion management solutions by assisting firms in identifying and personalizing experiences for their target audience. Marketers can answer important strategic issues by contrasting sophisticated inbound communication with conventional measures. In the e-commerce, retail, and business sectors, there is a growing interest in efficiently providing highly customized experiences as consumer expectations change. To successfully meet client needs, AI is essential.
22	Deliver the right message in time	With the help of AI technology, marketers can better understand their clients and prospects, enabling personalized messages at the perfect time. AI assists in the creation of thorough client profiles by gathering information from consumer interactions. Utilizing consumer information from keyword searches, social profiles, and online activities for creative and successful digital advertising, marketers can employ AI to improve campaigns and produce highly personalized content.
23	Assist businesses	By analyzing consumer purchase history and social media data, AI plays a crucial role in helping businesses comprehend customer wants and provide individualized experiences. Automating ads, recommending best practices, and addressing performance issues in social media marketing improves ad performance. Even in complex situations, AI techniques improve targeting and ad spending, enhancing campaign performance.

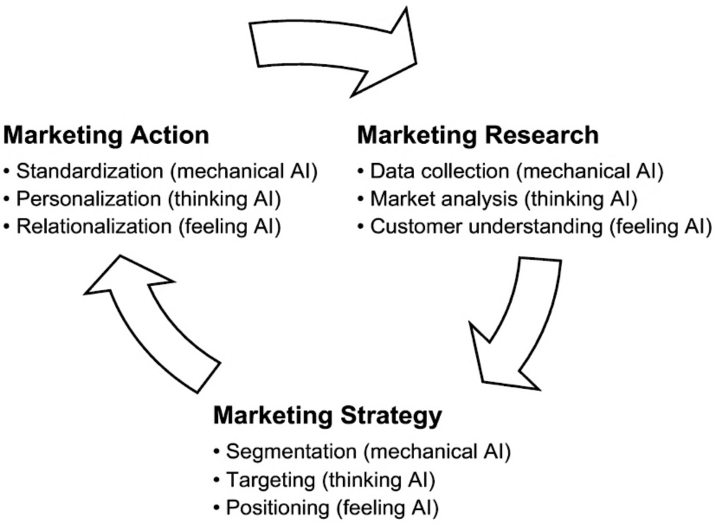

Figure 5. The path of strategic AI marketing decisions [94]

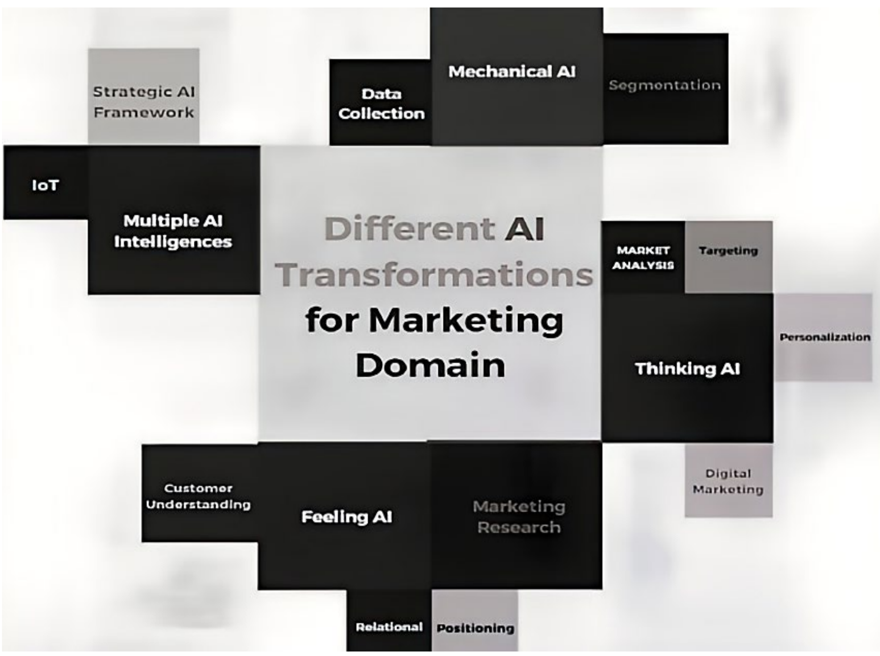

Figure 6. The areas of applications of AI in the marketing industry domain [87]

Table 3. A framework for AI in marketing decisions [94]

AI Intelligence Strategic Decision	Mechanical AI	Thinking AI	Feeling AI
Marketing research	Data collection: Automate continuous market and customer data sensing, tracking, collecting, and processing	Market analysis: Use marketing analytics to identify competitors and competitive advantages	Customer understanding: Use emotional data and customer analytics to understand existing and potential customer needs and wants
Marketing strategy (STP)	Segmentation: Use mechanical AI to identify novel customer preference patterns	Targeting: Use thinking AI to recommend the best target segments	Positioning: Use feeling AI to develop positioning that resonates with customers
Marketing action (4Ps/4Cs)	Standardization	Personalization	Rationalization
Product/Consumer	Automate the process and output of meeting customer needs and wants	Personalize products based on customer preferences	Understand and meet customer emotional needs and wants
Price/Cost	Automate the process of price setting and payment	Personalize prices based on customer willingness to pay	Negotiate price and justify the cost interactively
Place/Convenience	Automate customer access to product	Personalize frontline interactions	Personalize experience for customer engagement
Promotion/ Communication	Automate communication with customers	Customize promotional content for personal communication	Tailor communication based on customer emotional preferences and reactions

2.4.3 Machine learning and internet of things in Industry 4.0

The IoT, sensor networks, and ML are key to the industrial revolution. The change moved industries toward fully automated environments that include post-production, pre-production, supply chain management, and quality control. As ML-enabled intelligent robots handle physical activities, human engagement shifted to strategic thinking. Sensor networks will continuously gather real-time environmental data, allowing decisions to be made quickly based on the past. Automated systems rely heavily on machine learning algorithms to learn from the available data and make wise decisions. They are frequently used to forecast pricing or demand [97].

Rahman et al. [97] gave a descriptive summary of all the protocols, technologies, sensors, and algorithms that quantify the ML and IoT applications in Industry 4.0. The goal of Industry 4.0 research is to combine cutting-edge technology to build specialized and effective systems in various industries, particularly in agriculture and mining, where automation and a decrease in human dependence are essential. Key areas of concern include automated cold storage management, risk reduction, crop and land upkeep, and general automation. IoT and ML algorithms are necessary for gathering real-time data, monitoring equipment, and assuring economical energy use. Adapted to the needs of a particular industry, intelligent algorithms optimize power usage, production tracking, and quality control. These procedures are improved using adaptive algorithms that use reinforcement learning and real-world industrial data [97], and as seen in Figure 7, the application of Ml and IoT in Industry 4.0.

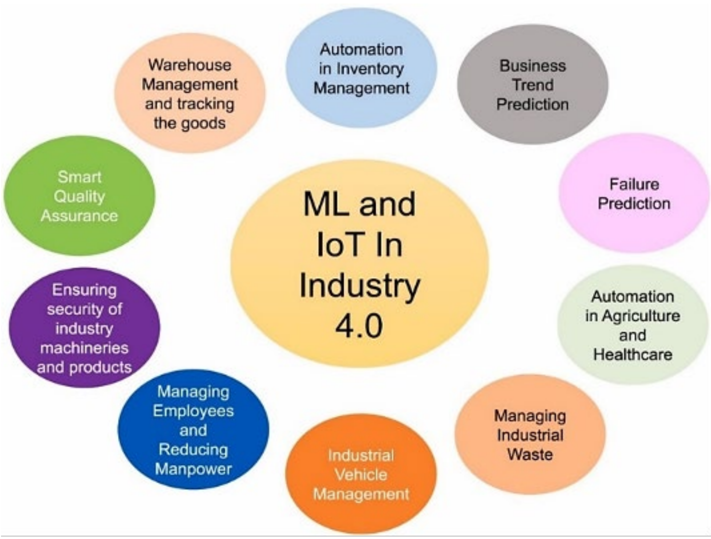

Figure 7. The application of ML and IoT in Industry 4.0 [97]

In addition, ML and AI address problems categorized and explained in a five-level hierarchical structure:

i) The development of connectivity infrastructure
ii) Advancements in artificial intelligence for data-driven decision-making
iii) System and process optimization
iv) The encouragement of industrial innovation
v) The promotion of societal progression

A framework for Industry 4.0 convergence is also presented, consisting of six dimensions: connection, collection, communication, computation, control, and creation [98]. Although this technology constantly evolves, few people know its importance to industry or its potential to revolutionize engineering [99].

2.4.4 Other Industry 4.0 contributions

Big data analysis, cloud computing, cloud manufacturing, cybersecurity, automation, robots, and additive manufacturing, encompassing 3D printing, 4D printing, and 5D printing, are additional technological breakthroughs in Industry 4.0 [86] Patil et al. [100] examined the industry's readiness for integrating big data and Industry 4.0, emphasizing sustainable supply chain management in the circular economy era. The main variables discovered are "readiness towards information system infrastructure," "Internet stability for developing Industry 4.0 infrastructure," and "circular process and awareness." The study suggests that stakeholders in the sustainable supply chain pay more attention to the processes of creating infrastructure, knowledge creation, and training connected to circular economy practices. With a focus on sustainability, these insights are intended to help stakeholders frame strategies and action plans for the digitalization of supply chains.

Cloud computing exemplifies the idea of "computing utilities," offering platform, infrastructure, and software services via a pay-per-use business model. This model is like shared delivery networks that provide services like water and electricity. Along with other integrated computing and networking concepts, including edge computing, fog computing, mist computing, IoT, SDN, digital twin, and industry 4.0, cloud computing has developed. A contemporary development that supports the needs of next-generation computing is the integration of these cloud computing paradigms and their archetypes. Furthermore, integrating machine learning approaches with these integrated cloud computing paradigms creates fresh research opportunities that address upcoming technological breakthroughs [101]. A hardware-software abstraction layer between manufacturing hardware and cloud-based applications, services, and platforms is implemented as part of software-defined cloud manufacturing, which attempts to improve cloud-based manufacturing. Software-defined systems like software-defined networks are the motivation for this idea. The main objective is to provide open, flexible, adaptable hardware platforms for simple software customization. Industry 4.0's networked manufacturing approach, known as "cloud-based manufacturing (CBM)", uses on-demand access to dispersed manufacturing resources. It establishes transient, reversible cyber-physical manufacturing lines, increasing productivity, lowering costs, and better allocating resources. CBM supports resource pooling and virtualization through networked manufacturing, scalability, agility, universal access, multi-tenancy, big data, IoT, and everything-as-a-service. Cloud-based design and manufacture (CBDM), a related concept, unifies cloud-based design and manufacturing. Through social networking, crowdsourcing platforms, and shared service pools of design and manufacturing capabilities, CBDM enables group open innovation and quick product development [102-105].

Networked manufacturing robots' cybersecurity vulnerabilities are a developing worry, with their ability to disrupt company operations and models being highlighted. Corallo et al. [106] proposed a structured classification of crucial industrial assets in Industry 4.0 after performing an extensive literature analysis and using ethnographic research. Data confidentiality, integrity, and availability of manufacturing machinery showed the adverse effects on corporate performance brought on by cybersecurity breaches. The study provides a framework for evaluating these impacts, which creates relationships between crucial assets and business effects and offers useful insights for industry and academics, guiding future analysis and investigations in the cybersecurity field. Papulová et al. [107] investigated automated manufacturing in the automotive sector, particularly emphasising Industry 4.0 technologies like high-resolution robotics, 3D printing, and the Internet of Things. Slovakia and the Czech Republic, two significant participants in the global automobile market, were surveyed for the study's manufacturing enterprises in the automotive industry. The study set out to confirm two beliefs about applying automation technologies. The results showed that sensors, programmable devices like PLC/HMI, and industrial robots were widely used. Compared to medium-sized and small-sized enterprises, larger companies were found to integrate automation features more sophisticatedly.

Additive Manufacturing (AM) was developed in response to the increased interest in integrating digital advanced manufacturing and production systems into Industry 4.0. This ground-breaking technology can fundamentally alter how companies conduct their operations and engage with customers, opening the door to increased profit margins and long-term business strategies. Elhazmiri et al. [108] analyzed AM's crucial function in addressing customers' intricate needs using various technologies and methods. The results show that AM brings new business models, boosting profitability and competitiveness through enhanced production methods. Furthermore, AM provides ground-breaking solutions for waste reduction, shorter supply chains, and longer product lifecycles, promoting its use for cost, energy, and material savings. The technological implementation of AM is still in its early phases and confronts issues with capability, IT integration, and results. After the global COVID-19 epidemic, the advancements in Industry 4.0 significantly impacted professionals' lives and work across the globe. According to some analysts, the fifth industrial revolution is the current trend. The fifth industrial revolution defines paradigms, although the futuristic directions are not yet clearly defined [109]. This research combines the key components of Industry 4.0 with the expected impact of Human-Machine collaboration on manufacturing performance in Industry 5.0.

2.5 Industry 5.0

Historically, a new industrial revolution has always been sparked by revolutionary advances, leading to significant changes in industries' operations. These changes have an impact on the economy and society, some of which are intended to be good and others of which are unanticipated and undesired. Various revolutions have changed the industrial landscape. The transition from human labor to machines was highlighted by Industry 1.0. Industry 2.0 fostered economic expansion and elevated unemployment because of automation. Digital technology like computers and the internet were first introduced during Industry 3.0. Industry 4.0 enabled data-driven decisions by integrating physical assets with cutting-edge technology like AI and IoT. Like its predecessors, Industry 4.0 is fueled by technology. Industry 5.0, in contrast, is founded on principles and focuses on effective and intelligent equipment to demonstrate how industries are constantly changing [110]. The latter is necessary for the former since it emphasizes important societal requirements, values, and obligations as its ultimate goals. In contrast, the latter depends on the former for technological breakthroughs and fixes [12]. Figure 8 shows the Industrial Revolution from its inception till date.

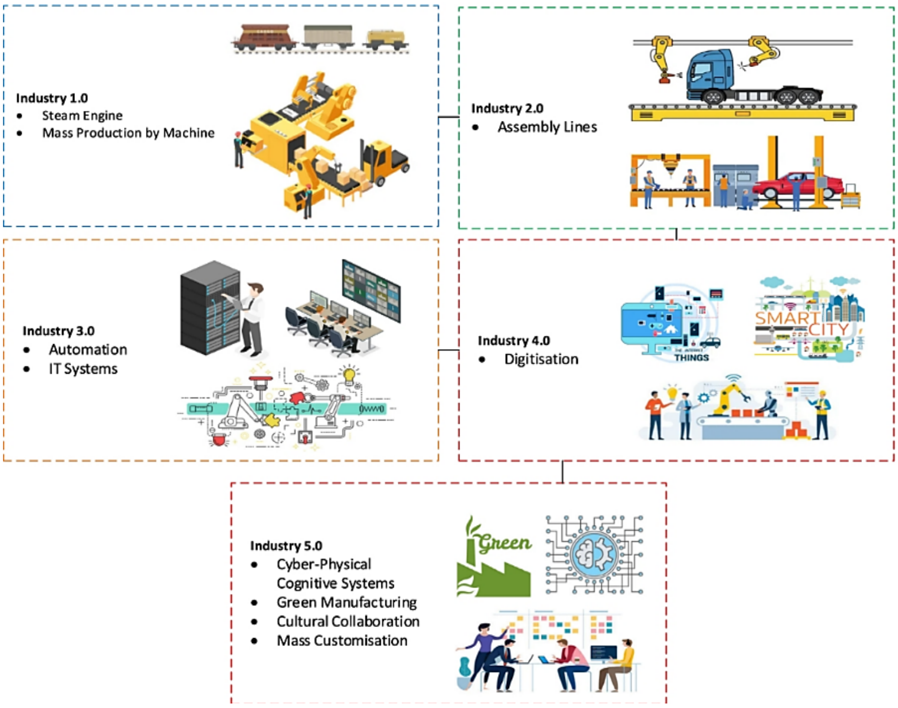

Figure 8. The industrial revolution from its inception till date [110]

The evolution of Industry 5.0 started in 2018, encompassing four main clusters. The first cluster highlights topics including Industry 4.0, manufacturing, personalization, digital transformation, society 5.0 vision, and sustainability. The second cluster investigates the future workplace, focusing on trends in supply chain resilience and human-machine collaboration (such as operator 4.0). The importance of digital twins is emphasized in the third cluster, particularly when it comes to mimicking, improving, and forecasting the behaviour of real things. Blockchain, IoT, augmented reality, 5G, and 6G are crucial technologies covered by the fourth and largest cluster [109]. Industry 5.0 emerged as Industry 4.0 started to receive acceptability from businesses and organizations. It is understood that the power of industry can be utilized as a resilient provider of prosperity by making the production process environmentally conscious, putting the well-being of industry workers at the centre, and, concomitantly, establishing the boundaries of our planet. Even though Industry 5.0 complements the existing Industry 4.0, its introduction is based on some observations that Industry 4.0 focuses more on efficiency and flexibility via AI-driven technologies and less on the original principles of social fairness and sustainability. The paradigm shift of Industry 5.0 focuses on the importance of research and innovation to support sustainability and planetary boundaries [10, 18]. Industry 5.0 leaves room for "smart working" [20], the "Age of Augmentation," where humans and machines reconcile and work in collaboration. Table 4 shows the comparison between Industry 4.0 and 5.0. Understanding how Industry 4.0 changed into Industry 5.0 was the main goal of the first cluster. Technology developments and human-machine interaction laid the groundwork for more socially focused digitalization clusters, such as customer experience. The succeeding clusters explored societal priorities for digital transformation, considering sustainability and retaining a technological foundation that developed from Industry 4.0 links to ideas like Operator 4.0 and Society 5.0.

Barata and Kayser [109] review covers various topics linked to Industry 5.0, including global problems, technical developments, education, and human-robot cooperation. Diverse viewpoints exist, with some emphasizing human-centric strategies for tackling global issues, such as fusing artificial intelligence with human-computer interfaces. The review focuses on technologically advanced approaches for sustainability objectives, such as data exchange and transportation efficiency. Industry 5.0 is examined as a paradigm shift towards individualized manufacturing that emphasizes human-machine cooperation. Technology security, worker adaptation, legal issues, and safety are all difficulties associated with Industry 4.0. The comparison of Industry 4.0 and 5.0 components demonstrates continuous technical development. Industry 5.0 debates include topics like customization, societal demands, and sustainable engineering, highlighting the significance of interoperability between Industry 4.0 and 5.0 ideas. Contrasting with Industry 4.0's technology-centric approach, Industry 5.0 promotes a future-focused, cross-sectoral approach. Industry 5.0 adopts a global viewpoint and prioritizes a customer- and, more importantly, a human-centric strategy. Industry 5.0 seeks to address broader environmental, energy, and social difficulties as opposed to Industry 4.0, which primarily concentrates on resolving manufacturing issues and increasing productivity using digital technologies [111]. This paradigm incorporates Industry 4.0's technology breakthroughs into a broader context outside factories. Industry 5.0 is value-driven rather than technology-driven, focusing on individualized products for customers and the collaboration of skilled human workers and robots. It positions Industry 5.0 as a paradigm change that merges industry and production to address global crises through a value-oriented approach. It sees humans as consumers and vital to solving global difficulties [112].

Table 4. Comparison between industry 4.0 and industry 5.0 [21, 110]

	Industry 4.0	Industry 5.0 (Vision 1)	Industry 5.0 (Vision 2)
Motto	Smart Manufacturing	Human-Robot Co-working	Bioeconomy
Motivation	Mass Production	Smart Society	Sustainability
Power Source	Electrical power Fossil-based fuels Renewable power sources	Electrical power Renewable power sources	Electrical power Renewable power sources
Involved Technologies	Cloud Computing Big Data Robotics and Artificial Intelligence	Human-Robot Collaboration Renewable Resources	Sustainable Agricultural Production Bionics Renewable Resources
Involved Research Areas	Organizational Research Process Improvement and Innovation Business Administration	Smart Environments Organizational Research Process Improvement and Innovation Business Administration	Agriculture Biology Waste Prevention Process Improvement and Innovation Business Administration Economy
Objective	Smart factory	Sustainability, human-centric, and resilient	
Motivation	Mass production	Smart society and sustainable development	
Human Factors	Human-computer interaction, monotonous movements	Employee protection and control, workforce learning and development	
Methodology	Real-time data surveillance, an interconnected network that accompanies all phases of the life cycle	The appropriate use of technology to improve human concerns and priorities, socio-centric technical decisions, the 6R methodology, and transportation efficiency design guidelines	
Enabling Technologies	Cloud technology, Internet of Things, big data and analytics, information security, and cyber-physical systems	Big data and analytics, cloud technology, the Internet of things, collaborative robots, digital security safety, support systems inspired by nature, decision-making systems, intelligent grids, servicing that is predicted, additive manufacturing, mixed reality	
Climate Inferences	Systems are cost-effective, waste is reduced through business intelligence, additive manufacturing, optimized systems, material consumption increased, power consumption increased, and the product’s life cycle has been expanded	Waste avoidance and regeneration, sources of sustainable power, data storage, transport, and analysis that use less energy, sensors that are smart and energy-efficient	

Industry 5.0 focuses on the interaction between people and machines, with intelligent devices linking them to advanced manufacturing facilities. This progression incorporates cutting-edge technologies, widespread customization, and a significant change in production methods. Through brain-machine interfaces and artificial intelligence, robots are now operating as partners as opposed to rivals. The next revolution, propelled by Industry 5.0, focuses on improving human-machine interactions using AI algorithms, resulting in better integration and more effective automation while utilizing human cognitive talents [113]. The shift from Industry 4.0 to Industry 5.0 aims to combine the strengths of humans and

machines, ultimately enhancing productivity and fostering interaction and collaboration between man and machine. Unlike earlier fears, robots will not take over manufacturing plants in Industry 5.0 [14, 114].

2.5.1 Core concepts of Industry 5.0

Industry 5.0 emphasizes precision, effectiveness, and reduced human effort through collaboration with robots, and it marks a substantial leap in production techniques. This shift is especially encouraging for industries like healthcare, where personalized technologies powered by AI are revolutionizing patient care. Predictive maintenance becomes essential for the maintenance of smart devices, assuring their effective operation and avoiding malfunctions. Industry 5.0's central tenet of sustainability emphasizes adopting eco-friendly techniques, local production, and waste reduction. Collaborative robots handle tedious chores, freeing human workers to focus on innovation and efficiency. Human-centricity is a significant focus [115]. Smart sensors improve environmental control by offering in-the-moment information on weather, energy use, and other factors that help organizations avoid losses and increase productivity. Smart machines and automation forecast production efficiency, allowing adjustments to optimize operations and prevent losses. Industry 5.0 encourages employees to use technology to produce creative concepts and individualized products that efficiently satisfy customer requests. The core values of Industry 5.0 are shown in Figure 9.

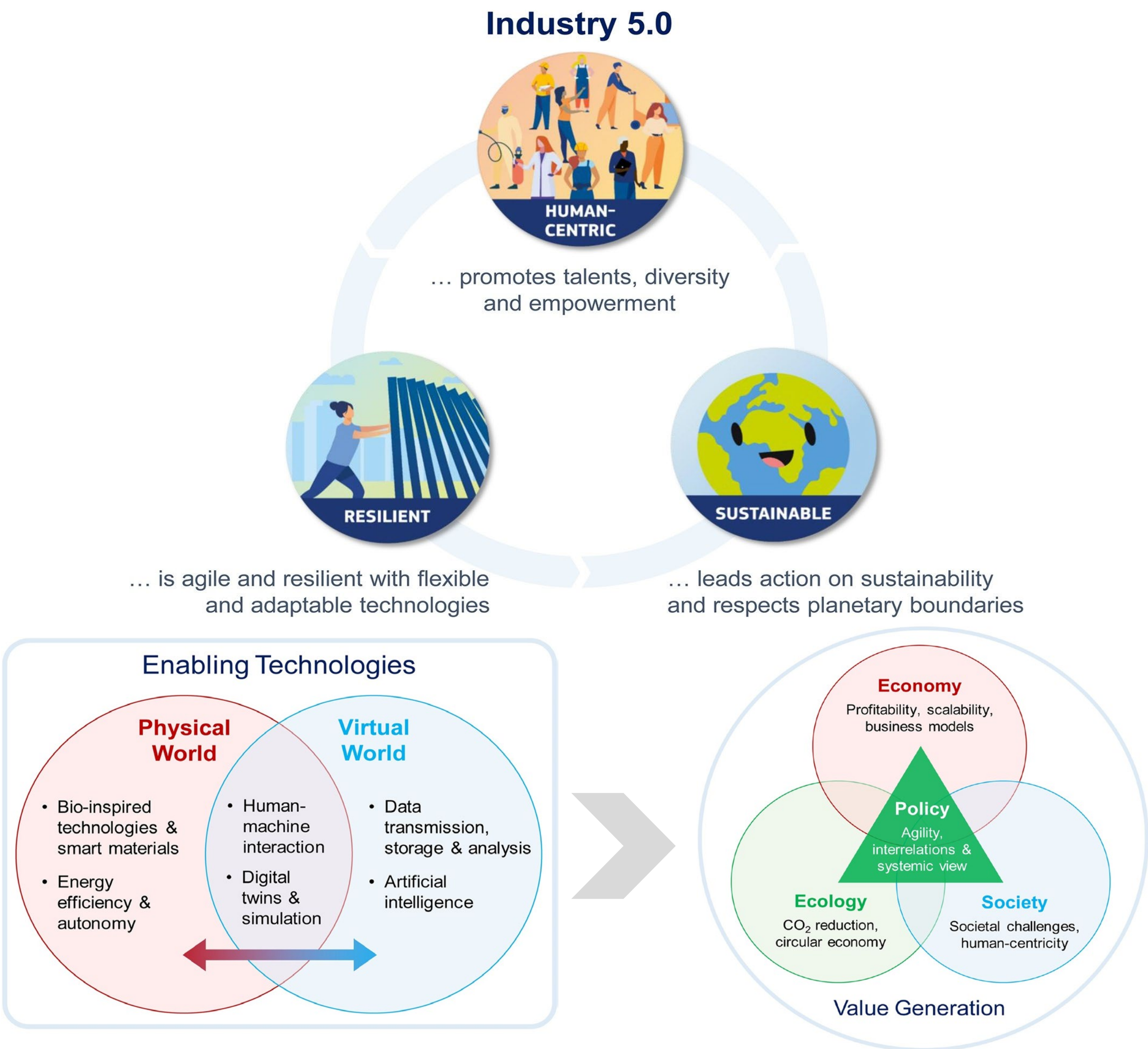

Figure 9. The core values of Industry 5.0 [12]

2.5.2 Industry 5.0 technologies

Industry 5.0 technologies focus on integrating human creativity and collaboration with advanced robotics and artificial intelligence to create more personalized and efficient manufacturing processes, as seen in Table 5, which explains these industry 5.0 technologies.

Table 5. Industry 5.0 technologies [110, 113]

No	Technology	Description
1	Cloud computing	Various computer services, including databases, software, analytics, and networks, are made available through the Internet as part of cloud computing. It makes managing and storing data on distant computers possible, offering on-demand resources like processing power and apps. The industrial cloud is a virtual environment that supports industry-specific applications, particularly IoT monitoring, in the industrial setting. Cloud providers create applications like IoT monitoring tools for mobile and web consumption to facilitate data standardization from many sources via APIs. Edge computing devices manage data analytics and enable business analyses with constrained resources. Scalable edge device infrastructure is provided by cloud computing, allowing for the management of various robot types and autonomous robots on manufacturing floors. Cloud computing in Industry 5.0 minimizes the amount of data transported to centralized servers, facilitating local data access. It also enables preventive data analysis, making finding machine issues easier and fixing them with a larger workforce.
2	Blockchain Technology	Manufacturers rapidly use blockchain technology to maximize investments, improve supply chain transparency, and streamline operations. By facilitating effective collaboration both within and across rival enterprises, this cutting-edge technology has the potential to transform how manufacturing companies conduct business entirely. The possibility for manufacturers to pioneer blockchain technology is second only to that of the financial industry. By automating transactions and payments, integrating blockchain with financial processes can significantly increase efficiency. Blockchain, cloud computing, and IoT sensors provide unmatched access and productivity throughout the value chain. Intelligent contracts eliminate manual intervention in the instantaneous execution of tasks and transactions related to tangible goods in logistics and transportation.
3	Unmanned Aerial Vehicle	The IoT and unmanned aerial vehicles (UAVs) are two examples of technologies integrated into Industry 5.0 to increase industrial intelligence and connectivity. UAVs, which have historically been employed in military and civilian applications, have great promise for advanced manufacturing since they enable real-time monitoring, wireless visibility, and environmental surveillance. UAVs serve as effective IoT devices that efficiently collect data, address problems before they arise, and help people make well-informed decisions. UAVs speed up industrial development by establishing long-distance communication links between diverse production units. UAV technology improves manufacturing efficiency with intelligent city and IoT applications, advancing Industry 5.0. With autonomous capabilities and Wi-Fi components, UAVs may gather and send sensory data to cloud servers, boosting their applicability in Industry 5.0 projects, public transportation, and pervasive computing.
4	5G and Beyond Wireless Technology	The next generation of communication networks, 6G, referred to as "Beyond 5G," prioritizes interpersonal interactions and content negotiation over technical developments. 6G, in contrast to earlier generations, intends to facilitate communication between gadgets, objects, and almost everything. Advanced testing techniques, wireless internet connectivity, Internet of Everything technologies, high-resolution real-time digital communications, and applications are key priorities in 6G research. It is essential in various industries, including telemedicine and autonomous mobility. Research focuses on the development of Industry 5.0, intelligent urban planning, and industrial technology systems. Maintaining the security of personal data is still a significant problem, emphasizing the responsibilities of developing this technology.
5	Exoskeleton Technology	Exoskeletons, cutting-edge wearable technology made for body parts like the hands and shoulders, are being employed more frequently in manufacturing to improve worker productivity and lower the incidence of musculoskeletal problems. Handling tools and materials requires less physical effort thanks to these technologies. Forecasts for the market indicate strong growth, with 274 million units shipped and USD 3.4 billion in revenue anticipated by 2030. Exoskeleton adoption is highest in the manufacturing sector, followed by the energy/utilities and oil/gas industries, demonstrating the technology's potential to transform several industries.
6	Collaborative robots	Industry 5.0 stresses individualized manufacturing above Industry 4.0's concentration on automation and data collecting by combining the special talents of skilled workers with robots. With an emphasis on human contributions and craftsmanship, this method reshapes the interaction between humans and machines in production. Industry 5.0 also includes the IoT, which uses sensors and software to connect physical items and devices. IoT makes efficient data interchange possible, increasing automation and organizational effectiveness. IoT implementation, nevertheless, poses questions about data security, access management, and authentication. Solutions like authentication schemes and access control strategies are essential to handle security concerns and assure authenticity, secrecy, and end-to-end latency management in IoT-based applications. Industry 5.0 delivers dynamic security measures for cloud platforms and data-centric applications in the context of the Internet of Things.

Table 5. (cont.)

No	Technology	Description
7	Big data analytics	Industry 5.0 uses cutting-edge technology, such as 3D symmetry and big data analytics, which examines enormous and varied datasets to elucidate hidden patterns and market trends. This strategy increases business competitiveness by delivering real-time data for strategic decision-making, addressing customer preferences, and enhancing the customer experience. The deployment of big data analytics faces difficulties in Industry 5.0; nevertheless, thorough data is not obtained throughout the manufacturing cycle.
8	Blockchain	Transaction data is maintained in blocks on a digital ledger using decentralized and distributed blockchain technology. This shared ledger makes asset monitoring and transparent, secure transaction recording possible inside a business network. Blockchain technology improves customer experience by enabling the tracking of orders, payments, and manufacturing processes by delivering immutable and shared information. The blockchain stores smart contracts that specify special company conditions and ensure the automatic execution of transactions. The system's irreversible chains and verification procedure increase data accuracy while eradicating time wastage caused by network users sharing information.
9	Mixed Reality	Through head-mounted see-through glasses, mixed reality (MR) combines the physical and digital worlds to create dynamic settings where digital and physical items coexist and communicate in real-time. In contrast to augmented reality (AR), mixed reality offers a more complex understanding of the actual area and can insert holographic pictures there. Deep learning algorithms are used in MR, often called hybrid reality or extended reality, to link specific locations in the actual world to digital information. Thanks to this technology, users can interact with digital content as if it were physical, enabling digital objects to interact with real-world objects. MR is used in various industries, as well as in training, education, and repair situations. For instance, by projecting holographic pictures of airplane parts, airline businesses employ MR to train repair specialists and enable hands-on contact without requiring actual disassembly. Although the processing demands of MR initially made it expensive, developments in technologies like big data, cloud computing, and artificial intelligence are lowering the cost of MR. MR is anticipated to profoundly transform how people engage with digital material as costs come down, revolutionizing human-computer interaction.
10	Additive Manufacturing	A key component of Industry 5.0 is additive manufacturing, often known as 3D printing, because it has the potential to produce less waste than subtractive techniques. In contrast to subtractive manufacturing, which involves removing material from a solid block of material, it consists of building objects layer by layer. An idea is typically designed using computer-aided software or scanning existing things, though additive manufacturing procedures can differ. The design is then converted into layers, which a 3D printer builds. This approach is promising for Industry 5.0 and dramatically decreases waste, coinciding with the objective of sustainable and effective production methods.
11	AI-Based IoT	The IoT, where numerous objects interact and work together, is replacing the "Internet of Computers". Wireless sensing networks are becoming more common, particularly in healthcare and weather forecasting industries. The IoT includes gadgets like RFID readers, sensors, and actuators that collaborate and communicate utilizing special addressing techniques. In the IoT context, artificial intelligence is essential for enabling intelligent online communication and creating evolving robotic systems. These developments are changing people's lives and interactions around the world.
12	Motion Capture Technology (Mo-Cap or Mocap)	Advanced sensing technologies, notably motion capture systems like optical cameras and inertial measurement units, enable Industry 5.0 to drive inventive industrial processes. These technologies allow teleworking, robotics, additive manufacturing, and consumer safety and are widely used in industrial applications. Motion capture, frequently used in entertainment and filmmaking, includes recording the movements of people or objects. A 3D computer model that faithfully imitates human motions can be created by capturing more complex patterns, such as face and fingertip movements, which is essential for many applications in Industry 5.0.
13	Digital Twin Technology	By improving the efficiency and performance of the manufacturing cycle, digital twins are essential to Industry 5.0. These digital representations of actual things or procedures imitate their physical counterparts and allow for the collection of useful information for product development and manufacturing processes. Digital twins forecast how processes will behave and can represent various entities, including entire cities and combat jets. They are software programs that use real-time data to imitate objects or processes in the real world and can combine software analytics, artificial intelligence, and IoT to enhance performance. The industrial revolution's limits have been overcome by digital twin technology and other innovations like augmented reality and machine learning, which have changed industrial production.

2.5.3 Challenges for Adopting Industry 5.0

Industry 5.0 poses substantial obstacles that must be overcome for its deployment due to its cutting-edge technology and collaborative approach between humans and machines:

i) Employee skill development is necessary for productive collaboration with sophisticated robotics and intelligent technology. This encompasses hard skills linked to cooperation and communication with smart technology and soft skills connected to technical skills, such as programming industrial robots.

ii) Adoption of Technology: Putting Industry 5.0 into practice will need a lot of time and effort from employees. Intensive adoption and integration efforts are required since collaborative robots, artificial intelligence, real-time data use, and IoT connectivity are key components.

iii) Money investments: Industry 5.0 technologies are expensive. The development of collaborative robots and other intelligent machines is a costly endeavor. The cost strain is increased further by the need to train the workers for these new tasks. Updating production lines to meet Industry 5.0 criteria can be prohibitive for a business.

iv) Security issues: Building confidence in Industry 5.0 ecosystems is essential. Authentication techniques must be strong for interactions with different devices to be secure. Additionally, the use of automation and artificial intelligence creates new security risks. Applications for Industry 5.0, especially those utilizing ICT systems, require rigorous security measures to prevent potential problems and guarantee data integrity and confidentiality.

3. HUMAN-ROBOT COLLABORATION IN MANUFACTURING INDUSTRY

The human-robot collaboration plays a crucial role in Industry 4.0. In human-robot collaboration, the human operators are assisted by robots in carrying out some tasks and duties, mostly certain tedious tasks like lifting heavy loads and putting heavy parts from one place to another. The collaboration aims to combine the skills of humans and machines to achieve more precise and accurate output. Many futuristic studies [12, 116] suggest that the future of manufacturing and production industries is in human-machine partnerships. The main advantages of human-robot collaboration are fewer risks, production flexibility, and high-quality performance, as seen in Figure 10, which shows human-machine collaboration in smart factories. A methodology for human-robot collaborative production is developed by utilizing sensor technology and three components of gesture recognition, including gesture identification, tracking, and categorization [117].

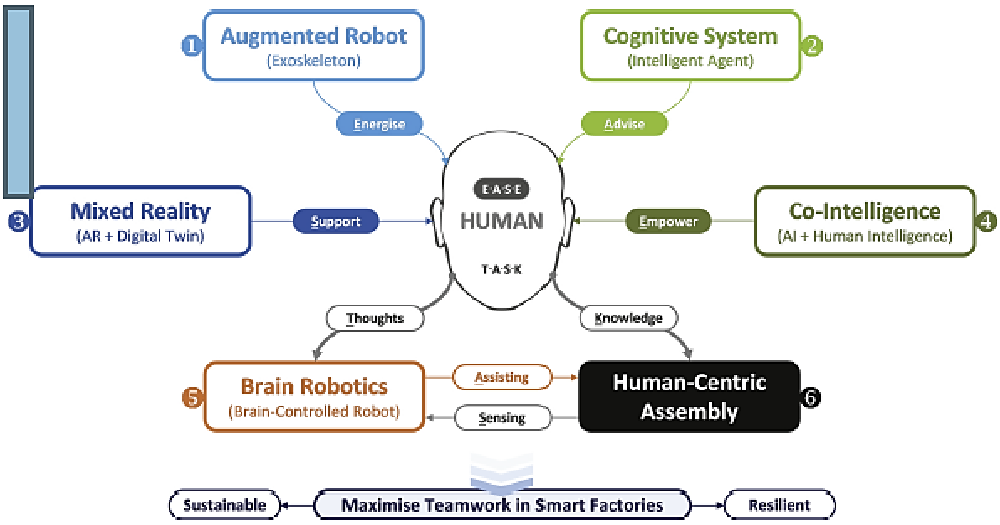

Figure 10. Human-machine collaboration in smart factories [116]

A collaborative robot (Cobot) is a robot that can learn new skills and assist people in various capacities. Additionally, the primary objective of these cobots is to collaborate with humans in the production or creation of items. Collaborative robotics, combined with AI and machine learning, produces a super-intelligent system that is critical for the operation of industrial robots. Prominent worldwide robotics firms such as FANUC and KUKA produce collaborative robots capable of operating alongside humans; thus, the collaborative features of cobots set them apart from conventional robots. Furthermore, cobots' adaptability allows for integrating additional functionalities using AI and machine learning, whereas conventional robots require significant programming to incorporate new capabilities. Examples of these collaborative robots include the KUKA LBR, which can execute many flexible jobs utilizing mobile platforms. The KUKA LBR employs advanced technology and high-performance sensors, offering manufacturing solutions. Engineers at a BMW manufacturing facility in South Carolina recently identified a method for outfitting a lightweight collaborative robot with a door panel to aid in the lifting of doors for assembly. There are four primary categories of collaborative robots. They are classified according to their programming attributes and safety measures. These cobots are categorized based on their ability to provide abstraction to human operators when faced with a potentially hazardous activity. Consequently, they are most suitable for various settings. KUKA, Franka, and Rethink Robotics are the primary collaborative robots utilized by manufacturers. Collaborative robots are used extensively in the manufacturing sector and healthcare.

3.1 The Major Types of Collaborative Robots

The four types of collaborative robots according to ISO 10218 part 1 and part 2 include:

i) Safety Monitored Stop Cobots are designed for applications that require minimal human interaction with the robots. Ideally, these cobots utilize traditional industrial robots combined with sensors that stop robotic operation when a human enters the work environment.

ii) Speed and Separation Cobots are similar to safety-monitored stop cobots. However, it utilizes more advanced vision systems that enable cobots to identify human workers and slow down their operation. The work environment usually consists of two zones: the warning zone and the stop zone. The cobot slows down its operation when it detects the entry of a human in the warning zone, and it stops its operation immediately when a human enters the stop zone

iii) Power and Force Limiting Cobots are designed with intelligent collision censors and are built without sharp corners, exposed motor or pinch points; instead, they have rounded corners. The function of the intelligent collision sensor is to quickly detect any contact with a human worker and stop its operation. The force limitation feature ensures no injury is sustained in case of any collision.

iv) Hand Guiding Cobots has a feature that enables the operator to easily re-programme it to carry out another operation by guiding it with a hand-operated device. This attribute allows quick reprogramming with limited downtime and reduces the requirement for specialized robotic programmers.

With the adoption of these cobots in Industry 4.0 and concurrently in the smart factory of Industry 5.0, manufacturers will introduce new products and services, enabling them to create new jobs to meet higher demand, yielding maximum growth in the existing markets. Data collection, digitization, and automation are the key principles of Industry 4.0 [118]. This principle can assist manufacturers in improving efficiency, streamlining costs, and ensuring a better and quality customer experience. Experts predict that human-machine collaboration will revolutionize the manufacturing industry. Previously, the automotive industry used cobots to avoid repetitive tasks; today, they perform various tasks. A recent study demonstrates Bosch's integration of Cobots in machine assembly [119]. In addition, the Hitachi manufacturing industry employs intelligent bosses and robotic warehouse workers to handle goods, programming these cobots to provide instructions to human workers within the work environment. The company reports a significant 8% increase in warehouse productivity compared to solely human-run warehouses [120], and they aim to expand the collaboration between humans and machines. Similarly, Amazon utilizes autonomous warehouse cobots to deliver items directly to human packing boxes. These intelligent bosses can monitor and evaluate the daily work of a shop floor worker and the efficiency by which they tackle and provide solutions to these problems; they also can modify their work order by studying the changing work environment and responding appropriately to these changes. Like Amazon, Loreal Company uses machine learning techniques and Radio-Frequency Identification (RFID) to signal an alarm when human workers reach too close to a vehicle [121].

3.2 Major Sectors of Application of Cobots

The fifth industrial revolution will see an added standard of living with increased economic activities. It is projected the potential for humans and machines to collaborate will be explored and utilized efficiently. Autonomous cobots are best suited for manufacturing industries, whereas, in a consumer-driven world, the value added within a shorter period is the main aim of the utilization of cobots. The potential applications of cobots in Industry 5.0 include:

i) *Manufacturing Industry*: Automation provides a solution to the recent challenges faced by the manufacturing industry, which include a shortage of skills and high labor costs. Cobots can perform hazardous tasks, such as heavy lifting and other physically demanding tasks. A cobot, for instance, can lift the interior-finishing elements of a car. Researchers predict the globalization of smart factories, where machines will likely take over dangerous and physically difficult tasks for humans, such as installing hybrid batteries that weigh more than 100 kilograms [122]. Cobots in a smart factory would monitor and control all physical processes in real-time. Additionally, vision systems use robot-based inspection systems to identify flaws in various parts and ensure accurate assembly.

ii) *Autonomous Vehicles*: The rise in road accidents due to population growth has prompted using automated guided vehicles (AGVs). The concern over reducing the number of accidents has led many industries, including manufacturing, agriculture, mining, logistics, and transportation, to adopt automated guided vehicles (AGVs) [123]. Presently, warehouses are using these AGVs to transport materials. In the industry, 5.0 AGVs are likely to shift from automation to intelligence. Using laser navigation, the latest technologies, and Wi-Fi, an AGV manufacturer created an intelligent parking robot to lift and part a car in 120 seconds.

iii) *Health Care*: The manufacturing sector uses robots to compound drugs, a cost-effective approach that enhances operator safety and quality. An example is the use of these cobots in an aseptic fill, where high accuracy is required, and human error can ruin an expensive batch of drugs. Robots can work efficiently with harmful chemicals and in environments that are hazardous to humans [124]. Other healthcare sectors employ cobots for surgical support and tele-assistance [125].

iv) *Mining*: The mining industry also employs robotics and current technologies, such as robot-operated drills, to drill deeper into the earth. They also gather precise data within the mine: drones and autonomous vehicles access oil and gas lines in disputable areas. Schlumberger uses autonomous vehicles to inspect sub-sea level conditions, conducting assessments without local team support. Similarly, autonomous ROVs, which are self-powered and self-driving vehicles, replace submersible ROVs that require support and control signals from the mother ship [126].

v) *Agriculture*: Self-driving tractors that give information on the soil condition and how to maintain planted crops.

3.3 Advantages of the Application of Cobots

Collaborative robots or cobots offer several distinct advantages in industrial and manufacturing processes. First, cobots help reduce production costs by increasing production speed and minimizing time wastage, improving overall efficiency. Second, their high level of accuracy reduces waste, leading to significant cost savings in material usage. Additionally, cobots enhance reliability and quality by performing repetitive tasks precisely, which is particularly beneficial in producing bulk items requiring consistent processes and specifications. Safety is another critical advantage, as cobots can handle dangerous tasks that pose risks to human workers. Finally, cobots are versatile and capable of performing multiple applications simultaneously, further enhancing productivity and operational flexibility in industrial environments.

4. FUTURE DIRECTIONS

There are difficulties in Industry 5.0, but there is also great potential. By anticipating breakdowns and enabling targeted repairs without interrupting ongoing operations, predictive maintenance, made possible by smart sensors and IoT devices, improves maintenance tactics. Human-machine collaboration makes it possible to use resources more effectively, eliminating waste, boosting local economies, and creating jobs. A key component of Industry 5.0 is empowering human workers so they may concentrate on creativity and invention while collaborative robots handle dangerous and repetitive duties [127-128]. Real-time climate monitoring in agriculture and other smart solutions allow for informed decision-making, lowering costs and boosting output. By incorporating human-like thinking into digital models, cognitive computing increases system adaptability. The emphasis on human-machine interaction ensures that people remain at the heart of operations by utilizing natural interfaces like gestures. Industry 5.0 also investigates quantum computing, which has significant opportunities for advanced problem-solving and sophisticated calculations. These developments highlight the revolutionary potential of Industry 5.0 despite obstacles [129]. Notably, Industry 5.0 has significant challenges such as integration, high implementation costs and skills gap, and policy and social heterogeneity issues, hence the need for Industry 6.0 [130]. Industry 6.0 envisions a future where human creativity is seamlessly integrated with advanced digital technologies to revolutionize manufacturing. The goal of the upcoming industrial revolution is to establish a workplace where people and machines work together, with people using their brainpower to operate machines with the help of cutting-edge technology directly. The foundation of Industry 6.0 is antifragility, sustainability, resilience, and harmony with the environment. Manufacturing will differ from previous revolutions because it will be flexible and user-oriented thanks to digital twins, quantum computing, and robots. It is a development of Industry 4.0 and 5.0, which were more concerned with automation and intelligent manufacturing than sophisticated integration, as promised by Industry 6.0 [131-132].

The COVID-19 epidemic has brought to light the necessity for industries to reconsider their approaches to manufacturing, supply networks, and consumer relations. Industry 6.0 will tackle these issues by emphasizing flexible, eco-friendly, and customer-centric production techniques. It will bring breakthroughs like robotics to guarantee patient safety, quantum computing to handle intricate problems, and 3D printing for medical purposes. Industry 6.0 seeks to develop strong, sustainable solutions that emphasize resilience against global crises like climate change and economic instability by embracing antifragile manufacturing systems that adapt and become more robust in the face of disturbances [133-134]. Industry 6.0 adoption has potential but also confronts several obstacles, such as high prices, digital transformation, and the requirement to reskill the workforce. Governments, companies, and other stakeholders must sustain and commit to integrating these cutting-edge technologies to drive the change. Industry 6.0 aims to improve human capacities and generate new possibilities by creating more employment than is lost, despite concerns about job loss due to automation. With a focus on virtualized services, dynamic value networks, and hyper-connected sectors, it presents a new age of manufacturing that prioritizes human creativity while tackling social and environmental issues.

5. CONCLUSIONS

The Industrial Revolution was highly dependent on available and needed materials by every generation. Hence, this review has considered the trends in human-machine interaction while dealing with these materials. Though the strong emphasis was not on materials, manufacturing processes must deal with materials to develop products. Thus, materials have also influenced these transitions over these decades. The transition towards Industry 6.0 signifies a significant evolution in manufacturing, marked by seamless collaboration between humans and intelligent machines. This transformative journey is driven by intelligent automation, devices, and systems facilitated by Artificial Intelligence and the Internet of Things. Industry 5.0 represents a shift towards human-centred manufacturing, where collaborative robots enhance efficiency and flexibility in shared work environments. Embracing this evolution offers manufacturers the potential for enhanced operational efficiency and customer satisfaction through bespoke products. Human-machine collaboration emerges as a cornerstone of future successes, unlocking innovation, productivity, and sustainability within the manufacturing sector. Industry 5.0 heralds For Peer Review an era of revolutionary transformations, blurring the boundaries between human ingenuity and machine intelligence. With Industry 6.0, there are many opportunities to create more effective, enduring, and interconnected manufacturing landscapes.

ACKNOWLEDGEMENT

The authors wish to acknowledge the management of the Federal University of Technology Akure, Nigeria, for providing the facilities for collating the information and other resources for this paper.

CONFLICT OF INTEREST

The authors declare no conflicts of interest

AUTHOR CONTRIBUTIONS

I. O. Oladele (Supervision, Project Administration, Methodology, conceptualization)
C. J. Okoro (Investigation, Writing-original draft)
S. O. Falana (Investigation, Writing - review & editing)
F. O. Olajesu (Writing-original draft, Data curation, conceptualization)
S. O. Adelani S.O (Data curation, Writing-original draft, conceptualization)
L. N. Onuh (Investigation, Writing-original draft)

AVAILABILITY OF DATA AND MATERIALS

The data supporting this study's findings are available on request from the corresponding author.

ETHICAL STATEMENT

Not Applicable

REFERENCES

[1] S. O. Falana, D. O. Folorunso, I. O. Oladele, G. Mogbojuri, L. N. Onuh, "Comparative effect of woodflour and granulated rice husk on the thermal insulation of termite hill clay," *Journal of Chemical Technology and Metallurgy*, vol. 59, no. 5, pp. 1093-1102, 2024.

[2] I. O. Oladele, A. D. Akinwekomi, J. G. Akinseye, S. O. Falana, S. R. Oke, "Evolution of bamboo derivative fiber-mollusk shell based calcite particulate hybrid reinforced epoxy bio-composites for sustainable applications," *Journal of Composite Materials*, vol. 58, no. 24, pp. 2597–2622, 2024.

[3] H. T. Owoyemi, B. O. Adewuyi, I. O. Oladele, S. O. Falana, S. A. Oyegunna, J. O. Ajileye, "Silver nanoparticles reinforced polyethersulfone composite for sustainable application," *Discover Polymers*, vol. 1, no. 4, pp. 1-21, 2024.

[4] I. O. Oladele, S. O. Adelani, B. A. Makinde-Isola, T. F. Omotosho, "Coconut/coir fibers, their composites and applications," in *The Textile Institute Book Series - Plant Fibers, their Composites, and Applications*, pp. 181-208, 2022

[5] F. O. Olajesu, I. O. Oladele, T. F. Omotosho, F. A. Atilola, S. O. Adelani, "Influence of quartz and marble on the performance of particulate-filled rigid polyurethane foams," *Journal of Engineering and Technology*, vol. 6, no. 1, pp. 8-25, 2024

[6] S. O. Adelani, I. O. Oladele I. Akinbamiyorin, A. Oyetunji, F.O. Olajesu, "Development of hybrid plantain fiber-calcite particles reinforced polyvinyl chloride biocomposites for automotive applications," *Journal of Thermoplastic Composite Materials*, vol. 37, no. 6, pp. 1938-1956, 2024.

[7] B. A. Makinde-Isola, A. S. Taiwo, I. O. Oladele, A. D. Akinwekomi, S. O. Adelani, L. N. Onuh, "Development of sustainable and biodegradable materials: A review on banana and sisal fibre based polymer composites," *Journal of Thermoplastics Composite Materials*, vol. 37, no. 4, pp. 1519-1539, 2024

[8] I. O. Oladele, T. F. Omotosho, G. S. Ogunwande, F. A. Owa, "A review on the philosophies for the advancement of polymer-based composites: Past, present and future perspective," *Applied Science and Engineering Progress*, vol. 2021, pp. 1-27, 2021.

[9] K. A. Demir, G. Döven, B. Sezen, "Industry 5.0 and human-robot co-working," *Procedia Computer Science*, vol. 158, pp. 688–695, 2019.

[10] F. Longo, A. Padovano, S. Umbrello, "Value-oriented and ethical technology engineering in Industry 5.0: A human-centric perspective for the design of the factory of the future," *Applied Sciences*, vol. 10, no. 12, p. 4182, 2020.

[11] S. Nahavandi, "Industry 5.0: A Human-centric solution," *Sustainability*, vol.11, no. 16, p. 4371, 2019.

[12] X. Xu, Y. Lu, B. Vogel-Heuser, L. Wang, "Industry 4.0 and Industry 5.0-Inception, conception and perception," *Journal of Manufacturing Systems*, vol. 61, pp. 530–535, 2021.

[13] Y. Lu, H. Zheng, S. Chand, W. Xia, Z. Liu, X. Xu, et al., "Outlook on human-centric manufacturing towards Industry 5.0," *Journal of Manufacturing Systems*, vol. 62, pp. 612–627, 2022.

[14] J. Vrana, R. Singh, "NDE 4.0—A design thinking perspective," *Journal of Nondestructive Evaluation*, vol. 40, no. 8, pp. 1-24, 2021.

[15] M. Javaid, A. Haleem, R. P. Singh, R. Suman, "An integrated outlook of cyber-physical systems for Industry 4.0: Topical practices, architecture, and applications," *Green Technologies and Sustainability*, vol. 1 no. 1, p. 100001, 2023.

[16] M. Golovianko, V. Terziyan, V. Branytskyi, D. Malyk, "Industry 4.0 vs. Industry 5.0: Co-existence, transition, or a hybrid", *Procedia Computer Science*, vol. 217, pp. 102–113, 2023.

[17] S. Grabowska, S. Saniuk, B. Gajdzik, "Industry 5.0: Improving humanization and sustainability of Industry 4.0," *Scientometrics*, vol. 127, no. 6, pp. 3117–3144, 2022.

[18] R. J. Duszak, "What will the radiologist's job description look like in a decade?" AC Medizin, 2024. [Online]. Available: https://acrbulletin.org/acr-bulletin-june-2016/492-technology-informatics-appropriateness

[19] M. Breque, L. De Nul, A. Petridis, "Industry 5.0: Towards a sustainable, human-centric and resilient European industry," *Publications Office of the European Union*: *Policy Brief*, 2021.

[20] Plattform Industrie 4.0, "What is platform Industrie 4.0?," Federal Ministry for Economic Affairs and Climate Action – Federal Ministry of Education and Research, 2023. [Online]. Avaialable: https://www.plattform-i40.de.

[21] P. M. Bednar, C. Welch "Socio-technical perspectives on smart working: creating meaningful and sustainable systems," *Information System Frontier*, vol. 22, pp. 281–298, 2020.

[22] A. Kadir, G. Demira, S. Bülent, "Industry 5.0 and human-robot Co-working," *Procedia Computer Science*, vol. 158, pp. 688–695, 2019.

[23] F. Maurizio, C. Yuval, "Intelligent cobot systems: Human-cobot collaboration in manufacturing," *Journal of Intelligent Manufacturing*, vol. 35, pp. 1905-1907, 2023.

[24] R. Duszak Jr, "What will the radiologist's job description look like in a decade? AC Medizin, 2024. [Online]. Available: https://acrbulletin.org/acr-bulletin-june-2016/492-technology-informatics-appropriateness

[25] L. Cannavacciuolo, G. Ferraro, C. Ponsiglione, S. Primario, I. Quinto, "Technological innovation-enabling industry 4.0 paradigm: A systematic literature review," *Technovation*, vol. 124, p. 102733, 2023.

[26] L. L. Har, U. K. Rashid, L. Chuan, Te, S. C. Sen, L. Y. Xia, "Revolution of retail industry: From perspective of retail 1.0 to 4.0," *Procedia Computer Science*, vol. 200, pp. 1615–162, 2022.

[27] A. Haleem, M. Javaid, R. P. Singh, "Perspective of leadership 4.0 in the era of fourth industrial revolution: A comprehensive view," *Journal of Industrial Safety*, vol. 1, no. 1, p. 100006, 2024.

[28] M. Javaid, A. Haleem, R. P. Singh, R. Suman, "An integrated outlook of cyber-physical systems for Industry 4.0: Topical practices, architecture, and applications," *Green Technologies and Sustainability*, vol. 1, no. 1, p. 100001, 2023.

[29] B. Rana, S. S. Rathore, "Industry 4.0 – Applications, challenges and opportunities in industries and academia: A review," *Materials Today: Proceedings*, vol. 79, pp. 389–394, 2023.

[30] A. Rashid, M. A. K. Kausik, "AI revolutionizing industries worldwide: A comprehensive overview of its diverse applications," *Hybrid Advances*, vol. 7, p. 100277, 2024.

[31] J. Zhou, P. Li, Y. Zhou, B. Wang, J. Zang, L. Meng, "Toward new-generation intelligent manufacturing," *Engineering*, vol. 4, no. 1, pp. 11–20, 2018.

[32] A. Raja Santhi, P. Muthuswamy, "Industry 5.0 or industry 4.0 - Introduction to Industry 4.0 and a peek into the prospective Industry 5.0 technologies," in *International Journal on Interactive Design and Manufacturing (IJIDM)*, vol. 17, no. 2, pp. 947–979, 2023.

[33] M. Elahi, S. O. Afolaranmi, J. L. Martinez Lastra, J. A. Perez Garcia, "A comprehensive literature review of the applications of AI techniques through the lifecycle of industrial equipment," *Discover Artificial Intelligence*, vol. 3, no. 43, pp. 1-78, 2023.

[34] M. Ghobakhloo, M. Iranmanesh, M. F. Mubarak, M. Mubarik, A. Rejeb, M. Nilashi, "Identifying industry 5.0 contributions to sustainable development: A strategy roadmap for delivering sustainability values," *Sustainable Production and Consumption*, vol. 33, pp. 716–737, 2022.

[35] S. Grabowska, S. Saniuk, B. Gajdzik, “Industry 5.0: improving humanization and sustainability of Industry 4.0,” *Scientometrics*, vol. 127, no. 6, pp. 3117–3144, 2022.

[36] G. Narkhede, S. Chinchanikar, R. Narkhede, T. Chaudhari, “Role of Industry 5.0 for driving sustainability in the manufacturing sector: an emerging research agenda,” *Journal of Strategy and Management*, vol. 17, no. 1, pp. 1-27, 2024.

[37] R. Rame, P. Purwanto, S. Sudarno, “Industry 5.0 and sustainability: An overview of emerging trends and challenges for a green future,” *Innovation and Green Development*, vol. 3, no. 4, p. 100173, 2024.

[38] A. Villar, S. Paladini, O. Buckley, “Towards supply chain 5.0: Redesigning supply chains as resilient, sustainable, and human-centric systems in a post-pandemic world,” *Operations Research Forum*, vol. 4, no. 60, pp. 1-46, 2023.

[39] S. Paul, M. Riffat, A. Yasir, M. N. Mahim, B. Y. Sharnali, I. T. Naheen, et al., “Industry 4.0 applications for medical/healthcare services,” *Journal of Sensor and Actuator Networks*, vol. 10, no. 3, p. 43, 2021.

[40] A. Malm, “The origins of fossil capital: From water to steam in the British cotton industry,” *Historical Materialism*, vol. 21, no. 1, pp. 15–68, 2013.

[41] H. Lasi, P. Fettke, H. G. Kemper, T. Feld, M. Hoffmann, “Industry 4.0,” *Business & Information Systems Engineering*, vol. 6, no. 4, pp. 239–242, 2014.

[42] J. Styles, “The rise and fall of the spinning jenny: Domestic mechanisation in eighteenth-century cotton spinning,” *Textile History*, vol. 51, no. 2, pp. 195–236, 2020.

[43] D. Satterthwaite, G. McGranahan, C. Tacoli, “Urbanization and its implications for food and farming,” *Philosophical Transactions of the Royal Society B: Biological Sciences*, vol. 365, no. 1554, pp. 2809–2820, 2010.

[44] J. Wan, Q. Wang, S. Miao, “The impact of urbanization on industrial transformation and upgrading: Evidence from early 20th century China,” *Sustainability*, vol. 16, no. 11, p. 4720, 2024.

[45] O. Bongomin, A. Yemane, B. Kembabazi, C. Malanda, M. Chikonkolo Mwape, N. Sheron Mpofu, et al., “Industry 4.0 disruption and its neologisms in major industrial sectors: A state of the art,” *Journal of Engineering*, vol. 2020, pp. 1–45, 2020.

[46] P. N. Stearns. The Industrial Revolution in World History. 5th Eds. New York: Routledge Taylor & Francis Group, 2018.

[47] A. Arora, S. Belenzon, A. Patacconi, J. Suh, “The changing structure of American innovation: Some cautionary remarks for economic growth,” *Innovation Policy and the Economy*, vol. 20, no. 1, pp. 39–93, 2020.

[48] M. Beckley, “Economic development and military effectiveness,” *Journal of Strategic Studies*, vol. 33, no. 1, pp. 43–79, 2010.

[49] A. Radfar, S. A. Asgharzadeh, F. Quesada, I. Filip, “Challenges and perspectives of child labor,” *Industrial Psychiatry Journal*, vol. 27, no. 1, pp. 17-20, 2018.

[50] Y. K. Dwivedi, L. Hughes, A. K. Kar, A. M. Baabdullah, P. Grover, R. Abbas, et al., “Climate change and COP26: Are digital technologies and information management part of the problem or the solution? An editorial reflection and call to action,” *International Journal of Information Management*, vol. 63, p. 102456, 2022.

[51] R. Pereira, N. dos Santos, “Neoindustrialization—Reflections on a new paradigmatic approach for the Industry: A scoping review on Industry 5.0,” *Logistics*, vol. 7, no. 3, p. 43, 2023.

[52] C. Hirschman, E. Mogford, “Immigration and the American industrial revolution from 1880 to 1920,” *Social Science Research*, vol. 38, no. 4, pp. 897–920, 2009.

[53] L. Kanger, F. Bone, D. Rotolo, W. E. Steinmueller, J. Schot, “Deep transitions: A mixed methods study of the historical evolution of mass production,” *Technological Forecasting and Social Change*, vol. 177, p. 121491, 2022.

[54] N. Anumbe, C. Saidy, R. Harik, “A primer on the factories of the future,” *Sensors*, vol. 22, no. 15, p. 5834, 2022.

[55] S. Phuyal, D. Bista, R. Bista, “Challenges, opportunities and future directions of smart manufacturing: A state of art review,” *Sustainable Futures*, vol. 2, p. 100023, 2020.

[56] C. Zhang, J. Yang. A History of Mechanical Engineering. 1st Ed. Singapore: Springer Nature, 2020.

[57] A. Iyer, “Moving from Industry 2.0 to Industry 4.0: A case study from India on leapfrogging in smart manufacturing,” *Procedia Manufacturing*, vol. 21, pp. 663–670, 2018.

[58] A. Sharma, B. J. Singh, “Evolution of industrial revolutions: A review,” *International Journal of Innovative Technology and Exploring Engineering*, vol. 9, no. 11, pp. 66–73, 2020.

[59] X. Xu, Y. Lu, B. Vogel-Heuser, L. Wang, “Industry 4.0 and Industry 5.0—Inception, conception and perception,” *Journal of Manufacturing Systems*, vol. 61, pp. 530–535, 2021.

[60] G. Mattioli, C. Roberts, J. K. Steinberger, A. Brown, “The political economy of car dependence: A systems of provision approach,” *Energy Research & Social Science*, vol. 66, p. 101486, 2020.

[61] K. Zhou, T. Liu, L. Zhou, "Industry 4.0: Towards future industrial opportunities and challenges," in *12th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD)*, pp. 2147–2152, 2015.

[62] D. A. Zakoldaev, A. G. Korobeynikov, A. V. Shukalov, I. O. Zharinov, O. O. Zharinov, "Industry 4.0 vs Industry 3.0: The role of personnel in production," in *IOP Conference Series: Materials Science and Engineering*, vol. 734, no. 1, p. 012048, 2020.

[63] X. W. Xu, "Realization of STEP-NC enabled machining," *Robotics and Computer-Integrated Manufacturing*, vol. 22, no. 2, pp. 144–153, 2006.

[64] S. A. M. Tofail, E. P. Koumoulos, A. Bandyopadhyay, S. Bose, L. O'Donoghue, C. Charitidis, "Additive manufacturing: scientific and technological challenges, market uptake and opportunities," *Materials Today*, vol. 21, no. 1, pp. 22–37, 2018.

[65] M. Soori, B. Arezoo, R. Dastres, "Sustainable CNC machining operations: A review," *Sustainable Operations and Computers*, vol. 5, pp. 73-87, 2024.

[66] A. Jandyal, I. Chaturvedi, I. Wazir, A. Raina, M. I. Ul Haq, "3D printing – A review of processes, materials and applications in industry 4.0," *Sustainable Operations and Computers*, vol. 3, pp. 33–42, 2022.

[67] T. Bauernhansl, B. Vogel-Heuser, M. Hompel. Allgemeine Grundlagen, in Handbuch Industrie 4.0 Bd.4. 2nd Eds. Heidelberg: Springer Vieweg Berlin, 2016.

[68] B. Vogel-Heuser, G. Bayrak, U. Frank, Forschungsfragen in "Produktionsautomatisierung der Zukunft". Diskussionspapier für die acatech Projektgruppe "ProCPS – Production CPS", *acatech - Deutsche Akademie der Technikwissenschaften*, 2012.

[69] Y. Lu, X. Xu, L. Wang, "Smart manufacturing process and system automation – A critical review of the standards and envisioned scenarios," *Journal of Manufacturing System*, vol. 56, pp. 312–325, 2020.

[70] Z. Liu, P. Sampaio, G. Pishchulov, N. Mehandjiev, S. Cisneros-Cabrera, A. Schirrmann, et al., "The architectural design and implementation of a digital platform for Industry 4.0 SME collaboration," *Computers in Industry*, vol. 138, p. 103623, 2022.

[71] T. L. Olsen, B. Tomlin, "Industry 4.0: Opportunities and challenges for operations management," *Manufacturing & Service Operations Management*, vol. 22, no. 1, pp. 113–122, 2020.

[72] A. Ghadge, M. Er Kara, H. Moradlou, M. Goswami, "The impact of Industry 4.0 implementation on supply chains," *Journal of Manufacturing Technology Management*, vol. 31, no. 4, pp. 669–686, 2020.

[73] F. Longo, L. Nicoletti, A. Padovano "Emergency preparedness in industrial plants: A forward-looking solution based on industry 4.0 enabling technologies," *Computers in Industry*, vol. 105, pp. 99–122, 2019.

[74] D. Russo, P. Ciancarini, T. Falasconi, M. Tomasi, "A Meta-Model for Information Systems Quality," *ACM Transactions on Management Information Systems*, vol. 9, no. 3, pp. 1–38, 2018.

[75] F. Brocal, M. A. Sebastián, C. González, "Advanced manufacturing processes and technologies," in *Management of Emerging Public Health Issues and Risks*, pp. 31–64, 2019.

[76] S. J. Oks, M. Jalowski, M. Lechner, S. Mirschberger, M. Merklein, B. Vogel-Heuser, et al., "Cyber-physical systems in the context of Industry 4.0: A review, categorization and outlook," *Information Systems Frontiers*, vol. 26, pp. 1732-1772, 2022.

[77] M. Javaid, A. Haleem, R. Pratap Singh, R. Suman, "Significance of quality 4.0 towards comprehensive enhancement in manufacturing sector," *Sensors International*, vol. 2, p. 100109., 2021.

[78] J. Pang, N. Zhang, Q. Xiao, F. Qi, X. Xue, "A new intelligent and data-driven product quality control system of industrial valve manufacturing process in CPS," *Computer Communications*, vol. 175, pp. 25–34, 2021.

[79] N. Mohamed, J. Al-Jaroodi, and I. Jawhar, "Cyber-physical systems forensics: Today and tomorrow," *Journal of Sensor and Actuator Networks*, vol. 9, no. 3, p. 37, 2020.

[80] A. A. Ahmed, M. A. Nazzal, B. M. Darras, "Cyber-physical systems as an enabler of circular economy to achieve sustainable development goals: A comprehensive review," *International Journal of Precision Engineering and Manufacturing-Green Technology*, vol. 9, no. 3, pp. 955–975, 2022.

[81] M. Javaid, A. Haleem, R. P. Singh, R. Suman, "Enabling flexible manufacturing system (FMS) through the applications of industry 4.0 technologies," *Internet of Things and Cyber-Physical Systems*, vol. 2, pp. 49–62, 2022.

[82] C. Martínez-Olvera, J. Mora-Vargas, "A comprehensive framework for the analysis of Industry 4.0 value domains," *Sustainability*, vol. 11, no. 10, p. 2960, 2019.

[83] F. A. Alenizi, S. Abbasi, A. Hussein Mohammed, A. Masoud Rahmani, "The artificial intelligence technologies in Industry 4.0: A taxonomy, approaches, and future directions," *Computers & Industrial Engineering*, vol. 185, p. 109662, 2023.

[84] J. Bajwa, U. Munir, A. Nori, B. Williams, "Artificial intelligence in healthcare: transforming the practice of medicine," *Future Healthcare Journal*, vol. 8, no. 2, pp. 188–194, 2021.

[85] A. Raja Santhi, A. P. Muthuswamy, "Industry 5.0 or industry 4.0S; Introduction to industry 4.0 and a peek into the prospective industry 5.0 technologies", *International Journal on Interactive Design and Manufacturing*, vol. 17, no. 2, pp. 947–979, 2023.

[86] A. Raja Santhi, P. Muthuswamy, "Industry 5.0 or Industry 4.0S? Introduction to Industry 4.0 and a peek into the prospective Industry 5.0 technologies," *International Journal on Interactive Design and Manufacturing*, vol. 17, no. 2, pp. 947–979, 2023.

[87] A. Haleem, M. Javaid, M. Asim Qadri, R. Pratap Singh, R. Suman, "Artificial intelligence (AI) applications for marketing: A literature-based study," *International Journal of Intelligent Networks*, vol. 3, pp. 119–132, 2022.

[88] S. Verma, R. Sharma, S. Deb, D. Maitra, "Artificial intelligence in marketing: Systematic review and future research direction," *International Journal of Information Management Data Insights*, vol. 1, no. 1, p. 100002, 2021.

[89] C. S. Pitt, A. S. Bal, K. Plangger, "New approaches to psychographic consumer segmentation," *European Journal of Marketing*, vol. 54, no. 2, pp. 305-326, 2020.

[90] D. Simester, A. Timoshenko, S. I. Zoumpoulis, "Targeting prospective customers: Robustness of machine-learning methods to typical data challenges," *Management Science*, vol. 66, no. 6, pp. 2495–2522, 2020.

[91] D. Antons, C. F. Breidbach, "Big data, big insights? Advancing service innovation and design with machine learning," *Journal of Service Research*, vol. 21, no. 1, pp. 17–39, 2018.

[92] K. Misra, E. M. Schwartz, J. Abernethy, "Dynamic online pricing with incomplete information using multiarmed bandit experiments," *Marketing Science*, vol. 38, no. 2, pp. 226–252, 2019.

[93] M. H. Huang, R. T. Rust, "Artificial intelligence in service," *Journal of Service Research*, vol. 21, no. 2, pp. 155–172, 2018.

[94] M. H. Huang, R. T. Rust, "A strategic framework for artificial intelligence in marketing," *Journal of the Academy of Marketing Science*, vol. 49, no. 1, pp. 30–50, 2021.

[95] A. H. Chiang, S. Trimi, "Impacts of service robots on service quality," *Service Business*, vol. 14, no. 3, pp. 439–459, 2020.

[96] S. Hlee, J. Park, H. Park, C. Koo, Y. Chang, "Understanding customer's meaningful engagement with AI-powered service robots," *Information Technology & People*, vol. 36, no. 3, pp. 1020–1047, 2023.

[97] M. S. Rahman, T. Ghosh, N. F. Aurna, M. S. Kaiser, M. Anannya, A. S. M. Sanwar Hosen, "Machine learning and internet of things in industry 4.0: A review," *Measurement: Sensors*, vol. 28, p. 100822, 2023.

[98] C. Lee, C. Lim, "From technological development to social advance: A review of Industry 4.0 through machine learning," *Technological Forecasting and Social Change*, vol. 167, p. 120653, 2021.

[99] G. Shankarrao Patange, and A. Bharatkumar Pandya, "How artificial intelligence and machine learning assist in industry 4.0 for mechanical engineers," *Materials Today: Proceedings*, vol. 72, pp. 622–625, 2023.

[100] A. Patil, A. Dwivedi, M. Abdul Moktadir, Lakshay, "Big data-Industry 4.0 readiness factors for sustainable supply chain management: Towards circularity," *Computers & Industrial Engineering*, vol. 178, p. 109109, 2023.

[101] D. Soni, N. Kumar, "Machine learning techniques in emerging cloud computing integrated paradigms: A survey and taxonomy," *Journal of Network and Computer Applications*, vol. 205, p. 103419, 2022.

[102] L. Feng, K. Zeng, F. Shu, "Study on the quality control of reputation-based on incentive service-oriented manufacturing network," *Open Journal of Social Sciences*, vol. 4, no. 7, pp. 10–16, 2016.

[103] L. Thames, D. Schaefer, "Software-defined cloud manufacturing for Industry 4.0", *Procedia CIRP*, vol. 52, pp. 12–17, 2016.

[104] D. Wu, M. J. Greer, D. W. Rosen, D. Schaefer, "Cloud manufacturing: Strategic vision and state-of-the-art," *Journal of Manufacturing Systems*, vol. 32, no. 4, pp. 564–579, 2013.

[105] X. Xu, "From cloud computing to cloud manufacturing," *Robotics and Computer-Integrated Manufacturing*, vol. 28, no. 1, pp. 75–86, 2012.

[106] A. Corallo, M. Lazoi, M. Lezzi, "Cybersecurity in the context of industry 4.0: A structured classification of critical assets and business impacts," *Computers in Industry*, vol. 114, p. 103165, 2020.

[107] Z. Papulová, A. Gažová, L'. Šufliarský, "Implementation of automation technologies of Industry 4.0 in automotive manufacturing companies," *Procedia Computer Science*, vol. 200, pp. 1488–1497, 2022.

[108] B. Elhazmiri, N. Naveed, M. N. Anwar, M. I. U. Haq, "The role of additive manufacturing in industry 4.0: An exploration of different business models," *Sustainable Operations and Computers*, vol. 3, pp. 317–329, 2022.

[109] J. Barata, I. Kayser, "Industry 5.0 – Past, present, and near future," *Procedia Computer Science*, vol. 219, pp. 778–788, 2023.

[110] A. Adel, "Future of Industry 5.0 in society: Human-centric solutions, challenges and prospective research areas," *Journal of Cloud Computing*, vol. 11, no. 40, pp. 1-15, 2022.

[111] M. Marinelli, "From Industry 4.0 to Construction 5.0: Exploring the path towards human-robot collaboration in construction," *Systems*, vol. 11, no. 3, p. 152, 2023.

[112] N. Jafari, M. Azarian, H. Yu, "Moving from Industry 4.0 to Industry 5.0: What are the implications for smart logistics?" *Logistics*, vol. 6, no. 2, p. 26, 2022.

[113] B. Alojaiman, "Technological modernizations in the Industry 5.0 era: A descriptive analysis and future research directions," *Processes*, vol. 11, no. 5, p. 1318, 2023.

[114] A. Akundi, D. Euresti, S. Luna, W. Ankobiah, A. Lopes, I. Edinbarough, "State of Industry 5.0—Analysis and identification of current research trends," *Applied System Innovation*, vol. 5, no. 1, p. 27, 2022.

[115] K. P. Iyengar, E. Zaw Pe, J. Jalli, M. K. Shashidhara, V. K. Jain, A. Vaish, et al., "Industry 5.0 technology capabilities in trauma and orthopaedics," *Journal of Orthopaedics*, vol. 32, pp. 125–132, 2022.

[116] A. Lihui, "A futuristic perspective on human-centric assembly," *Journal of Manufacturing Systems*, vol. 62, pp. 199-201, 2022.

[117] H. Liu, L. Wang, "Gesture recognition for human-robot collaboration: A review," *International Journal of Industrial Ergonomics*, vol. 68, no. 850, pp. 355-367, 2018.

[118] O. Givehchi, H. Trsek, J. Jasperneite, "Cloud computing for industrial automation systems—A comprehensive overview. in *Emerging Technologies & Factory Automation (ETFA)*, pp. 1-4, 2013.

[119] OEM Update, "Top robotic applications in the automotive Industry," I-Tech Media Pvt Ltd., India 2018. [Online]. Available: http://www.oemupdate.com/technology/top-robotic-applications-in-automotive-industry/

[120] D. Gershgorn, "Popular science: Hitachi hires artificially intelligent bosses for their warehouses," Hitachi Vantara, 2015. [Online]. Available: https://www.popsci.com/hitachi-hires-artificial-intelligence-bosses-for-their-warehouses

[121] C. Swedberg, "L'Oréal Italia prevents warehouse collisions via RTLS," RFID Journal, 2014," [Online]. Available: https://www.rfidjournal.com/articles/view?12083

[122] S. Fawcett, "The future of automation and Industry 4.0," Institute of Engineering and Technology, 2017. [Online]. Available: https://eandt.theiet.org/content/sponsored/essentra-the-future-of-automation-and-industry-40/

[123] E. Daniel, "How autonomous vehicles are changing the face of transportation," WIPRO Limited, India, 2021. [Online]. Available: https://www.wipro.com/business-process/how-autonomous-vehicles-are-changing-the-face-of-transportation/

[124] M. Hasham, "Robotics in Healthcare," The British Standards Institution, 2018 [Online]. Available: https://compliancenavigator.bsigroup.com/en/medicaldeviceblog/robotics-in-healthcare/

[125] K. Baggaley, "Robots are replacing humans in the world's mines: Here's why," NBC News, 2017 [Online]. Available: https://www.nbcnews.com/mach/science/robots-are-replacing-humans-world-s-mines-here-s-why-ncna83163

[126] N. Anand, K. Akshi. A roadmap to Industry 4.0: Smart Production, Sharp Business and Sustainable Development. Advances in Science, Technology & Innovation. 1st Ed. Switzerland: Springer Cham, 2020.

[127] G. Chen, B. Xu, M. Lu, N. S. Chen, "Exploring blockchain technology and its potential applications for education," *Smart Learning Environments*, vol. 5, no. 1, pp. 1-10, 2018.

[128] K. A. Demir, G. Döven, B. Sezen, "Industry 5.0 and human-robot co-working," *Procedia Computer Science*, vol. 158, pp. 688–695, 2019.

[129] M. Kouhizadeh, S. Saberi, J. Sarkis, "Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers," *International Journal of Production Economics*, vol. 231, p. 107831, 2021.

[130] S. Chourasia, A. Tyagi, S. M. Pandey, R. S. Walia, Q. Murtaza, "Sustainability of Industry 6.0 in global perspective: Benefits and challenges," *Journal of Metrology Society of India*, vol. 37, no. 2, pp. 443–452, 2022.

[131] D. B. Kramer, M. Baker, B. Ransford, A. Molina-Markham, Q. Stewart, K. Fu, et al., "Security and privacy qualities of medical devices: An analysis of FDA postmarket surveillance," *PLoS ONE*, vol. 7, no. 7, p. e40200, 2012.

[132] G. Liang, Y. Liu, K. Feng, Y. Pan, Y. Liu, M. Yuan, "Design of home intelligent robot of internet of things," in *MATEC Web of Conferences*, vol. 336, p. 03001, 2021.

[133] D. V. Dimitrov, "Medical internet of things and big data in healthcare," *Healthcare Informatics Research*, vol. 22, no. 3, pp. 156-163, 2016.

[134] M. Santello, M. Bianchi, M. Gabiccini, E. Ricciardi, G. Salvietti, D. Prattichizzo, et al., "Hand synergies: Integration of robotics and neuroscience for understanding the control of biological and artificial hands," *Physics of Life Reviews*, vol. 17, pp. 1–23, 2016.