The Evolution of Automation: from Cyber Physical System in Industry 4.0 to Cobots in Industry 5.0

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***Abstract*— A smart factory is an advanced manufacturing facility that uses cutting-edge technologies to optimize production processes. Industry 4.0 integrates automation and data exchange in manufacturing with advanced technologies like IoT, cloud computing, AI, machine learning, automation, and robotics to enhance productivity. It is a cyber physical system that combines robots, tools, and workpieces in a cyber-physical environment, allowing for continuous collaboration and communication that leads to production that is self-organizing and self-optimizing Industry 5.0 focuses on collaboration between humans and machines, with collaborative robots being a key part. Industry 5.0 will build upon the strengths of Industry 4.0 to make companies more agile and future-proof. Assistant professor**

***Index Terms*— Cobots, Cyber physical system, Industry 4.0 , Industry 5.0 , Smart factories**

I. INTRODUCTION

A idea for expressing the digitization of industry is the "Smart Factory." In the most widely used sense, a "smart factory" is a highly digitalized shop floor that uses networked machinery, gadgets, and production systems to continuously gather and share data. The data can subsequently be utilized by self-optimizing devices or across the organization as a whole to anticipate problems, enhance production methods, and adapt to changing needs.AI, Big Data Analytics, Cloud Computing, and Industrial IoT (Internet of Things) are just a few of the technologies that have enabled smart manufacturing techniques to become completely integrated. Smart factories are able to monitor every aspect of production, from individual shop floor operators to manufacturing tools and the supply chain, by establishing connections between the real and digital worlds. When fully operational, smart factories leverage collaborative, fully integrated manufacturing systems to maximize operational flexibility and adaptability[1].

Industry 4.0, also referred to as the Fourth Industrial Revolution, is a technology revolution that includes smart factories and smart manufacturing [2]. Each of the first three industrial revolutions began with the invention of a novel piece of technology that fundamentally altered how we lived and produced commodities. We're going to see industry 5.0 in the future. Industry 5.0 describes intelligent and robotic equipment that collaborate with humans while including sustainability and increased resilience. Industrial 'cobots' or collaborative robots are designed to work intelligently and securely with humans, and they are expected to play a key role in industry. 5.0. Industry 5.0 aims to bring back human, environmental, and social factors into the equation, whereas Industry 4.0 concentrated on technologies like the Internet of Things and big data [3].

II. LITERATURE SURVEY

This paper [3] (Morteza Ghobakhloo et al.) 2024, The study investigates two key debates regarding the developing Industry 5.0 schedule. It aims to clarify the reasons behind the rapid growth of Industry 5.0 during the ongoing digital industrial revolution and examines how its sustainability values can be effectively achieved. The study reviews literature to show how Industry 4.0 deficiencies have negatively affected sustainability values and proposes a new method to enhance the sustainability goals of Industry 5.0 by leveraging Industry 4.0 sustainability functions. While Industry 4.0 has improved economic and environmental sustainability at certain levels, it has negatively impacted social sustainability values. This has led to the emergence of Industry 5.0, which can benefit from leveraging specific Industry 4.0 functions

to achieve its economic and socio-environmental objectives. The study identifies scenarios where utilizing Industry 4.0 capabilities can lead to sustainable innovation in the business world, offering important implications for the advancement of Industry 5.0 sustainability values.

This paper [5] (Alessia Napoleone et al.) 2020, New technologies are changing the way companies compete in unpredictable markets. This study focuses on Cyber-Physical Systems (CPSs) as a key concept for future smart factories. While much research has gone into the technological side of CPSs, there is a lack of knowledge on how to manage these systems. This paper reviews literature to differentiate between technological and operations management characteristics of CPSs for building smart factories. It emphasizes the importance of studying operations management characteristics to support the implementation of CPS-based factories in manufacturing.

This paper [6] (Amr adel),2022, Industry 4.0 has been in place for the past decade to address industry needs and shortcomings; now, it is time for industry 5.0. Smart factories are boosting productivity, leading to limitations of industry 4.0. This article explores opportunities and challenges of industry 5.0 along with future research prospects. Industry 5.0 shifts focus from technology to human-machine collaboration for progress. It enhances customer satisfaction through personalized products. Industry 5.0 is crucial for competitive advantage and economic growth in modern business. The paper examines potential applications, definitions, and advanced technologies of industry 5.0, including in healthcare, supply chain, and cloud manufacturing. Technologies like big data analytics, IoT, robots, Blockchain, digital twins, and future 6G systems are discussed. Challenges in human-robot collaboration on assembly lines are also addressed in this study.

This paper [7] (Swapnil patil et al.) 2023, It explores the use of collaborative robots, known as cobots, in multiple industries. Cobots are favored for their safe interaction with humans and the paper discusses their design, control strategies, safety features, and human-robot interaction. It begins with a history of cobots, reviews control strategies and safety features like collision detection and sensors, and includes a systematic review of ergonomics. The paper also addresses challenges and opportunities in cobot technology, such as the need for standards, impact on employment, and benefits to industry. It delves into the latest research on human-robot interaction and underscores the current limitations and the necessity for further research to overcome technical and ethical challenges. This paper is a valuable resource for academics and professionals interested in developing and applying cobot technology.

III. METHODOLOGY

A. Industry 4.0

Industry 4.0 is revolutionizing the way companies manufacture, improve, and distribute their products through the integration of technologies such as Internet of Things, cloud computing, analytics, artificial intelligence, and machine learning[1]. Smart factories utilize sensors, software, and robotics to gather and assess data, enabling improved decision-making. These digital advancements lead to increased automation, predictive maintenance, self-optimization for process improvement, and improved efficiencies and customer responsiveness that were not attainable before. Creating smart factories allows the manufacturing industry to tap into the fourth industrial revolution[2]. Examining the vast quantities of big data gathered from sensors in the factory guarantees immediate insight into manufacturing assets and offers resources for conducting proactive maintenance to reduce equipment downtime. Implementing advanced IoT gadgets in intelligent factories results in increased efficiency and enhanced quality. Switching from manual inspection business models to AI-powered visual insights can decrease manufacturing errors and save both money and time. Quality control staff can easily establish a smartphone connected to the cloud for monitoring manufacturing processes with just a small investment. Industry 4.0 principles and technologies can be implemented in various industrial sectors, such as discrete and process manufacturing, as well as oil and gas, mining, and other industrial fields. Industry 4.0 involves automating tasks previously done by humans using real-time data analysis, artificial intelligence, and communication between production line components. Not adapting to Industry 4.0 will result in organizations losing competitiveness [4].

Technologies used in industry 4.0:
Internet of Things (IoT) - The IoT plays a crucial role in smart factories by connecting machines with sensors that have IP addresses, enabling them to communicate with other web-enabled devices. This connectivity allows for the collection, analysis, and exchange of valuable data in large quantities[11].

Cloud computing - Cloud computing is essential for every Industry 4.0 plan. Smart manufacturing requires seamless integration of various departments like engineering, supply chain, production, sales, distribution, and service, which can be achieved through cloud technology. Moreover, cloud enables more efficient and cost-effective processing of large volumes of stored and analyzed data. Additionally, it allows small- and medium-sized manufacturers to lower their startup costs by adjusting their resources according to their needs and scaling as their business expands[12].

AI and machine learning - AI and machine learning enable manufacturing companies to fully utilize the data produced not only in the factory, but also in other business divisions, as well as from external partners and sources.AI and machine learning have the ability to generate valuable information, offering visibility, predictability, and automation for operations and business processes. Utilizing data gathered from industrial machines can assist businesses in implementing predictive maintenance strategies through machine learning algorithms, ultimately leading to increased operational time and improved productivity[13].

Digital twin - A digital twin is a virtual simulation of a real-world machine, product, process, or system built using IoT sensor data. This essential aspect of Industry 4.0 enables firms to better understand, analyze, and improve the performance and maintenance of industrial systems and products. A digital twin, for example, can help an asset operator identify a specific malfunctioning item, predict foreseeable problems, and increase uptime[14]

Autonomous robots - A new breed of autonomous robots is coming with Industry 4.0. Autonomous robots, which are designed to carry out activities with minimum human assistance, come in a wide range of sizes and capacities, from autonomous mobile robots for pick and place jobs to inventory scanning drones. These robots, outfitted with advanced software, artificial intelligence (AI), sensors, and machine vision, can execute intricate and challenging jobs. They can also analyze and respond to data they get from their environment[15].

Cybersecurity - With growing connection and the usage of Big Data in Industry 4.0, good cybersecurity is critical. Companies that deploy a Zero Trust architecture and technologies such as machine learning and blockchain may automate threat detection, prevention, and response, reducing the risk of data breaches and production delays across their networks[16].

CSP in industry 4.0:
A system that combines sensing, computation, control, and networking within physical objects and infrastructure, linking them to the internet and each other. Both physical and digital behaviors are closely connected in this system. Users can mirror characteristics of the physical system in a digital realm. Software algorithms capture the dynamic behavior of a physical system in spatial and temporal domains, then display it in an intuitive digital user interface. Cyber-physical systems play a key role in Industry 4.0, the fourth industrial revolution driven by advanced automation and intelligence. Intelligence and cognitive computing are integrated into the design and simulation of physical systems, which may include advanced operations like robot-assisted nanodevice manufacturing. Engineers create digital replicas of instruments and processes to simulate adjustments and manage operations through a centralized interface[5].

Cyber-physical systems have practically infinite uses. These days, a wide range of businesses, including the manufacturing, healthcare, and energy sectors, use them. Among the typical applications for CPS are:

- IoT devices
- The architectural plans of infrastructure and buildings
- Robotics
- Manufacturing
- Smart cities and smart grids

B. From Industry 4.0 to Industry 5.0

Industry 5.0 is building upon the transformations initiated by Industry 4.0. The manufacturing sector has been revolutionized by smart technologies, particularly cyber-physical systems enabling machine-to-machine communication. This evolution has focused on sensor technology and data utilization, democratizing manufacturing processes and enhancing operational transparency. These achievements were significant, and it is accurate to say that Industry 4.0 had a successful period. Why should we consider making changes? Despite its groundbreaking focus on automation, Industry 4.0 also has limitations. While machines are essential in planned situations, human operators play a critical role that has been overlooked. When unexpected issues arise, machines lack the ability to adapt and solve problems efficiently, leading to potential escalation from small errors. The upcoming advancements aim to address this oversight[8].

Industry 5.0:

The phrase "Industry 5.0" describes the collaboration between humans and robots and smart machines.. It is about robots assisting humans in working more efficiently and effectively by exploiting cutting-edge technology such as the big data and Internet of Things (IoT). It brings a personal human touch to the Industry 4.0 pillars of automation and efficiency. Robots have traditionally been used in manufacturing to do risky, monotonous, or physically demanding tasks such as welding and painting in automobile manufacturers and loading and unloading large products in warehouses. As technologies in the workplace become smarter and more connected, Industry 5.0 aims to merge cognitive computing skills with human intellect and resourcefulness in collaborative operations[6].

From robots to cobots:

Collaborative robots are designed to work together with humans to improve human capabilities safely. Unlike traditional robotic deployments that operate independently from humans and are usually enclosed in cages. They can be instructed to halt their operation upon detection of a human presence in the area where they are working, preventing unnecessary delays in production. Cobots can function in the same facility as humans, monitoring the surroundings and maintaining performance and safety[7].

Cobots are continuously advancing in various areas of industry development. Progress in faster reaction time, precise movement patterns, orientation capabilities, and human imitation capabilities all contribute to the ongoing development of cobots. Moreover, the field of brain-computer interfaces has seen notable advancements. Once we can accurately interpret and transmit brain signals to robots, we will have the opportunity to engage with them in a novel manner. Cobots are most beneficial when humans work closely with them, such as guiding, monitoring, or learning from them. The compatibility between cobots and 5G systems is evident, especially in areas like smart manufacturing, where quality of service needs change depending on the situation[20].

Research is currently focusing on teaching robots to imitate human actions and choices. Meanwhile, AI algorithms have shown they can outperform humans in solving problems, as seen in game strategies and design. Using cobots could enhance human productivity and improve human-robot collaboration. Industrial cobots, or collaborative robots, are made to work alongside humans in a smart and safe way, and are expected to play a significant role in industry 5.0. The addition of these smaller, quicker, and more adaptable cobots is crucial for the advancement of Industry 5.0, as their enhanced safety features will enable humans to play a central role in a wider variety of manufacturing processes[25].

Industry 5.0 strategies:

Human-centric - The human-centric approach prioritizes core human needs and interests in production processes, empowering workers through digital devices. Technology is used to adapt production processes to worker's needs, supporting and empowering them while also increasing safety. Workers are included in the design and deployment of new technologies like robotics and AI. The Extended Operator approach enhances industrial workers' abilities with innovative technology instead of replacing them with robots, maximizing benefits for both the company and the worker[17].

Sustainable - In order to align with planetary boundaries, the industry must prioritize sustainability. This involves implementing circular practices to repurpose resources, minimize waste, and cut down on

environmental impact. Sustainable efforts also focus on reducing energy usage and greenhouse gas emissions to prevent resource depletion. Technologies such as AI and additive manufacturing can enhance energy efficiency, resource utilization, and waste reduction. By integrating competitiveness with sustainability, the industry can thrive as a key driver of change. Embracing innovative solutions and adapting business models are crucial steps in this transformation journey[18].

Resilient - Resilience involves strengthening industrial production to withstand disruptions and uncertainties, ensuring a more robust approach to globalized production. Developing resilient strategic value chains, adaptable production capacity, and flexible business processes is essential for the future industry to remain a sustainable engine for prosperity, capable of quickly adapting to changing circumstances. Leveraging digital technologies is important for enabling resilient technologies, but also increases vulnerability to technical disruptions and cyberattacks, emphasizing the need for cybersecurity in the resilient industry of the future[19].

IV. RESULT EVALUATION

Industry 4.0 and 5.0 denote distinct phases in the development of manufacturing and industry, each bringing in new technologies and processes. Nevertheless, Industry 5.0 is not widely acknowledged yet.

Industry 4.0, also called the Fourth Industrial Revolution, is the current technological transformation in manufacturing. It includes integrating technologies like IoT, AI, big data, and automation in creating "smart factories" for production optimization and cost reduction. Industry 4.0 offers various advantages such as boosted productivity, enhanced quality control, cost savings, and added flexibility in manufacturing procedures. By incorporating digital technologies in production, companies can enhance their efficiencies, simplify supply chains, and enhance customer satisfaction.

Industry 5.0 is a recent concept coined by experts to signify a future phase of industrial progress that surpasses the automation and optimization of Industry 4.0. Industry 5.0 encompasses the change of contemporary manufacturing along with various processes, both commercial and non-commercial, to facilitate human and machine collaboration. Utilizing collaborative robots, known as cobots, has become common in Industry 5.0, which represents the current technological transformation in manufacturing. Industry 5.0, on the other hand, is still in the developmental stage and lacks widespread recognition or definition.

V. CONCLUSION

A smart factory is a digitalized and interconnected production facility that utilizes smart manufacturing. It is a cyber-physical system with advanced technologies like artificial intelligence (AI) and machine learning to analyze data, automate processes, and continuously learn. This innovative approach is part of industry 4.0's technological revolution. Industry 4.0, or the fourth industrial revolution, has greatly affected the global economy and business operations in various sectors, making companies more flexible, productive, and eco-conscious. Industry 4.0 is known for its utilization of connected technology, enabling real-time data exchange, process optimization, cost reduction, and quality improvement. Industry 5.0 is currently under development with a focus on human-machine collaboration to enhance skills utilization, ensure safer and more efficient work, and provide more meaningful experiences. Industry 5.0 is set to bring in more advanced technologies like artificial intelligence and robotics, which will aid and work alongside humans in innovative ways. In conclusion, Industry 5.0 promises an exciting future for businesses, and it is advisable to closely monitor its progress. Many technological innovations are anticipated during the shift from Industry 4.0 to Industry 5.0. It is expected that companies will depend more on self-learning systems to enhance efficiency and automation. Collaboration between humans and machines will be enhanced through advanced robotic systems and artificial intelligence. Robots can handle physically challenging or risky tasks, while humans focus on complex decision-making and monitoring. Moreover, the use of augmented reality is expected to rise for more interactive and intuitive industrial maintenance or work instructions. These advancements will enhance companies' agility in adapting to market changes and speeding up product innovation. It is crucial to

highlight that the implementation of Industry 5.0 does not entail the full replacement of Industry 4.0. Instead, Industry 5.0 will build upon the strengths of Industry 4.0, enhancing company agility and future resilience. Additionally, it aims to enhance collaboration and connectivity across the value chain, fostering closer relationships among customers and suppliers.

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