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Chapter 1

Artificial intelligence, machine learning, and deep learning technologies as catalysts for industry 4.0, 5.0, and society 5.0

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Abstract: Industry 4.0 brought with it by the next-gen Industry 5.0 and Society 5.0 paradigms, catalysed by Artificial Intelligence (AI), Machine Learning (ML), and Deep Learning (DL) technologies. These advances have the benefit of encouraging sustainability, improving output, and updating manufacturing. By enabling self-decision, continuous monitoring, and predictive maintenance with the processing of large data, AI is dramatically reducing downtime and associated costs of system downtime. As a result, ML algorithms, in light of their applicability for continuous learning and adaptation, have contributed to enriching product quality, streamlining supply networks and okaying personalized customer experiences. Neural networks are also being leveraged to improve computer vision and speech capabilities, for applications such as smart automation and human-robot cooperation in challenging industrial contexts. Industry 5.0 truly puts humans back at the centre of innovation. It is aimed to create an evolved society in which AI, ML, and DL are fused with the digital and physical world Society 5.0. The integration aims to address a plethora of societal challenges: environmental sustainability, health and ageing population, among others. It is a convergence of these said technologies that lead to a paradigm shift towards more resilient, adaptive, and sustainable industrial ecosystems. This paper aims to address these questions in a systematic way to offer a comprehensive view of what the future industrial landscape could look like leveraging the promise of Industry 4.0 and Industry 5.0 thus, and more opportunities to embrace intelligent and sustainable industries of tomorrow.

Keywords: Artificial intelligence, Machine learning, Deep learning, Internet of things, Industry 4.0, Industry 5.0, Society 5.0

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1.1 Introduction

Industry 5.0 and Society 5.0 represent the next phase of modernization in the way technologies have incorporated into industrial processes and societal framework on Industry 4.0, the fourth industrial revolution during which digital systems are integrated with the physical systems, and the associated common realities of increased automation, data exchange, and real-time capabilities enabled by contemporary industrial technologies such as; cloud computing, cyber-physical systems, and the Internet of Things (IoT) (Paschek et al., 2022; Raja Santhi, & Muthuswamy, 2023, Paramesha et al., 2024a). The people and machine collaboration are the main intention for Industry 5.0 to make a profession in which workers and machines can easily work together (Paschek et al., 2022; Rane et al., 2024a). Industry 5.0 represents the combined method among Industry 4.0 and worker-friendly on-line applications using this usage or want of labour, which who will be playing a contemporary interface among humans and the newest technology (Mourtzis et al., 2022; Rane et al., 2024b). It uses the power of the human creativity to solve problems and is complemented by the precision and efficiency of intelligent systems. In Society 5.0, a future society in which both the public and private sectors can craft solutions to many of the structural societal challenges by leveraging sophisticated societal-technical approaches, these ideas are explored in greater detail (Huang et al., 2022). These transformational changes can be achieved by deep learning (DL), machine learning (ML) and artificial intelligence (AI) which are the three basic building blocks (Adel, 2023; Paramesha et al., 2024b; Rane et al., 2024c). They are analytical and computational abilities to help us process and analyse large volume of data, find patterns and make self-decisions. Being an AI enabled organization to build Industry 4.0 through specifically focusing on AI and ML and a bit of what DL enables for predictive maintenance, in product quality. They are the ones which allow Industry 5.0 to bring that personalized and human-cantered touch, where automation is now a catalyst to human skills and not a replacement. Society 5.0 realizes a kind of utopia, the beneficiaries of that being, sharing and creating all kinds of information resources in this world and better than its predecessors, being blessed with the benefits of solving the complex societal problems with AI powered solutions on the environment, health, safety or even urban planning. The application of AI, ML and DL combined with the principles of Industry 4.0, 5.0 and Society 5.0 appear to take us to a new realm of intelligent and flexible systems (Kasinathan et al., 2022; Paschek et al., 2022; Paramesha et al., 2024c). Such intersectionality leads to a better, more balanced society and it also makes people perform and think better. All of these emerging technologies are being assimilated, in progress, into newer healthcare systems, autonomous vehicles, and smart cities. Challenges of Implementation Despite the exciting possibilities of AI, ML, and DL in complex industrial and societal systems, the actual implementation is a challenging task to achieve (Rane, 2023a). Factors include the need for strong regulatory frameworks, issues of ethics, and challenges around data privacy. In addition, the worker must continually cultivate new skills and adapt to changing technology, underscoring the importance of education and retraining.

Contributions of the research work:

1) The literature review provides a comprehensive analysis of current trends, challenges, and potential future developments in this field.
2) This study provides a snapshot of the current research field by extracting the most frequent keywords and topical clusters that have mostly been discussed in the relevant articles in recent years.

1.2 Methodology

In this study by applying a systematic approach, an attempt is made to understand the interplay of AI, ML, DL technologies in Industry 4.0, Industry 5.0, and Society 5.0 based on literature review. The methodology started with a systematic literature review for extracting significant research articles, conference papers, and review papers for different kinds of areas, from a range of different academic databases (e.g., IEEE Xplore, ScienceDirect, SpringerLink, and Google Scholar). This search was conducted with targeted keywords of "Industry 4.0", "Industry 5.0", "Society 5.0", "AI", "ML", and "DL" with the intent to cover the past ten years of work to provide a comprehensive view of recent advancements and trends. The literature was then screened based on title, abstract, followed by full-text review of selected papers to extract key information and insights. This thematic arrangement led to a large perspective of the part of AI, ML, and DL based technologies in enhancing Industry 4.0, Industry 5.0, and Society 5.0, and allowed us to recognize research spaces and potential area of focus for future investigation. Next, a keywords analysis was conducted to update on research trend, focus area within the literature in the corpus of the paper selected. Extracted keywords were analyzed to find the most popular terms in the identified papers, which would also give an idea on the focal areas and emerging themes of concern among the academic bandwagons. A word cloud with the former to intuitively display the main topics and the latter to quantify the dominance and significance of those topics respectively.

To observe the relationships between different themes in research, we have carried out a co-occurrence analysis of the keywords utilized in the included studies. The research analysed how often two keywords appeared together in the papers. We used the co-occurrence data to build a network map in order to show the connections and interactions between different research topics. This network map assisted in identifying the clusters of co-occurring themes and central topics that help to bridge different bodies of research. In order to reveal deeper insights into the structure and organization of the research landscape, we performed a cluster analysis of the co-occurrence data. We implemented clustering algorithms to partition the network of co-occurring keywords into clusters. Every cluster was a clear lump of topics that were often titled together in the literature. Clusters were analyzed considering themes and sub-themes throughout the research field. The results of the cluster analysis provided a more explicit knowledge of the multifaceted aspect of AI, ML, and DL technologies with respect to Industry 4.0, Industry 5.0, and Society 5.0

1.3 Results and discussions

Co-occurrence and cluster analysis of the keywords

The network diagram (Fig. 1.1) shows the cluster analysis along with keyword co-occurrence. The network illustrates these areas of concern and how they are inter-related by showing the occurrence and connections of important terms on Industry 4.0, 5.0 and Society 5.0. Centrally on the diagram is "Industry 4.0" placed and thus also the underlying technologies of interest are highlighted. The concept of Industry 4.0 is the fourth generation of industrial transformation that includes cyber-physical systems, the internet of things, and the internet of systems. Another buzzword that entered into relevance is the "artificial intelligence" suggesting the urgency in guiding innovation and efficiency in numerous fields. Since the nodes are larger it implies, they are frequent and quite critical in the literate. On only two hubs, clusters "machine learning" and "deep learning". Machine learning is the aspect of AI science and includes the building of algorithms that allow a computer to learn from data and make accurate predictions. Deep learning falls under machine learning, which many machine learning algorithms are based off of used large layered neural networks to interpret and learn from complex data patterns. This is because these nodes are very close to each other and they have strong connections with each other, thus depending upon each other, cumulating to Industry 4.0 footprint.

The Internet-of-Things (IoT) is another widely used term that highlights the necessity in the same domain, its basic functionality to connect, share data, and automation. The term of IoT cluster, a liaised term with "cyber-physical system" or "embedded system" or "5G mobile communication system", provides the technological framework in terms of which devices and systems can connect to each other. Within the context of Industry 4.0, the areas of "smart manufacturing" and "decision making" are the most important domains. Smart manufacturing is the application of cutting-edge technology to factories, with the goal of using machine learning and artificial intelligence to produce the best results for a company. This association is indicative of how AI-driving technologies are transforming the industrial sector towards data and automation. The Fig. 1.1, another key concept that further addresses the importance of "sustainability" and "sustainable development"; that keeps with the current and growing trend of environmentally friendly practices within the industry. This class is represented by the themes of energy efficiency and energy use, indicating the need to reduce resource use and energy in order to meet sustainability targets.

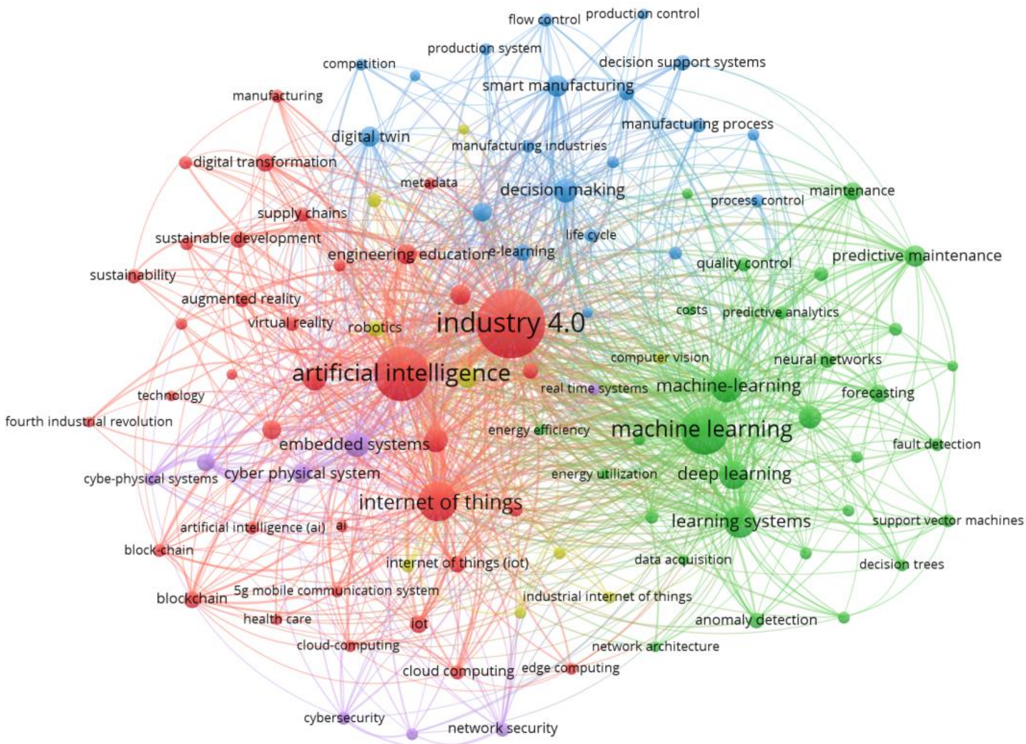

Fig. 1.1 Co-occurrence analysis of the keywords in literature

Blockchain and cloud computing are basic sectors of the networking industry and they are supposed to dominate the future for the safe, decentralised processing of data and allowing for a parallel free use of computational power. These technologies combined form an integral part of how to automates industries could be applied to advance visibility, protectiveness, profitability over industries. The security of a computer network refers to one of the broadest areas defining the needs in secure interconnections of any networked devices against cybercrime or another form of cyber-incidents of potential unauthorized parcels being made available by these networks. Considering these packages have tight connections with AI and related projects like IoT, it becomes a rather necessary point for the heavy usage of robust security controls in an era of more connected and more automated industrial environments. The use of AI and ML techniques in predictive maintenance allow for the prediction of possible equipment breakdowns and at the same time, enables one to select carefully the schedule of maintenance, of different activities. This classification falls under "quality assurance," "error detection," and "forecasting analysis" which, again, is proof to how valuable data-driven information can be in regard to achieving higher TI and reducing downtime.

Within the network, the "digital twin" and "augmented reality" apportion a part of the emerging technology pie in the industry 4.0 context. The digital twin is the sophisticated virtual/visual depiction of the physical system that enables real-time inspection and real-time evaluation. Augmented reality, on the other hand, displays virtual information on top of the real world to enhance user interaction and decision making. On another side there is education, training and innovation and how it is helping to develop skills and human capital and these clusters are closely related with new technologies such as AI, and IoT.

Evolution of industry 4.0, 5.0, and society 5.0

Fig. 1.2. Shows the industrial revolutions. The Industrial Revolution was one of the most tremendous transformations throughout human history. It began in late 18th-century England and was a colossal shift in production methods from manual labour to mechanized factories. Mechanization and the introduction of steam power generally influenced agricultural output and productivity in manufacturing. This era reshaped the structure of societies, economies, and people's style of life and laid the foundation for industrialized society. Today, it still symbolizes the technological-industrial impetus of humankind.

Fig. 1.3 describes the fundamentals of Industry 5.0 and Society 5.0, emphasizing their shared pillar: human-centricity. Both Industry 5.0 and Society 5.0 aim to create a sustainable, resilient, and human-centric future, leveraging advanced technologies to enhance both industrial processes and overall quality of life.

Industry 5.0 has three basic focuses:

1. Sustainable: Actively leading in sustainability and respect for planetary boundaries.

2. Resilient: The value of being agile and resilient lies in the flexibility and adaptability of technology.

3. Human-Centric: Talent promotion, diversity, and empowerment in all aspects, with an overarching commitment to human-centric design and operation.

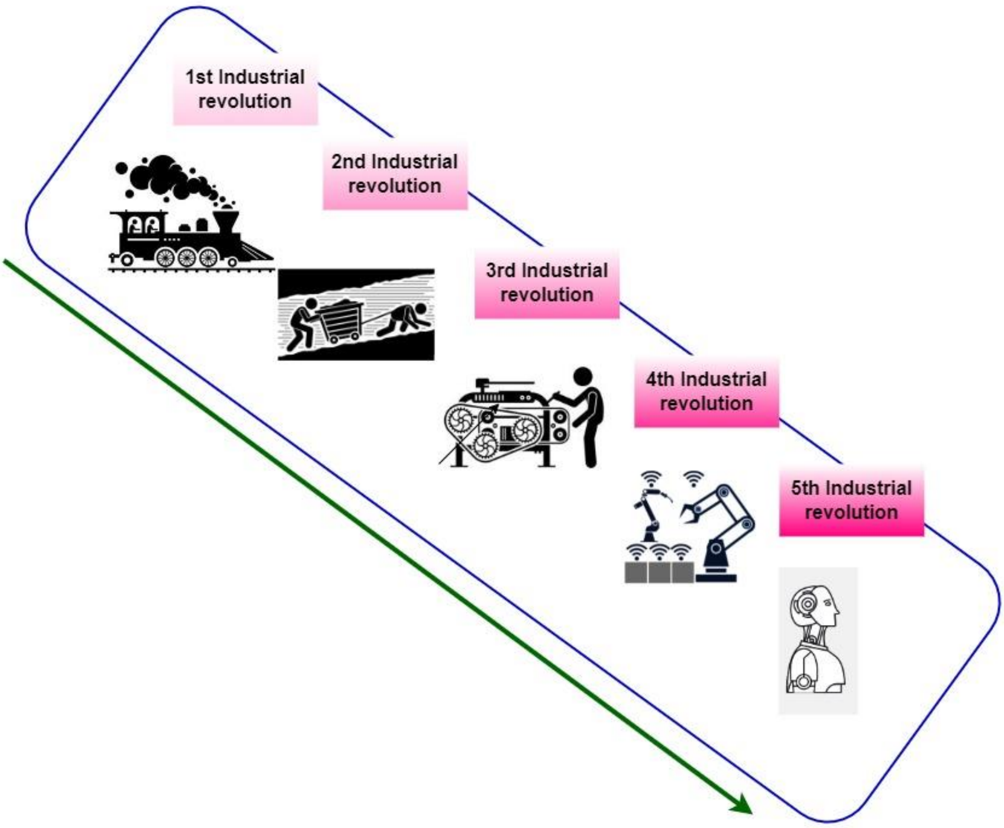

Fig. 1.2. The industrial revolutions

Society 5.0 integrates the principles of Industry 5.0 into society, moving toward a super-smart society with:

1. Super Smart: Cyberspace will integrate perfectly with the physical space using technologies such as those associated with 5G, large sets of data, and artificial intelligence, amongst others.

2. Lean: Guaranteed supply of goods and services required with a focus on efficiency at required levels and times.

3. Human-Centric: Wrapping up a high-quality life with comfort and vitality, extending even further the human-centric approach of Industry 5.0.

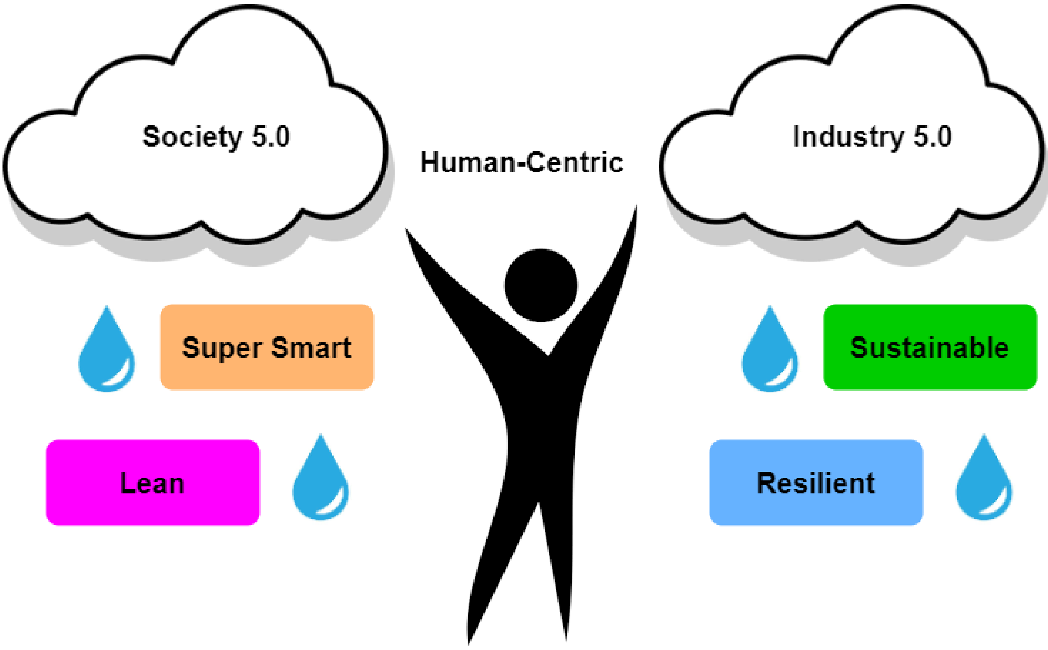

Fig 1.3 Human-Centric Evolution: Industry 5.0 and Society 5.0

Table 1.1 compares the different technological perspectives between Industry 4.0 and Industry 5.0. Perspective one is centered on the continuation and incremental improvement of already existing digital technologies viewed as a part of a natural extension of Industry 4.0. Technologies emphasized by this perspective include additive manufacturing, big data analytics, blockchain, cloud computing, and the Internet of Things (IoT). The second perspective symbolizes a far-reaching digression from conventional digital technologies with a revolutionary change in technological advancement. It focuses on innovations like artificial general intelligence, bio-inspired technologies, brain-machine interfaces, and self-healing materials. Perspective Three bridges both Industry 4.0 and Industry 5.0 with a hybrid approach, focusing more on transformative new technologies. From this perspective, one finds adaptive robotics, cognitive cyber-physical systems, extended reality, and intelligent energy management systems. These three visions combine in an all-inclusive, stage-by-stage concept of the development of different directions in industry digital transformation.

Table 1.1 Comparison of Technological Perspectives in Industry 4.0 and Industry 5.0

Perspective One: Well, it's like the natural, incremental extension of Industry 4.0.	**Perspective Two**: Radical Departure from Industry 4.0	**Perspective Three**: Considerable transformation of Industry 4.0 technologies

Additive manufacturing: Boosting the power of 3D printing for custom production.	Artificial General Intelligence: A system with cognitive capabilities like humans.	Adaptive, cognitive robotics—robots which adapt and learn in non-stationary environments.
Big data means advanced analytics for improved decision-making.	Bio-inspired technologies: Imitation of biological processes for innovation.	Cognitive cyber-physical systems: An integrated AI basis of physical processes to Smarter Operations.
Blockchain: Protecting transactions and data integrity.	Biosensors: Real-time monitoring of biological conditions.	Cognitive/creative artificial intelligence: AI systems that do create and innovate.
Cloud computing: Scalable, flexible IT resources.	Brain-machine interfaces—direct communication between brains and machines.	Extended Reality: Augmented and Virtual Realities for Immersive Experiences.
Cybersecurity and Cryptography: The Security of Digital Infrastructures.	Causal artificial intelligence would be AI that understands cause-effect relations.	Human Recognition Technologies: High-Tech Biometric Systems for Security and Personalization.
Edge computing: Processing data at source.	Fiber computing technologies: High-speed data transmission and processing.	Industrial wearables: intelligent devices that empower workers' abilities and safety.
Embedded Systems: Specialized computing systems inside larger devices.	Genomics: advances in personalized medicine and genetic engineering.	Internet of Everything: All devices interconnected for the purpose of perfect communication.
Enterprise systems are integrated software for business processes.	Humanoid robots: These are robots that the resemblance and act like human beings.	Mobile autonomous robots are designed to move on their own and perform tasks independently.
Execution systems: Those systems in charge of production and operation management.	Internet of Medical Things: Connected Medical Devices for Healthcare.	The multiscale dynamic simulation will compute processes at various involved scales for optimization.
Industrial control systems: Manufacturing process electrification and automation.	Autoself-healing/repairing material: Materials that, in some way, automatically self-repair.	Smart energy management systems: Efficiency through better use of energy.
Industrial robots: These are production automatons.	Smart learning material: Educational material	Smart product lifecycle management: Managing product data from creation to disposal.

	responding to learners' needs.	
Internet of Things: Interconnected devices sharing data.	Swarm Intelligence: A Collective Behavior in Decentralized Systems.	
Machine Learning: Algorithms that improve from experience.		
Networking Infrastructure: Robust, scalable networks.		

Key technologies in Industry 4.0, 5.0, and Society 5.0

Industry 4.0, Industry 5.0, and Society 5.0 are stages in technology development and integration into different aspects of human life (Carayannis et al., 2022; Paramesha et al., 2024d). Every phase leverage innovation from the phase before, as new technologies and paradigms are added, which escalates the overall societal efficiency, productivity, and prosperity of society (Kasinathan et al., 2022; Tyagi et al., 2023). The basic tenets of Industry 4.0 are the IoT, big data analytics, AI, cloud computing, and cyber-physical systems. Table 1.2 shows the key technologies in Industry 4.0, 5.0, and Society 5.0.

Industry 4.0: The fourth industrial revolution

IoT: IoT is the base of Industry 4.0 which connects physical devices to the internet and collecting and sharing the data (Dautaj, & Rossi, 2021). This interconnection allows real-time tracking, maintenance forecasts and automation (Roblek et al., 2021; Dautaj, & Rossi, 2021). Smart factories, for example, use the IoT to streamline production lines, minimize downtime and improve operational performance.

Big Data Analytics - The data collected by IoT devices is massive and big data analytics needs to be employed to find actionable insights from it (Trehan et al., 2022; Paramesha et al., 2024e). For manufacturers, big data analytics is all about analysing trends, making better decisions and reducing waste in the process. It assists in equipment failure predictions, improves quality of products and lowers operational costs.

AI: AI plays a fundamental role in converting data into insights, so it is essential to every organization (Huang et al., 2022; Carayannis, & Morawska-Jancelewicz, 2022). Cash flow forecasting, supply chain optimization and product design update can be improved with the use of machine learning algorithms. There are other ways in which AI could also be used to increase the accuracy and speed of manufacturing like in this instance, with AI-powered robots and automation systems, manufacturers can improve the level of coordination between these systems and carry out a large portion of tasks automatically, hence minimizing human error and operational costs.

Cloud Computing: A type of internet-based computing that provides shared processing resources and data to computers and other devices with all 24/7 on-demand Cloud computing systems are one of the most cost-effective ways to utilize AI (Paschek et al., 2022; Sharma et al., 2024). It facilitates collaboration between locations, promoting integration and organization of stages of production. Another important facility that cloud platforms provide are advanced security measures to secure sensitive data.

Cyber-Physical Systems (CPS): A system that connects the worlds of embedded systems by connecting the digital and real worlds through networks and allows information sharing and control in real time (Jazdi, 2014). CPS enables the realization of smart factories, where machines and entire systems are networked and able to communicate and act autonomously (Jazdi, 2014; Oks et al., 2022). This results in higher efficiency, lower wastage and better quality of the product.

Industry 5.0: Human-centric innovation

It is a phase focused on personalization, sustainability, and ethics-based on technologies like cobots (collaborative robots), AR (augmented reality), and advanced HMIs (human-machine interfaces) (Xu et al., 2021; Leng et al., 2022). Fig. 1.2 shows the sankey diagram on key technologies in Industry 4.0, 5.0, and Society 5.0.

Collaborative Robots (Cobots): Cobots are designed to collaborate with humans to increase efficiency and safety (Prassida, & Asfari, 2022; Liao et al., 2023). These machines are built with sensors and AI to be able to adapt human movements so that they can be near them without danger in the work area, something that industrial robots could not do until now. These are increasingly used for tasks requiring precision and flexibility such as assembly, quality inspection and packaging.

Augmented Reality (AR): AR superimposes digital information on the physical world, offering workers real-time help (Leng et al., 2022; Zafar et al., 2024). AR can also be used to help technicians in manufacturing navigate a complex assembly job, catch mistakes and improve training. It also opens up the possibility of remote collaboration, so experts in one location can provide immediate support to another no matter how many miles apart they are.

Human-Machine Interfaces (HMIs): facilitate human interaction with machines with ease (Adel, 2023; Panter et al., 2024). Intend interfaces use natural language processing (NLP), gesture recognition, and brain-computer interfaces (BCIs) in order to establish simple and effective communication pathways. The role of HMIs is essential in improving user experience and making technology cater to human demands.

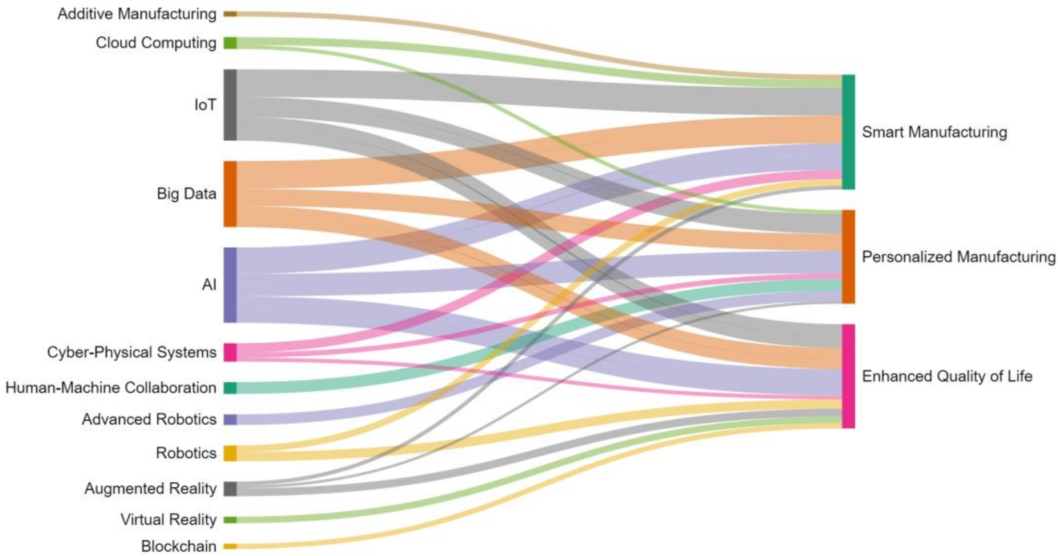

Fig. 1.3 Sankey diagram on key technologies in Industry 4.0, 5.0, and Society 5.0

Personalization and Customization: Industry 5.0 instead is shift is towards making individualized products which are more in line with individual preferences. One example is the use of advanced AI algorithms that use the data of consumers for predicting trends and preferences, so that we can manufacture personalized-at-scale products. It improves customer satisfaction as the seller only produces goods when an order is placed.

Sustainability and ethical issues incorporating sustainability into Industry 5.0 is important the need for a sustainable economy that is, an economy which has the ability to continue to, over a long period of time, function well, support community and ecological vitality, and be flexible enough to adapt to change (Tyagi et al., 2024). AI and IoT are leveraged here for sustainable energy management and reduce pollution, emissions or circular economy. Industry 5.0 also encompasses ethical issues that cover data privacy and labour rights, among others to make sure that the adoption and advancement of technology benefits society at large.

Table 1.2 Key technologies in Industry 4.0, 5.0, and Society 5.0

References	Technology Category	Industry 4.0	Industry 5.0	Society 5.0
Coronado et al., (2022)	Automation and Robotics	Advanced robotics and automation	Human-robot collaboration	Social robots and human-centered robotics
Mourtzis et al., (2022); Uddin et al., (2023)	AI	AI and machine learning for process optimization	AI for personalized solutions and human enhancement	AI for societal well-being and sustainable development
Mourtzis et al., (2022); Adel, (2022); Saikia, (2023)	IoT	IoT for connected machines and devices	IoT for human-centric applications	IoT for enhancing quality of life and smart living
Mourtzis et al., (2022); Adel, (2022); Troisi et al., (2023)	Big Data and Analytics	Data analytics for operational efficiency	Data-driven decision making with human input	Data for societal insights and public services
Adel, (2023)	Cloud Computing	Cloud-based infrastructure and services	Hybrid cloud solutions for better human interaction	Cloud services for public welfare and smart cities
Sverko et al., (2022); Taj, & Zaman, (2022)	Cyber-Physical Systems (CPS)	Integration of physical and digital systems	Human-in-the-loop CPS	CPS for societal challenges and disaster management
Yao et al., (2024); Mourtzis et al., (2022)	Additive Manufacturing	3D printing and rapid prototyping	Customization and personalization through 3D printing	Distributed manufacturing for local needs
Leng et al., (2023); Hemamalini et al., (2024)	Blockchain	Secure and transparent supply chains	Blockchain for trust and human rights	Blockchain for secure digital identities and democracy
Hassan et al., (2024)	Augmented Reality (AR) and Virtual Reality (VR)	AR/VR for training and maintenance	AR/VR for enhanced human-machine interaction	AR/VR for education, healthcare, and social inclusion

Mourtzis et al., (2022); Narkhede et a., (2023)	Sustainable Technologies	Green manufacturing and energy efficiency	Sustainable practices with human focus	Technologies for environmental sustainability
Adel, (2023); Sharma et al., (2024)	Edge Computing	Real-time data processing at the edge	Enhanced human-machine interaction at the edge	Edge computing for public safety and emergency response
Efe, 2023; Sharma et al., (2024)	Quantum Computing	Emerging quantum technologies for complex problems	Quantum computing for advanced human applications	Quantum computing for societal problem-solving
Alves (2022); Pereira et al., (2023)	Human Augmentation	Wearable technology and exoskeletons	Augmented reality interfaces and brain-computer interfaces	Human augmentation for disability support and enhancement
Lv, (2023); Wang et al., (2024); Fernández-Caramés, & Fraga-Lamas, (2024)	Digital Twin	Real-time digital replicas of physical assets	Digital twins for human-centric applications	Digital twins for societal infrastructure and services

Society 5.0: A Smart Society

AI: AI is the primary element in innovation across all sectors in Society 5.0 (Zamzami et al., 2022). Better patient outcomes through AI-guided diagnostics and tailored treatment plans in healthcare (Al Mamun et al., 2021; Zamzami et al., 2022). Autonomous vehicles and smart traffic management systems using AI can improve safety and reduce traffic congestion in transportation. AI also ensures proper education for students using personal learning experiences, along with advancement by providing the facility of acquiring knowledge.

IoT: As in the important stage of society, IoT play a key role in the fifth stage, connecting devices and systems to create smart cities, homes and industries (Nair et al., 2021; Mishra, & Pandey, 2023). Through IoT, smart city initiatives monitor and manage urban infrastructure such as waste management, energy distribution, and public safety. IoT devices in smart homes increase convenience and energy efficiency by automating and monitoring in real time.

Robotics: Society 5.0 is by definition not only an industrial robotics but also a robotics for healthcare robotics and for agriculture robotics for daily living (Calp, & Bütüner, 2022; Bissadu, et al., 2024). Inspired by this, there exist some caregiving robots that can help older persons maintain an active and independent lifestyle (Dautaj, & Rossi, 2021; Calp, & Bütüner, 2022). Farmers can use agricultural robots to improve farming methods, increasing output and reducing menial tasks. In daily life, robots are useful tools for cleaning and lower their burden work.

Data security, transparency and trust in blockchain technology: For finance, blockchain allows for transactions that are more secure and more efficient by preventing fraud and increasing trust (Beniiche et al., 2022; Tyagi, et al., 2023). Blockchain in supply chain management provides visibility and traceability, ensures the genuineness of products. This also provides support for decentralized identity and enablement of data privacy and security through blockchain.

5G Connectivity: Delivering the high-speed, low-latency connectivity necessary for seamless IoT device integration and high-volume, real-time data exchange (Ghosh et al., 2021). It also makes possible innovations such as telemedicine, autonomous driving and smart grid operation. The birth of Society 5.0 is a reality, but to make a comprehensive impact necessitates the realization of 5G, which separately supports the large-scale data transmission and communication burdens associated with a super-smart society (Ghosh et al., 2021; Thakur et al., 2022).

Quantum Computing: Quantum computing has the potential to address problems so complex that it is beyond the reach of classical computers (Griffin et al., 2021). Quantum computing can be powerful enough to reverse-engineer, and Society 5.0 fields like cryptography, materials science, and drug discovery, will forever alter (Griffin et al., 2021; Zamzami et al., 2022). When it comes to processing huge amounts of data extremely fast it could potentially revolutionise many industries and provide huge gains in optimisation and innovation.

This Sankey diagram (Fig. 1.3) reveals how advanced technologies flow and inter-relate across three major industrial and societal paradigms. The diagram predicts that in Industry 4.0, technologies such as IoT, Big data, AI, cyber-physical systems, cloud computing, robotics, additive manufacturing, and augmented reality will be increasingly applied towards smart manufacturing processes. This kind of technologies helps to automate things, real-time data analysis and run an efficient production process. In Industry 5.0, the focus moves to personalized manufacturing of goods, people will collaborate machine-human, replaces advanced robotics, AI, IoT, Big data, cyber-physical systems, cloud computing, and augmented reality etc. This approach highlights the collaboration between human intelligence and machine abilities to develop new manufacturing systems that are more flexible and effective. Society 5.0 goes further to apply these technologies to improve our quality of life as a society. The applications illustrate how AI, IoT, Big Data, robotics, augmented reality, virtual reality, blockchain, and cyber-physical systems are key to alleviating the challenges across the different aspects of daily life, including health, mobility and general societal welfare. The diagram also shows cross-industry technologies AI, IoT, Big data are crucial for all 3 paradigms. This is evidently the case for AI, which has proven itself to straddle various industries in its role in smart manufacturing, personalized manufacturing and health as an example of just three ways it is having such a profound impact on lives. IoT and Big data were among the areas that showed big influences that marked these two areas as critical to connecting devices, analysing large amounts of data and driving decision with insights. This holistic perspective highlights the interplay and versatility of technology to create innovation and productivity across various industrial and societal domains.

Role of artificial intelligence technologies in Industry 4.0, 5.0, and Society 5.0

Industrial revolution 4.0, also known as the Industry 4.0, refers to process integration of digital technologies in manufacturing industries (Rane, 2023b). To this end, AI technologies contribute to improving efficiency, productivity, and flexibility in manufacturing systems (Huang et al., 2022; Kasinathan et al., 2022). Key AI applications for Industry 4.0 are predictive maintenance, quality control and autonomous robots. Predictive maintenance tools usually have machine learning models implemented that use data from the sensors put into machinery. The physical effects of wear and tear on equipment can be predicted to determine when equipment is likely to fail and with predictive maintenance manufacturers can proactively manage and prevent these failures which in turn can reduce downtime and operational costs. Another key domain in which AI has an extraordinary potential is quality control (Carayannis, & Morawska-Jancelewicz, 2022; Paschek et al., 2022). AI-supported computer vision systems scan products for defects faster and more accurately than humans, with greater consistency and less waste. Production lines are being transformed by AI-controlled robots that are independent of human guidance.

Industry 4.0 is about the automation and digitalization of the manufacturing processes, meanwhile, Industry 5.0 focuses more on the collaboration between humans and machines and wants to go to a more human-centric and sustainable way (Mourtzis et al., 2022; Polat, & Erkollar, 2021). The research conducted presents a vision for the former which includes the essential role of AI in human-machine collaboration and manufacturing sustainability improvements. Aggregation of AI based cobots Industry 5.0 involving AI driven cobots (Collaborative robots) to aid the existing workforce and provide power to existing workers rather than replacing them. Cobots are collaborative robots that are built to understand and react to the actions of humans, while the cobots execute the tasks and the cobots adapt. AI-based exoskeletons can help employees to lift heavy objects which reduces the physical load and is improves efficiency. Industry 5.0 is also marked by sustainability (Trehan et al., 2022; Rane, 2023c). AI is an invisible hand that makes resource management more efficient in terms of energy consumption, reduces waste and reduces the environmental burden of manufacturing. An example: By examining data from production lines, AI algorithms can root out inefficiencies and recommend changes that save energy and reduce emissions. Further, the optimal supply chain realignment using AI ensures that procurement of raw materials is sustainable and inventory levels are kept low in a way which reduces the carbon footprint of manufacturing operations. Through AI implementation across the value chain, Industry 5.0 revolves around the idea of creating a circular economy by recycling and reusing resources as well as repurposing them, thereby fostering sustainability and cutting down the carbon footprint.

Conceptualized in Japan, Society 5.0 refers to the ultimate positive shaping the ideal future-creating a human-centric super smart society overflowing with prosperity and solutions to social challenges that innately feel like improvements (Huang et al., 2022; Kasinathan et al., 2022). This vision is not limited to just the industrial sector, but includes all walks of life, from healthcare and education to transportation and public services. AI is changing the landscape of diagnostics, treatment and patient care in healthcare. AI tools can process medical images, such as x-rays or MRIs, to perform cancer detection with high efficiency. Powered by machine learning, predictive analytics unveil patterns in patient data, and inform personalized treatment plans and proactive healthcare management. In addition, AI-powered virtual assistants are being used in telehealth to offer medical advice and consultations in remote areas. AI in Society 5.0 is also transforming the educational landscape. With the help of AI, learning platforms can provide bespoke education that meets the needs of the individual student, delivering a learning experience that is both engaging and targeted to improve learning outcomes. Finally, intelligent tutoring systems (ITS) that provide immediate feedback to students can provide better ways to learn difficult concepts. Additional, AI can support teachers by doing some of their administrative job, making them to engage in teaching and communicate with the students more. Throughout the transportation industry, AI is fuelling a new wave of applications that improve safety, efficiency, and sustainability. Self-driven vehicles by AI are assumed to lower accidents caused by human mistakes and to optimize traffic. Traffic management systems can be optimized using AI algorithms to reduce congestion and emissions. What is more, delivery routes can benefit from AI-powered logistics solutions, so that the transportation of goods is done faster and more efficiently. AI is also changing public services in Society 5.0. AI-powered Smart cities provide improved services to their citizens by optimizing the allocation of resources and better urban planning. This includes real-time monitoring of air quality, or the potential to measure traffic conditions with sensors powered by AI, and thus allow city authorities to respond proactively and improve the life comfort in the end. An example of AI used for public safety includes crime prediction in which sophisticated data analysis and surveillance technologies help identify and prevent crime.

AI is making its way to the construction industry and is changing the vast world of construction building project efficiency, environmental and worker safety, and sustainability (Rane, 2023d; Marinelli, 2023). Every part of construction, from design and planning to execution and maintenance, are harnessing AI powered solutions. Combining Building Information Modeling (BIM) with AI technology produces an intelligent 3D model, which revolutionizes the planning, design, and execution of construction projects. Using these models can help us to identify some of this early on therefore reducing costs and time delays. This includes the ability to use AI-driven predictive analytics to forecast project timelines, costs and resource needs, and speaks to those capabilities as well as the platforms should give projects a lift by enhancing project management and decision-making confidence. AI-enhanced drones and robots are also widely used to lay bricks, excavate, and perform scanning amongst others, for tasks such as surveying, this autonomous construction equipment's are growing faster in these construction activities and is known to improve accuracy while bringing down labour costs. In addition, AI is allowing for safer construction sites through real-time site condition monitoring, predictive hazard identification, and alerts for avoiding any accidents. Because the benefits of AI are not limited to our daily life but also in terms of sustainability when it comes to construction such as energy efficiency, waste reduction, and use of environmentally friendly materials (Marinelli, 2023; Musarat et al., 2023). By leveraging AI systems, smart buildings can help minimize energy consumption, which is essential to the overall efficiency and sustainability of the built environment. The construction industry will further evolve towards becoming even more efficient, safe, and sustainable as AI technologies continue to integrate with it, in the name of Industry 4.0, 5.0, and Society 5.0.

Table 1.3 shows the benefits for every industry. Cloud computing has made a great deal of difference in varied verticals during recent years. It is a model for providing IT resources, like storage and processing, over the internet. This allows organizations to gain enormous benefits from technology without actually investing in and managing their infrastructure, which they can do without. The table below shows some of the significant advantages of cloud computing in different industries. Not every single benefit and drawback may point to or relate to an industry. Cloud computing is a vital tool with many advantages that can greatly help any business. However, every company must be aware of its own needs and requirements before choosing any particular solution for cloud computing. In addition, companies need to realize the various disadvantages of cloud computing.

Table 1.3 Benefits for every industry: unveiling the advantages of cloud computing

Industry	Advantages
Healthcare	* Remote patient monitoring and diagnosis * Robotic-assisted surgeries and minimally invasive procedures * Electronic health records (EHRs) and secure sharing of patient data
Manufacturing	* Optimization of production lines and reduced downtime * Supply chain management and inventory tracking * Enhanced collaboration for product development and innovation
Education	* Personalized learning experiences and online courses * Augmented learning and virtual reality (VR)-based education * Improved communication and collaboration tools for teachers and students
Supply chain management	* Real-time asset tracking and visibility * Blockchain technology for secure and transparent supply chain management * Faster and more efficient deliveries
Disaster management	* Early warning systems and advanced analytics for emergency response * Coordination of resources for disaster recovery and reconstruction * Improved communication between citizens and authorities

Role of machine learning technologies driving Industry 4.0, 5.0, and Society 5.0

Cyber-physical systems, IoT, cloud computing, and cognitive computing are an intensely industrialized, well assembly line in the world of Industry 4.0 (Mourtzis et al., 2022; Trehan et al., 2022). At the heart of this ecosystem lies ML which helps to make automation intelligent, predictive maintenance and lets the organisations take performant decisions (Polat, & Erkollar, 2021; Iqbal et al., 2022). For example, ML algorithms are used in manufacturing to process the large amount of data created by IoT equipment and sensors to predict failure of machinery in advance which, in turn, allows the industry to reduce downtime and save on maintenance costs (Paschek et al., 2022; Mishra et al., 2023). This type of predictive maintenance solution not only increases operational efficiency but also increases lifespans. In addition to this, machine-learning-enabled quality control systems make use of computer vision and pattern recognition to confirm that no defects occur, as they can be identified in real time and avoided from then on, leaving no room for further discrepancy in production quality. Supply chain management also gets benefitted a lot machine learning. Using historical data and existing market trends, ML models predict demand, optimize inventory, and enhance logistics. This results in lower costs, higher customer satisfaction, and a more robust supply chain.

In Industry 4.0, automation and efficiency, Industry 5.0, human-machine collaboration, sustainability, and resilience machine learning remain a core aspect themselves, augmenting human capabilities and creating a more sustainable industrial ecosystem (Mourtzis et al., 2022; Mishra et al., 2023). Rather, in Industry 5.0, automation needs to be harmonized with humans so that robots and smart systems will assist human labour only during more complicated tasks (Roblek et al., 2021; Iqbal et al., 2022). This is where machine learning comes in handy, as it will teach these systems to know how people are reacting and how they prefer things to be administered to them, and sometimes learn about their emotions. Such as collaborative robots (or cobots) with ML and computer vision capabilities, which can be trained on the job by human operators and help them in jobs that need accuracy and motor skills. In addition to increased efficiency, the collaboration notably makes the workplace safer and less physically demanding for employees. Another major target of Industry 5.0 is sustainability. This is in part being accomplished with machine-learning technologies that reduce energy demand and reduce waste. ML algorithms in smart grids can optimize the balance of energy demand and supply on a real-time basis, and thus facilitating the better integration of green energy and minimizing carbon emissions. ML models are used in the manufacturing segment to streamline production processes leading to reduced resource utilisation and less waste generation, thereby, making it a sustainable and circular economy.

Perhaps the most important contribution of machine learning to Society 5.0 would be in healthcare (Mourtzis et al., 2022; Iqbal et al., 2022). They scour imaging scans and electronic health records to detect underlying diseases and propose a personalized course of treatment. That way, they can offer healthier alternatives to patients who may be at risk of developing one or more chronic diseases, in particular, and thus diminish the overall pressure on the healthcare system. In addition, by analyzing large volumes of data using machine learning algorithms, these algorithms can help bring drug discovery to new heights by rapidly finding new therapeutic agents. ML empowers cities in the domain of smart cities to operate smartly by improving traffic management, public safety, resource management using learning from usage data. Smart city is aimed specifically towards IoT systems that help create the smart city infrastructure, ML-backed traffic prediction systems would basically process live data from sensors and cameras to control the flow of traffic, reduce congestion and improve air quality. For public safety, ML algorithms use data from different sources (social media, surveillance systems) to predict and action against potential hazards, thus making living environment safer, and public safer.

Role of deep learning technologies in Industry 4.0, 5.0, and Society 5.0

Deep learning, a specialized subset of machine learning, has a crucial role to play in Industry 4.0, 5.0, and Society 5.0, as it adds value through more sophisticated data analytics, predictive maintenance, and self-driven decision-making capabilities (Mourtzis et al., 2022; Iqbal et al., 2022). Predictive Maintenance is one of the important applications of deep learning in Industry 4.0. Industries are able to predict equipment failures before they even occur by using deep learning algorithms like convolutional neural networks (CNNs) and recurrent neural networks (RNNs). This in turn, minimizes downtime, lower maintenance costs and extends the machinery life cycle. Deep learning-powered predictive maintenance solutions saved a lot finance by increasing operational effectiveness. Deep Learning is behind predictive maintenance as well as improving quality control and inspection tasks. Deep learning-based computer vision systems can identify product defects and anomalies with previously unheard-of precision (Rane, 2023a). Deep learning proponents companies such as Siemens to look at generated parts as they come off a line to detect defects. Supply chain optimization is a very critical area where deep learning is utilized to a great extent. Deep machine learning models are fed with data from multiple sources and can help to efficiently maintain inventory, demand forecasting and logistics. Amazon, for instance, uses deep learning algorithms to help improve efficiency and cut costs in its supply chain operations which ultimately results in faster delivery.

In Industry 5.0, cobots, or collaborative robots are a hallmark (Taj, & Zaman, 2022; Khosravy, et al., 2023; Adel, et al., 2023). Robots integrated with advanced deep learning algorithms that work alongside human workers to complement their abilities demonstrate enhanced productivity. An example would be cobots by Universal Robots that use deep learning to learn human actions and perform with high precision and efficiency in operations like assembly and quality inspection. Deep learning also makes personalized manufacturing, a critical part of Industry 5.0 possible. Deep learning models can use these to tweak products at own convenience, automatically, by analysing customer preferences and feedback over time. For as the automotive industry is concerned personalized offerings can be a seen where companies like Tesla utilise deep learning to provide tailor-fit and bespoke customizations and functionality to one's needs which would elevate user experience. Sustainability is another area where Industry 5.0 emphasizes, and this vision is accelerated partly by deep learning. Deep learning applies global optimization methods that use advanced data analytics to reduce energy consumption, waste and dependency on non-renewable sources. In agriculture, deep learning can help enable more sustainable farming practices, by optimizing irrigation and fertilization processes.

In fact, as per healthcare, the era of diagnostics treatment as well as patient care is near to a breakthrough, thanks to deep learning technologies (Taj, & Zaman, 2022; Dlamini et al., 2023). Deep convolutional neural networks (DCNNs) have been used to classify medical images with great success, and this capability has been employed for early identification of diseases like cancer. One of the concepts that is emerging in the healthcare sector of Google is face recognition using deep learning and diagnostic tools that can exceed human radiologists in tasks. In addition, deep learning is revolutionizing personalized medicine. For example, components such as genetic data, lifestyle information, and medical history can be analysed with deep learning to inform more refined, personalized treatment plans for individual patients. One such example is the IBM Watson Health, which uses deep learning to administer personalised medicine for cancer patients on the basis of their mutational signatures. One area in which the practice of deep learning does that is education. AI-driven intelligent tutoring systems can be customized to suit individual student learning preferences and speeds, delivering tailored instruction and assistance. Deep learning algorithms are used by platforms like Coursera to optimize learning by providing users with personalized content and feedback. In Society 5.0, even transportation systems are being revolutionized by deep learning. Deep learning for Navigation, object detection and decision-making which is the central theme for autonomous vehicles of future smart cities relies heavily in these AI technologies.

1.4 Conclusions

The convergence of cloud computing, IoT, and cyber-physical systems, collectively referred to as Industry 4.0 has enabled the rapid adoption of advanced capabilities such as AI and ML to streamline and improve the efficiencies in use cases such as supply chain management, predictive maintenance, and optimizing industrial processes. This digital revolution also helps in big data analytics, based on which real-time decisions can be made, ultimately leading to efficient productivity and thereby cutting operational costs. Industry 5.0 shifts more towards solutions that put the needs and well-being of humans above the technological advancements that benefit from it. Underpinned by AI and DL, this paradigm is being realised by having collaborative robots (cobots) working in tandem with humans, increasing efficiency whilst maintaining safety and ergonomic capabilities. Furthermore, futuristic customized products created on demand with AI personalized manufacturing solutions in an industrial environment more resilient and responsive. Society 5.0 aims to address societal challenges and improve the quality of life for individuals in a super-smart society with any-time, any-place access to the digital revolution of life. In AI-powered smart cities, this idea becomes a reality, as it combines the power of AI services with infrastructure. AI and deep learning maintain a significant position in building resilient and inclusive cities. These systems include smart healthcare systems for prescribing personalized courses of treatment and forecasting diagnostics and complex transport systems for streamlining traffic flow and reducing emissions. The AI, ML, and DL when integrated into industrial and societal paradigms enable economic development along with progressing global environmental goals. These technologies should be harmonised with renewable energy technologies, and must be propelled by principles of the circular economy. It is imperative that we set up rigorous governance mechanisms and ethical considerations when utilizing new technologies. However, at the end of the day, AI, ML, and DL are reshaping verticals and steering us towards a more predictable, more diverse, and more eco-friendly destiny.

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