

Chapter 17

Impact of Artificial Intelligence in Industry 4.0 and 5.0

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ABSTRACT

Industry 4.0 uses the network concept to establish an interconnected manufacturing system. Industry 4.0 integrates the more recent digital concepts such as artificial intelligence (AI), the internet of things (IoT), big data, cloud computing, and 3D printing. The next maturity level, Industry 5.0, aims to shift the focus back to human-centric production by creating a sustainable and collaborative environment with humans and machines. Every manufacturer aims to find new ways to increase profits, reduce risks, and improve production efficiency. AI tools can process and interpret vast volumes of data from the production floor to spot patterns, analyze and predict consumer behavior, and detect real-time anomalies in production processes. This work studies the impact of AI in Industries 4.0 and 5.0. In Industry 4.0, AI can help in classic tasks such as predictive maintenance, production optimization, and customer personalization. Industry 5.0 enables sustainable manufacturing development and human-AI interaction. In this work, the authors demonstrate the impact of AI in Industry 4.0 and 5.0.

1. INTRODUCTION

In recent years, we have witnessed remarkable advancements in artificial intelligence (AI) that have revolutionized various domains. AlphaZero's ability to learn from scratch and master complex games, like chess, shogi, and Go, without prior knowledge or human guidance marked a significant milestone in AI research in 2017. In 2020, another notable advancement in the medical field was the discovery of the antibiotic Halicina, inspired by the HAL software of the movie '2001: A Space Odyssey'. The same year, OpenAI's GPT-3 (Generative Pre-trained Transformer) made significant strides in natural language

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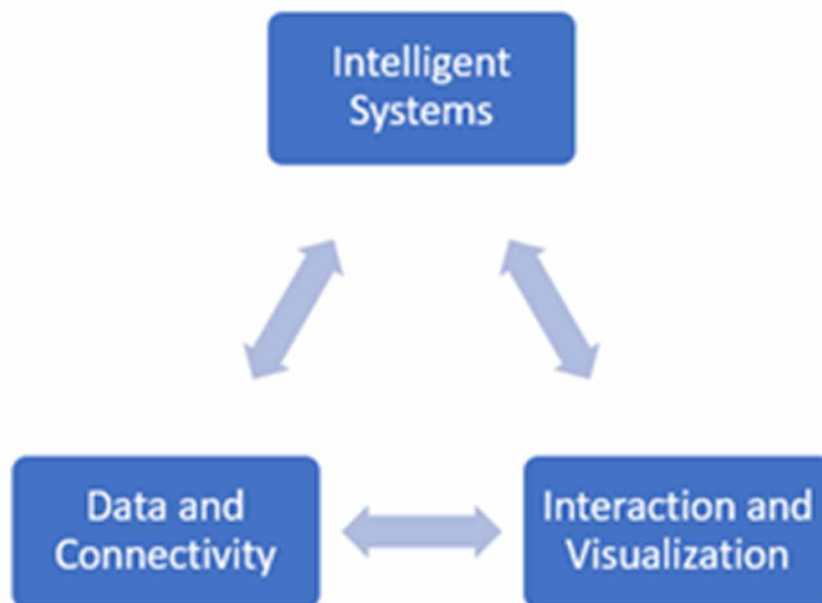
processing and generation. GPT models, such as GPT-3.5, have demonstrated impressive capabilities in understanding and generating human-like text (Kissinger et al. 2022).

Evaluating AI's impact in Industry 4.0 and 5.0 is challenging since many technologies contribute to this area. Various topics like the Internet of Things (IoT), Big Data, Cloud Computing, 3D printing, Robotics, Cobots, G6 networks, and FabLabs disperse the reader without giving him unity.

This work aims to find a framework for several technologies and study how AI relates to other technologies in Industry 5.0, recognizing the legacy of Industry 4.0.

For this purpose, we choose the classic I/O framework, or pipeline, with three steps: (i) data and connectivity, (ii) intelligent systems, and (iii) interaction and visualization, shown in Figure 1.

Figure 1. A framework of the types of technologies of Industry 4.0 and 5.0



The contribution of this work is to distinguish between Industry 4.0 and Industry 5.0 and prophesy which technologies are the most substantive in Industry 5.0 while focusing on AI.

In this work, we aimed to identify technologies encompassing Industry 4.0 and Industry 5.0 and align with the previous framework with three technology sets. The result with the more relevant technologies is presented in Figure 2. Each technology will be further developed in the document.

The remaining paper is organized as follows. Section 2 presents the technologies of Industry 4.0. Section 3 reports the technologies that support Industry 5.0. Finally, in Section 4, we draw some conclusions.

Figure 2. More relevant technologies of Industry 4.0 and 5.0

	Industry 4.0	Industry 5.0
Data and connectivity	big data	data quality
	smart sensors	6G
Intelligent systems	robots	cobots
	AI/ML	generative AI
Interaction and visualization	digital twins	personal fabrication
	additive manufacturing	FabLabs
	augmented reality	extended reality

2. INDUSTRY 4.0

Industry 4.0 is revolutionizing companies’ manufacturing by integrating new technologies (Bornet et al. 2020). In order to better understand the impact of AI in Industry 4.0, this section proposed the framework with three levels: (i) Data and Connectivity, (ii) Intelligent Systems, and (iii) Interaction and Visualization.

The subjects of Big Data and Smart Sensors regarding data and connectivity are discussed. Intelligent Systems and Robotics are detailed concerning intelligent systems. To illustrate the level of interactions and visualization, the topics of Digital Twins, Additive Manufacturing/3D Printing, and Augmented Reality are discussed.

2.1. Industry 4.0, Data, and Connectivity

Big Data

The digitization of services, from sophisticated stock transactions to the simple purchase of coffee, along with social networks and mobile devices (tablets, smartphones), produces enormous data. Beyond the quantity of data, the update rate of this data is also immense. Currently, in 2023, more data is generated every 2 minutes than all the data from prehistory up to 2003.

On the other hand, processing capability has also seen significant increases. Over the past 40 years, the integration capacity of integrated circuits has allowed us to double processing power every two years (Moore 1965), increase storage capacity, and reduce its price. Moore’s Law has been proven over the past 40 years, enabling a processing increase in the value of 2 raised to the power of 20 (2^{20}).

To get a sense of the increase in capacity, given the difficulty of humans in understanding the meaning of exponential growth, let us use the example of travel time from Lisbon to Porto. Suppose a trip from Lisbon to Porto 40 years ago took an average of 6 hours. If the evolution of transport were as significant as in computers, the travel time from Lisbon to Porto today would be two-hundredths of a second ($6.60.60 / 2^{20}$).

The large volume of data, offset by increased processing capacity, has given rise to new concepts, such as Big Data, and the creation of new professions like data scientists, dubbed by the Harvard Business Review as the sexiest profession of the 21st century.

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With the advent of Web 2.0 (the people's web) associated with mobile devices and the Internet of Things, classic business applications have surpassed data volume.

In a study conducted in 2012, the estimated value of information on the planet was 2.8 ZB (zettabytes, 1021 bytes). The change in scale in data volume and its update rate gave rise to what is generically called Big Data.

Big Data is associated with the 3V acronym: volume, update speed, and various formats. Some authors include a fourth V of value or data veracity.

The concept of 'dark data' is often used in data management, similar to the concept of dark matter in astrophysics. The concepts' similarities are because only a tiny percentage of the matter is visible and possibly contains several explanations for the universe's origin. Of the 2.8 ZB, 85% are unstructured data, i.e., media like video, photography, and sound. Of the remaining 15% of formatted and text data, only 3% are analyzed. Thus, we conclude that only a small percentage of 0.45% of the planet's data is subject to analysis, and 99.55% of unanalyzed data is called Dark Data.

With the emergence of new formats for structured data, the concept of NoSQL arose within Big Data. NoSQL, or Not-only SQL, allows data storage, processing, and querying very efficiently. NoSQL solutions are divided into a few groups: Key/value storage, like LinkedIn's Voldemort; Super-columns storage, like Facebook's HBase or Cassandra; Document storage, like XML database or MongoDB; Graph storage, like HyperGraphDB or ArangoDB and Object-oriented storage, like Db4object.

From the relational model and the declarative SQL (Structured Query Language) used in most corporate databases, NoSQL presents itself as the alternative for dealing with large volumes of data.

The structures of NoSQL solutions have been simplified compared to the relational model and ensure very efficient information querying with algorithmic complexities of order $O(1)$.

In NoSQL, the maximum complexity should be of the order $O(N)$, where N is the file size. Unlike SQL, the operation of joining tables does not exist, given its high complexity of order $O(N^2)$ for the worst case.

For data aggregation, MapReduce is used, implemented in two phases. The Map operator function selects data into subgroups, and the Reduce operation aggregates the information from each subgroup. The worst-case algorithmic complexity will be twice $O(N)$.

The concept of Big Data brings new challenges for dealing with large volumes of data, both for companies and the scientific community. Developing new algorithms is critical since the algorithmic complexities are preferable to order $O(1)$ and should never exceed order $O(N)$.

As a result, Big Data creates new opportunities in data-driven decision-making. Director of Google Research, Peter Norvig, stated, "We do not have better algorithms; we have much more data" (Davenport 2014).

Smart Sensors

Sensor networks can improve the world through diagnostics in medical applications, improved performance of energy sources like fuel cells, batteries, and solar power, improved health, safety, and security for people, and sensors for exploring space and known universities. Sensor proliferation and sensor fusion will continue to accelerate as security within the IoT improves and makes it safer to transmit critical data (Sofi et al. 2022).

When we think of the plethora of applications for sensors, one cannot avoid seeing an Artificial Intelligence (AI) potential in each. The technology may not inspire many unique or novel sensors, but it will generate a massive demand for sensors of all types. Moreover, with the need for compact designs, sensor fusion will become more the norm than application-specific.

Sensor technologies will help us meet environmental goals surrounding cleaner energy and lower carbon footprints, including the electrification of vehicles. Sensors also serve autonomous vehicles and smart city infrastructures; sensors collect the big data needed for management, control, and safety. Sensor technologies are also widely used in the medical market. Our aging global population is driving a trend toward home healthcare. With the pandemic, this drive has accelerated with the increased use of remote patient monitoring and diagnostic devices, including medical wearables.

One particular space that is set to be boosted by IoT sensor technology in the future is smart cities. Analyzing the stream of crucial data produced by sensors is critical in keeping structures – and therefore communities, economies, and livelihoods – safe and operational. When this approach is scaled up to include whole urban environments, the potential of smart cities will be fully realized.

IoT sensors are also primed for aiding sustainability efforts across companies of all sizes and could see further innovation with the aid of AI. The development and adoption of 100% solar-powered sensors remove the need for lithium-ion batteries in most IoT devices today, enabling long-term, maintenance-free deployments.

We cannot change batteries in billions of sensors every few years. Sensors have become more compact while offering more functionality. They now employ micro-electro-mechanical systems (MEMS) architecture, and plug-and-play sensors are integrated into packages to adapt to the various market and application requirements.

Major league baseball is on the cutting edge in capturing and studying microdata. MEMS and sensors track everything on the field and measure games in unprecedented ways, from following a single player's eye movement to an entire team's coordinated response to a fly ball.

Instead of a baseball field, imagine a store full of sensors. If MEMS and sensor technology make it into stores, we could track how customers interact with products, how they move through the store, and what customer segment they belong to, all with unparalleled precision. We could unlock a new universe of insights significantly more than our digital footprint.

2.2. Industry 4.0, Intelligent Systems

Intelligent Systems

Artificial Intelligence (AI) is a revolutionary field set to act as a primary component in emerging technologies like big data, robotics, and IoT. It has moved from fantasy to reality, with AI systems now embedded in everyday items, from cars to apps. The evolution of AI started with knowledge engineering, shifted to model- and algorithm-based machine learning, and is now focused on perception, reasoning, and generalization (Stephanopoulos, Han 1996).

Despite impressive advancements, current AI programs possess specialized intelligence, meaning they can solve only one problem at a time and are rigid in response to input changes. The ultimate goal is to create AI with general intelligence similar to humans, which is still one of science's most ambitious objectives.

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AI forms the foundation of computer learning, capable of analyzing massive amounts of data to make optimal decisions in a fraction of the time compared to humans. AI algorithms differ from conventional algorithms in their ability to change and rewrite themselves in response to data inputs, displaying a form of intelligence.

AI and machine learning (ML) will transform the scientific method. Their ability to analyze enormous data sets and discover complex relationships will catalyze a new era of scientific discovery. We have already seen significant advancements in specialized AI due to the availability of large data sets and computational resources.

AI is becoming integral to many industries, including online retail, where automated systems replace human workers. However, with proper investment in education and upskilling, AI is predicted to create more jobs than it eliminates, changing the narrative from “humans or computers” to “humans and computers.”

In the future, AI and human intelligence will combine to develop sophisticated cybersecurity measures. The transportation and manufacturing sectors will also benefit significantly from AI, with predictions of commercialized autonomous vehicles and enhanced factory operations.

AI also promises transformative consumer experiences, enabling concepts like the metaverse and cryptocurrencies. Exciting research is happening in reinforcement learning and generative adversarial networks (GAN), which will have substantial near-future ramifications.

AI algorithms offer great potential in bridging the gap between digital and physical realms, facilitating the integration of frictionless capitalism into the economy. However, these developments pose significant challenges to personal privacy and freedom from discrimination, necessitating proper data ownership and control measures.

Further research will focus on AI techniques such as multiagent systems, experience-based reasoning, and developmental robotics. These techniques could provide the key to equipping machines with common sense, learning the relations between their actions and environmental effects.

A survey from Oxford University’s Future of Humanity Institute suggested that by 2026, machines could write school essays (in some form, ChatGPT already meets this milestone); by 2027, self-driving trucks could make drivers redundant; and by 2137, all human jobs could be automated.

Robotics

The ability of machines and robots to learn could give them an even more diverse range of applications. Future robots that can adapt to their surroundings, master new processes, and alter their behavior would be suited to more complex and dynamic tasks. Ultimately, robots have the potential to enhance our lives. As well as shouldering the burden of physically demanding or repetitive tasks, they may be able to improve healthcare, make transport more efficient, and give us more freedom to pursue creative endeavors (Jeyakumar 2022).

Thanks to improved sensor technology and more remarkable advances in Machine Learning and Artificial Intelligence, robots will keep moving from mere rote machines to collaborators with cognitive functions. These advances and other associated fields are progressing upward, and robotics will significantly benefit from these strides. We can expect to see more significant numbers of increasingly sophisticated robots incorporated into more areas of life, working with humans.

An accelerated move towards attended automation is one of the trends we see unfolding in the future. Organizations worldwide understand that they must empower their employees via attended automation to automate more processes and maximize the returns on their existing RPA (Robotic Process Automation) investments (Langmann, Turi 2023). Attended automation, sometimes called desktop automation, extends the functionality of bots even further. An attended automation robot—essentially a digital personal assistant that lives on the desktop—guides employees to deliver a better customer experience, automating repetitive desktop tasks faster and more accurately. Attended bots take care of mundane tasks like populating forms for the employee and can also provide the following best action and compliance guidance as the customer service representative helps a customer resolve an account query, for example. The attended automation bots bridge tasks in the back and front offices, allowing more complex processes to be automated end-to-end.

Robot designers use Artificial Intelligence to give their creations enhanced capabilities like: (i) Computer Vision: Robots can identify and recognize objects they meet, discern details, and learn how to navigate or avoid specific items. (ii) Manipulation: AI helps robots gain the fine motor skills needed to grasp objects without destroying them item. (iii) Motion Control and Navigation: Robots no longer need humans to guide them along paths and process flows. AI enables robots to analyze their environment and self-navigate. This capability even applies to the virtual world of software. AI helps robot software processes avoid flow bottlenecks or process exceptions. (iv) Natural Language Processing (NLP) and Real-World Perception: Artificial Intelligence and Machine Learning (ML) help robots better understand their surroundings, recognize and identify patterns, and comprehend data. These improvements increase the robot's autonomy and decrease reliance on human agents.

2.3. Industry 4.0, Interaction, and Visualization

Digital Twins

The concept of making a duplicate or 'twin' of an asset to enable simulations and predict outcomes based on changes in the operating conditions finds its origins in the 1960s with the Apollo space program. The concept gained prominence in April 1970 when NASA engineers utilized duplicates of the spacecraft systems, initially designed for training purposes, to aid in the rescue of Apollo 13 following a catastrophic oxygen tank explosion. As the astronauts slept in the lunar module, the command module had to be powered down to preserve the batteries. NASA engineers used what amounted to a twin of the command module's electrical system to devise a series of steps to power up the frozen spacecraft without draining what little power remained in the batteries. A process typically took two days on the launchpad and was completed in under two hours. It was an extraordinary feat. Nevertheless, the technology has only matured since then. Clarifying the distinction between a model and a Digital Twin can help to demystify the technology and its applications (Grieves, Vickers 2017).

Deploying Digital Twins in production across operations and supply chains is now an upward trend. Not only in production, but the underlying technology has advanced to provide extremely high-fidelity twins with previously unimaginable capabilities.

Digital twins are a virtual representation of a physical object. It could be anything – as complex as a car or a manufacturing production line or as simple as a piece of furniture. The digital twin emulates all the parts of the object (or a set of connected objects) to create a virtual proxy. A car's digital twin would model its shape, tires, seats, engine, transmission, and everything. Companies use a digital twin

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to design a 3D model of the original, enabling teams to analyze the performance of the object under different conditions. Successfully deployed, digital twins can save serious money, improve product designs, and elevate efficiency and productivity (Tao et al. 2019).

Advances in edge computing and in-memory processing enabled by scalable computing delivered through containers, along with new pervasive network technologies like 5G supporting streaming data, make it possible to interconnect these twins. The results can be seen in real-world projects with twinned complete manufacturing lines and complex interconnected processes like supply chain integration. Digital Twins are becoming essential to everything from smart city planning to improving healthcare. For example, Singapore has created a complete digital twin of the city-nation to track traffic, pollution, climate, and city layouts so city managers can test accessibility options, see the potential impact of new construction, manage emergency responses, and monitor city health. Meanwhile, doctors are creating patient-specific Digital Twins of lungs to help decide on ventilator use when treating COVID-19 patients. In a lighter example, craft beer drinkers taste Industry 4.0 intelligence with digital twins.

To construct an effective Digital Twin, it is crucial to identify the problem to be solved, the opportunity to be explored, and the required accuracy of the predictions. Understanding the goal of a Digital Twin determines which data and sensor feeds are required to achieve predictive value within a defined confidence interval. To create a digital twin, one must record the object's base information and capture how it is performing and being used. Sensors do that, whether it is a machine in a factory or a tire on the road. The development of the Industrial Internet of Things (IIoT) has pushed digital twins even further. IIoT-enabled machines and components collect and feed data in real-time, meaning they essentially self-report their conditions.

The potential for Digital Twins in almost every industry is endless. Previously siloed departments across operations, maintenance, finance, sales, and marketing can all use digital twins to access a unified source of real-world data to predict maintenance, improve design, understand usage, and adjust pricing. Companies utilize digital twins to create 3D models of the original objects, which allows teams to analyze the object's performance under various conditions. Successfully deployed, digital twins can save serious money, improve product designs, and elevate efficiency and productivity. As the cost and complexity of digital twins have fallen, their adoption has spread beyond manufacturing to many different types of businesses. The cost of sensors continues to decline, the amount of data collected exponentially grows, and storing is affordable in various cloud services. Digital twins are also enabling new business models. For example, an equipment manufacturer may lease a digitally enabled component. Customers reap the advantages through such a 'product-as-a-service' model because there is a much smaller initial financial outlay and much less downtime. While we may not understand the inner workings of a machine or component until it malfunctions, a digital twin, in conjunction with IIoT, allows for proactive maintenance and servicing due to predictive analytics. A digital twin could identify and solve many 'what-if' scenarios to enable better decision-making for highly complex supply chains. This vision of creating digital twins of supply chains has a significant obstacle to overcome in sharing intelligence. Companies often hold their data close, which gets in the way of efficiency.

Over the long run, digital twins will form their networks, which experts call a 'digital thread'. Suppose a digital twin enables us to digitally represent a piece of equipment or facility. In that case, a digital thread is the continuous, connected stream of information an intelligent asset provides throughout its life cycle, from design to decommissioning (Jagusch et al. 2021). Implemented effectively, digital twins can serve as strategic catalysts. They can provide visibility into an organization's processes and ways to improve them and, in turn, strengthen the customer experience and relationships. Digital twins provide a

sandbox for testing and refining innovations before launching into the real world. They afford businesses a cost- and time-efficient way to design more innovative products and assets while capturing more information about them. So they enable companies to make products better, faster, and safer and generate new revenue opportunities. These include service offerings that create as-a-service business models, which remove the burden of significant capital outlays and lifetime maintenance from the customer and keep them connected with the service provider.

Additive Manufacturing and 3D Printing

Additive Manufacturing (AM) or 3D printing, a significant player in digital transformation, involves creating an object layer by layer, offering potential value over traditional manufacturing techniques (Shahrubudin et al. 2019). This technology eliminates the need for tooling and switching costs between production sites, introducing a new paradigm distinct from the labor-intensive manufacturing methods of the past 150 years.

In additive manufacturing, 'additive' refers to building an object layer by layer. Additive manufacturing, also known as 3D printing, involves the sequential deposition of material to form a three-dimensional object. Unlike traditional subtractive manufacturing methods that involve cutting, drilling, or carving away material from a larger block, additive manufacturing adds material in a controlled manner to construct the final product.

AM technologies provide four potential sources of value. Firstly, they offer unparalleled design freedom, enabling the creation of parts that outperform or cost less than conventional alternatives. Secondly, as there is no need for molds or fixed tooling, every part can be unique, enabling mass customization. Thirdly, AM eliminates time-consuming fabrication operations, accelerating product development and reducing time to market. Lastly, it simplifies the maintenance and support of products in the field by enabling on-demand production of spare parts.

While some claim that 3D printing is overhyped, it is evident that technology has significantly strengthened supply chains, especially during crises. The coming decade is expected to increase AM's role as more companies utilize 3D printing to create consumer-facing parts, custom manufacturing aids, and decentralized production.

The distributed manufacturing model transforms product strategies, enabling companies to manufacture final products closer to the customer. Advancements in Digital Light Processing (DLP) 3D printing processes have improved throughput by increasing speed, building volume, and reducing post-processing. These advances have contributed to greater simplicity and higher efficiency in the manufacturing process.

Experts predict additives will become the dominant mass-manufacturing technique, aiding the battle against global warming through light-weighting, reducing energy consumption and waste, and transitioning to plant-based materials. AM also promises to increase sustainability in production, pushing for the use of renewable sources of electricity.

We will likely see more mass production using AM technology, not just for custom or high-added value products but also for serialized products. Advanced material composites and the ability to produce highly complex geometries will unlock new manufacturing possibilities.

The next decade presents excellent opportunities for 3D printing to enter emerging markets like commercial space, drones, UAVs (unmanned aerial vehicles), robotics, urban mobility, etc. These markets are expected to grow staggeringly, pushing the growth of enabling technologies like 3D printing.

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Over the next decade, AM will become a practical tool covering the entire product life cycle, from concept models to aftermarket spares, including volume production. Questions remain regarding the discovery of new 3D printing materials, the application of metamaterials, and the acceleration of efforts to produce bio-based polymers or recapture waste plastics and metals.

Additive Manufacturing will establish itself as the manufacturing technology in the next ten years, supporting the transition to a sustainable and resource-efficient civilization. As AM material and production costs continue to drop, we will see more supply chain disruption, and parts printed locally becoming more cost-effective than those shipped from global manufacturing hubs.

Additive manufacturing could revolutionize supply chain and inventory management, making high-mix, low-volume manufacturing economical. The Distributed Recycling and Additive Manufacturing (DRAM) technology, which enables us to use 3D printers at home to recycle waste plastic into valuable products, is poised to impact consumer manufacturing significantly.

Augmented Reality and Beyond

The revolution in the digital world is driving the transformation of various industries. Today, Extended Reality (XR) – including virtual and augmented reality (VR/AR), is becoming increasingly prevalent in intelligent industrial environments. AR assists machinery operators, such as those driving cranes, in loading and unloading containers from ships. At the same time, VR is often deployed to train workers on using heavy and potentially hazardous equipment.

Connectivity is considered a cornerstone, enabling many of the cutting-edge technologies we see today. For instance, deploying AI at scale or processing data in real-time, especially near the action, requires robust connectivity. Connectivity becomes particularly relevant when dealing with autonomous robots, which have been used in industrial manufacturing for several decades. However, when these robots are integrated with AI, IoT, edge computing, and other emerging technologies, they become more potent, versatile, and practical.

Various new and affordable technologies are available, sparking significant advancements in various fields. New tools such as 3D printers, robotics, microprocessors, artificial, virtual, and augmented reality, e-textiles, “smart” materials, and novel programming languages empower individuals to invent and create. These tools and digital sharing capabilities have amplified this evolutionary leap.

The extensive range of contemporary exponential technologies encompasses 3D printing, artificial intelligence (AI), augmented and virtual reality, digital biology, biotech, nanomedicine, computing systems, and autonomous vehicles. Holography, for instance, is a budding technology set to transform Industry 4.0 completely. Holograms may seem more like a concept straight out of a science-fiction novel; however, rapid advancements in telecommunications, particularly 5G, are set to change this perspective.

Current hologram technology, like Hologauze, offers significant 3D hologram effects on a large scale. It works with 3D polarized projection systems and is a 2D hologram effect. In industrial applications, holographic technology finds its use in quality control during manufacturing and fracture testing, such as holographic non-destructive testing. Moreover, it has applications across various fields like medicine, the military, weather forecasting, virtual reality, digital art, and security.

Automation and real-time network connectivity are at the core of the Industry 4.0 revolution, with holography playing a pivotal role. The technology substantially benefits various development processes, features, and applications, focusing on ‘holography for Industry 4.0’. Adopting holographic technologies could significantly improve the efficiency of existing products and services in other technology sectors

such as architecture, 3D modeling, mechatronics, robotics, and healthcare and medical engineering. Therefore, hologram technology is emerging as a new industry trend influencing various aspects of Industry 4.0.

3. INDUSTRY/SOCIETY 5.0

Industry 5.0 is the next phase in the evolution of the industrial sector, building upon the advances of Industry 4.0 by incorporating more sophisticated human-machine interactions. It leverages critical technologies such as the Internet of Things (IoT), Big Data, Artificial Intelligence (AI), and smart manufacturing to improve business productivity and efficiency.

The core premise of Industry 5.0 is the collaboration between humans and machines, often called cobots. This shift from an overemphasis on technology to a more balanced human-machine collaboration promises to improve customer satisfaction by producing personalized products, giving businesses a competitive advantage, and promoting economic growth. Universal robots aid human workers, enhancing productivity in the manufacturing industry (Maddikunta et al. 2022).

Society 5.0, emerging alongside Industry 5.0, originates from Japan, marking the evolution after earlier societal stages like hunter-gatherer and industrial eras. It emphasizes human-centricity and sustainability over mere technological advancements. This concept envisions a harmonious blend of technology and human life, addressing societal challenges (Deguchi et al. 2020).

Additionally, Industry 5.0 contributes to sustainability efforts by striving to establish systems that run on renewable energy. This new industrial era incorporates technologies such as collaborative robots, digital twins, and platforms like Nexus Integra for managing industrial assets on a large scale, facilitating digital transformation.

The philosophy behind Industry 5.0 is not just about manufacturing for profit. It promotes principles of sustainability and human-centricity. A prime example of Industry 5.0 implementation is seen in multinational companies like Toyota and Repsol. Repsol uses Blockchain and robotic process automation technology to improve business security and productivity, showcasing how Industry 5.0 principles can be practically applied. On the other hand, Toyota makes significant investments in Industry 5.0 technologies to stay ahead of the curve.

Industry 5.0 aims to revolutionize manufacturing by automating repetitive tasks and integrating intelligent robots into supply chains and workflows. It adopts cognitive computing and intelligent automation to enable hyper-personalization. Future technological advancements, such as 6G networks, are set to augment Industry 5.0 further, making it an influential force in the industrial sector.

In order to better understand the impact of AI in Industry 5.0, this section proposed the same framework with three levels: (i) Data and Connectivity, (ii) Intelligent Systems, and (iii) Interaction and Visualization.

The subjects of Data Quality and 6G Networks regarding data and connectivity are discussed. Cobots are detailed concerning intelligent systems. To illustrate the level of interactions and visualization, the topics of Personal Fabrication and FabLabs are discussed.

3.1. Industry 5.0, Data, and Connectivity

Data Quality

Data Quality is gaining importance among data researchers as the volume of data generated by social networks, e-commerce, IoT, and other connectivity systems continues to grow. Despite the significant investment in storage technologies for managing large volumes of data, many of these datasets are unstructured or contain missing and incorrect values (Ehrlinger, Woss 2022).

Data Quality in Machine Learning can have a significant impact on bias. Bias refers to the systematic error or prejudice in the data or the learning algorithm, leading to unfair or discriminatory outcomes. If the training data used to train the machine learning model is biased, the model can learn and perpetuate those biases. For example, suppose historical data used to train a hiring algorithm predominantly consists of male candidates being selected. In that case, the algorithm may learn to favor male candidates in the future, leading to gender bias. Addressing data quality issues is crucial to mitigate bias in machine learning. Techniques such as careful data collection, diverse and representative training datasets, data augmentation, preprocessing techniques, and fairness-aware algorithms can help improve data quality and reduce bias in machine learning models.

Data has become crucial in academia and Industry 4.0 in recent years. However, much of the available data in the public domain, including text, tables, and linked data, is often incorrect, incomplete, or ambiguous.

Data needs to undergo an assessment and improvement process using Data Quality Management policies to ensure quality information. The pipeline should consider (i) Data Profiling, understanding data and metadata characteristics and identifying anomalies; (ii) Data Assessment, measuring data quality using predefined metrics; (iii) Data Cleansing, correcting errors and inconsistencies in the data; and (iv) Data Monitoring, continuously monitor data quality to detect and address issues.

Data quality can be understood as the “fitness for use” for a given application or use case. Assessing data quality involves computing multiple quality metrics rather than relying on a single metric for a specific application. Data Quality must meet criteria/dimensions such as accuracy, completeness, validity, consistency, uniqueness, timeliness, and fitness for purpose to ensure high-quality outcomes.

6G Network

6G, the sixth generation of wireless communication technology, is set to be a substantial upgrade from its predecessor, 5G. Expected to achieve download speeds near 95 Gb/s, it aims to eliminate latency, reduce congestion on mobile networks, and support an enormous number of devices with ultra-low latency requirements. This significant increase in speed and capacity is expected to make real-time data processing and analytics more efficient, fundamentally transforming how we understand and implement digital technologies (Tomkos et al. 2020).

With the shift to 6G, we are likely to see advancements in technologies such as Extended Reality (XR), digital twinning, tera-Hertz and millimeter waves communication, tactile Internet, non-orthogonal multiple access (NOMA), small cells communication, and fog/edge computing. These technologies will integrate terrestrial, aerial, and maritime communications into a robust and reliable network.

A significant area where 6G can profoundly impact is Industry 5.0. Industry 5.0 is characterized by the collaborative working of humans and robots or intelligent machines, leveraging technologies like big

data analytics, the Internet of Things (IoT), collaborative robots, Blockchain, digital twins, and future 6G systems — the Industry 5.0 paradigm benefits from these technologies to optimize operations and create efficient supply chains.

6G networks are expected to meet the intelligent information standard that provides high energy efficiency, reliability, and increased traffic capacity. They can help manage large amounts of data, making big data analytics a key enabling technology for Industry 5.0. IoT, an essential aspect of Industry 5.0, can be significantly improved with the advent of 6G, offering opportunities to reduce operating costs by addressing issues in communication networks, waste management, supply chain optimization, and more.

3.2. Industry 5.0, Intelligent Systems

Cobots

The COVID-19 pandemic has accentuated the need for resilient supply chains and human-machine collaboration. Full or partial shutdowns and social distancing regulations require factories and workspaces to operate with a minimal onsite crew. Despite labor shortages, supply chain disruptions, and other production challenges, manufacturers are under constant pressure to respond to the evolving market needs. The demands for mass customization, quality expectations, faster product cycles, and product variability are at an all-time high. Tackling these persistent challenges requires combining human skill and ingenuity with the strength and speed of robots. To bring the best of both worlds – human creativity and robotic precision – manufacturers should adopt cobots (collaborative robots) that can reduce human interaction in feasible situations and accelerate production cycles (Lefranc et al. 2022).

Cobots allow manufacturers to maximize production and address the changing demands while ensuring the safety of their employees, clients, and partners. Cobot stands for ‘collaborative robot,’ which says it all – cobots are robots designed to work alongside and assist human employees while making sure they do not cause any harm to us carbon-based lifeforms. Unlike industrial robots, which generally work in isolation and can be dangerous for passers-by, cobots feature sensors and collision avoidance, making them safe to work in the same space as humans.

Collaborative robotics include both robots and robot-like devices and generally are part of processes that cannot be fully automated, and that is precisely why we often see them in close quarters with people. Moreover, cobots in manufacturing are assigned tasks that fall into the Four D’s: dangerous, dull, dirty, or dear (Marr 2017).

Automation industry experts all seem to agree that the future of collaborative robotics is looking better every day. The market is expected to grow fast over the next decade, with future growth beyond that. Robot manufacturers are quickly adapting to customer demands, and engineers are solving some of their most complex problems with automation.

Capable of collaborative work with humans, cobots improve performance through safer and more efficient processes in the supply chain and manufacturing industry. Compared to industrial robots placed in cages to work independently, cobots have features, such as sensors and vision technology, that enable them to halt operation if immediate danger to humans is detected.

Machine-enhanced manual tasks are increasingly seen in modern factories with collaborative robots or cobots. Cobots can work alongside humans to deliver more excellent performance than by either working independently. Manufacturers can better decide which tasks to automate and which to perform manually, making production lines more efficient. Cobots could also reshape the whole concept of the

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factory floor. If robots can work safely with humans, they can be utilized away from the controlled, safety-fenced world of the shop floor. In the food and beverage industry, cobots with dexterous limbs, intelligent sensors, and advanced safety parameters could dramatically speed the process of getting goods from factory to shelf. Faster picking, placing, sorting, and loading are just the start.

Collaborative robots, better known as cobots, have seen severe uptake across the manufacturing industry due to COVID-19. Despite industry challenges caused by depleting workforces and supply issues, investment has been made in cobots due to their cost efficiency, ease of use, and collaborative convenience. Cobots work alongside humans to facilitate productivity, reducing the need for unskilled labor and providing upskilling opportunities for workforces still required to manage warehouse automation and cobot integration.

These benefits have made cobots noticeably popular with small and medium-sized enterprises (SMEs), as they require a gradual introduction of automation while retaining flexibility and manageable costs. In order to work at maximum efficiency, engineers must program a cobot to learn its boundaries, maximize functional space, and understand restricted modes. With an ongoing industrial transformation journey underway, the use of cobots alongside an upskilled, people-led workforce can be expected. The result looks to be a vast increase in efficiency and output while retaining key employees through incentivizing progression opportunities.

A study by the World Economic Forum in association with Advanced Robotics for Manufacturing found that collaborative robots can cut nearly two-thirds of the cycle time required to pack boxes onto pallets. Because cobots are designed to work without any breaks, they reduce the idle time between cycles. The International Society of Automation reports that cobots can save production costs by reducing 75% of manual labor. Traditional robots increase the installation costs for manufacturers as they need to set up additional safety measures around the deployment area. Cobots do not incur such extra expenses as they can be set up close to humans.

One of the less-known benefits of collaborative robots is their nearly maintenance-free operation and long-term reliability. Not only are they easy to maintain, but they are also easy to program, and this is even the case in the most demanding environments that would put human workers to the test.

Many small and medium-sized businesses (SMEs) believe automation is out of their reach as they cannot afford giant, complex robots that also do not fit within their limited floor space. Cobots are changing the game for these organizations, providing a more cost-effective and straightforward way to introduce automation into their workflows.

With remote network capabilities powered by high signals and bandwidth alongside low latency, a cobot with 6G systems can significantly add invaluable service to any manufacturing industry. The possibilities in the future are endless, especially with newer developments and growing optimization opportunities in Industry 5.0 for AI and collaborative work.

To effectively scale cobot deployment, the market must have use cases of successful business models. From hardware design to sensors, actuators, vision systems, data processing, artificial intelligence, and more, cobot technology requires the development of user safety and predictable results.

Cobots are quickly becoming a significant part of automation in manufacturing as the technology is proving reliable, which means that more and more companies are ready to use them. Cobots will grow more sophisticated and versatile in the upcoming years. As AI improves, so will cobots' fulfillment of precision and cognitive tasks. Moreover, the connectivity of cobots with IIoT, meaning the connection to other machines, devices, network databases, and so on, will allow them to improve multiple factory workflows and even provide valuable data analytics, including predictive analytics and suggestions on

improving processes. Connecting cobots via the Industrial Internet of Things has connected cobots to surrounding machinery. By extension, adding connectivity adds machine visibility, data analytics, and improved predictive maintenance. This connection has led to increased precision, flexibility, and efficiency.

Denmark-based Universal Robots reports that cobots are at the heart of Industry 5.0. Cobots democratize robotic capabilities, serving as a personal tool that any workforce member can leverage to apply creative skills and generate more value. Cobots can be used as a plug-and-play solution across various manufacturing and industrial operations such as automotive production, food processing, chemical plants, medical devices, and kits. Since they collaborate well with humans in a safe environment, cobots will augment intelligent decision-making, drive high-quality products to the market, enable mass customization and personalization, optimize manufacturing costs, generate new job roles (e.g., Chief Robotics Officer), and boost virtual education to make the most of collaborative robotics.

Generative AI

Generative AI (GenAI) is the domain of AI that can create new content from pre-existing sets of information, supported by large-scale neural networks ('deep neuronal networks'), i.e., with millions of artificial neurons. The process of calibrating parameters between pairs of neurons is called neural network learning.

Large Language Models (LLM) are GenAI models for natural language processing. The well-known ChatGPT from OpenAI is based on the GPT architecture, which stands for "Generative Pre-trained Transformer".

ChatGPT has two features that are entirely different from previous information retrieval systems. The first feature is a significant advantage: the system can maintain a dialogue based on user sentences (prompts) with an awareness of context (context-aware), i.e., it considers previous sentences in the conversation. The second feature of the system is a disadvantage: on particular subjects, the system generates sentences that do not correspond to reality. In these cases, we say the system 'hallucinates'.

ChatGPT and similar models based on GPT-3 and GPT-4 are designed to account for the context of the conversation, unlike older Question Answering systems that responded to the posed question. Formulating the 'prompt' is critical to obtain desired answers on the user's side. The use of imperative sentences like "rewrite the sentence", "summarize the sentence", or "expand the sentence" makes the conversation more effective.

Generative AI in Industry 5.0 offers unparalleled personalized production and rapid prototyping opportunities. Augmenting human creativity fosters a harmonious collaboration between man and machine. Moreover, its potential in optimizing supply chains and enhancing consumer interactions places it at the forefront of the next industrial evolution. This synergy promises both efficiency and a reinvigorated emphasis on the human touch.

3.3. Industry 5.0, Iteration, and Visualization

Personal Fabrication

Personal fabrication is an emerging field in Human-Computer Interaction that allows individuals to fabricate products in their homes using digital data and 3D printers. This technology uses these printers and other digital fabrication tools to create three-dimensional solid objects from digital files in just a few hours. Both additive and subtractive processes are used, allowing the production of precise parts

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from polymers and metals. Despite the potential for non-technical users to create custom objects, most currently rely on downloading existing models (Camburn, Wood 2018).

The democratization of personal fabrication has the potential to significantly disrupt industries such as product design, interior design, carpentry, and engineering. It empowers individuals, allowing them to use computing for physical matter. This democratization of design can be compared to the impact of the Internet on consumers and producers, presenting new opportunities just as the Internet did.

The development of user-friendly 3D design software, like TinkerCAD and SketchUp, has made 3D design accessible to a broader audience, even in educational contexts. The rise of virtual design tools and platforms, such as online video games and Lego's online factory, have further allowed users to develop design skills, share ideas, collaborate, and customize and hack products.

Physical computing, which includes embedding interactivity or intelligence into everyday objects, is another aspect of this maker trend. Microcontrollers like Arduino have facilitated a greater understanding of electronics among people. Biomimicry, the practice of reverse-engineering natural materials and processes, is also a valuable source of inspiration for designers and scientists in various fields.

Personal fabrication also has the potential to impact the profession of industrial design significantly. For example, the Portuguese brand Feltrando exemplifies how personal fabrication can combine local cultural heritage, sustainability, craftsmanship, and industrial textile residue (felt) to create high-quality textile products. As demands for faster, more powerful, functional, minor, cheaper, and user-friendly products increase, the challenges faced require unconventional problem-solving techniques and exploration of new technologies, such as personal fabrication.

FabLab

FabLabs, or digital fabrication laboratories, were first created by Professor Neil Gershenfeld at MIT in 2001 to provide an accessible and affordable maker space. These labs offer a place for creativity, learning, and innovation, allowing anyone to use advanced technology, such as 3D printers and laser cutting, to make almost anything. FabLabs are small-scale workshops with computer-controlled tools aiming to disrupt the traditional manufacturing industry, akin to how microcomputers changed computing (Savastano et al. 2017).

They serve multiple purposes, including the rapid prototyping of industrial products and the low-cost manufacturing of open-source designs. Their versatility is seen in their ability to empower individuals to create bespoke devices adapted to specific needs. These labs are critical to Do-It-Yourself (DIY) communities, cultures, and projects. They provide a platform for transforming ideas into physical prototypes.

Despite not yet competing with mass production for widely distributed products, FabLabs has shown potential in empowering individuals to create intelligent, personalized devices, which is not practical or economical with mass production. They provide physical spaces offering access to digital and industrial-grade fabrication, electronics tools, open-source software, and programs supporting prototyping.

The projected growth of FabLabs is termed "Lass' Law," which predicts that these labs will double roughly every 18 months due to the increasing affordability and digitization of machinery. This proliferation could lead to custom fabrication becoming ubiquitous in the future.

The estimated cost of creating a mobile FabLab is \$298,000, including the design, procurement, construction, preparation, and training phases. This process can take 6-18 months, depending on the project and the network's capacity.

There are examples of successful FabLab implementation worldwide. They have been used as place-based policy tools in Europe to respond to regional and local challenges. Shepherds in Norway used their FabLab to create a system for tracking sheep using mobile phones. At the same time, people in Ghana made an innovative truck refrigeration system powered by the vehicle's exhaust gases.

FabLabs can contribute to urban regeneration and local transformation, exemplified by the Municipality of Lisbon's decision to open a Fab Lab in a central location, re-purposing a new food market into a fully-equipped digital maker space.

These labs also strengthen the culture of innovation and creativity. FabLab EDP in Portugal aims to interact with society by promoting entrepreneurship and active citizenship and providing resources for generating and implementing ideas.

In conclusion, FabLabs presents a significant innovation in manufacturing and prototyping, offering unprecedented opportunities for creativity, entrepreneurship, and problem-solving at the local level. Their anticipated growth may lead to a significant shift in how we perceive and engage in manufacturing processes.

4. CONCLUSION

This work details a set of technologies for Industry 4.0 and Industry 5.0, structured in a framework with three steps: (i) data and connectivity, (ii) intelligent systems, and (iii) interaction and visualization. The role of Artificial Intelligence (AI) in Industry 4.0 and 5.0 needs to include input (the data and the connections) and output (the visualization and the interactions).

From our point of view, Industry 4.0's topics, like digital twins, additive manufacturing, and augmented reality, where holography plays a pivotal role, will continue to evolve.

Regarding Industry 5.0, the spirit of AI will be combined with topics such as Data Quality, 6G networks, Cobots, Personal Fabrication, and FabLabs. Data Quality enables us to improve fairness and reduce bias in machine learning models. 6G networks play a significant role, projecting to offer even faster speeds, lower latency, and higher capacity than its predecessor. Cobots offer the advantages of automation, promoting harmonious human-robot collaboration in the workplace. Personal fabrication is the next step in additive manufacturing, using both additive and subtractive processes and allowing the production of precise parts from polymers and metals. Fabric labs, or fabrication laboratories, are critical to Do-It-Yourself communities by extending the open-source concept from software to hardware design.

The philosophy behind Industry 5.0 is not just about manufacturing for profit. It promotes principles of sustainability and human-centricity. As shown in Figure 1, the role of AI is the hinge between the pairs (data and connectivity) and (interaction and visualization).

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