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Sustainable development with Industry 4.0: A study with design, features and challenges

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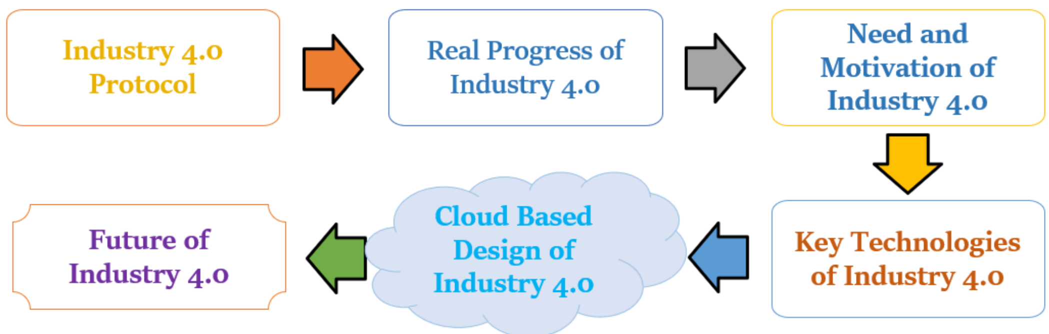
ABSTRACT



A new revolution called "Industry 4.0" uses internet connection technologies to bring together various components of industrial systems to create future factories and manufacturing enterprises. Industry 4.0 and related technologies are driven by disruptive innovation because it has the potential to unlock enormous, untapped value creation across all major market areas. Due to cybersecurity and data privacy vulnerabilities affecting contemporary Internet technologies, adopters of Industry 4.0 technology will face significant obstacles and barriers. The security and privacy vulnerabilities associated with Industry 4.0 go beyond those of traditional Internet-based businesses. Industry 4.0 may never reach its full potential without fixing these issues. The industrial sector has benefited from the rapid development of new technology and applications. The fourth industrial revolution, or "Industry 4.0," ushers in a new era of organization and control across the whole value chain of a product's life cycle, with an emphasis on the increasingly individualized needs of the consumer. The Internet of Things (IoT), Big Data and Analytics, and Cloud-Based Design are all components of Industry 4.0, a notion that is both futuristic and highly relevant. Continuous improvement, a focus on value-added jobs, and waste prevention can only be achieved by fully incorporating human beings into the Industry 4.0 process.

Keywords: Internet of Things (IoT), Information and communication technologies (ICT), Cyber-Physical System (CPS), Cloud Based Design

INTRODUCTION

In November 2011, the German government published an article titled "Industrial 4.0," which described a technical vision for 2020[1]. The fourth industrial revolution, sometimes known as "Industry 4.0," follows the mechanical, electrical, and digital processes. The term "Sector 4.0" has recently gained prominence, prompting discussion among various global industries, including IT (information technology). The advent of "Industry 4.0" will have far-reaching effects on manufacturing around the globe[2]. Multiple manufacturing revolutions have occurred since the first Industrial Revolution. Water and steam-driven machines have given way to electrical and digital automated production[3]. These developments have added complexity, sustainability, and automation to manufacturing, allowing devices to function by humans in a simple, effective, and consistent way[4]. For clarity, "Industry 4.0," also known as the "fourth industrial revolution," denotes a new level of organization and control across the whole value chain of a product's life cycle, emphasizing the dynamic preferences of individual consumers[5]. The primary objective of Industry 4.0 is to meet unique client requirements, which has implications for order management, R&D, plant commissioning, product delivery, product use, and

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recycling. Industry 4.0 differs from Computer Integrated Manufacturing (CIM) in prioritizing human labor over mechanical processes[6]. Workers in the Industrial Revolution 4.0 (I4.0) are highly valued, in contrast to the CIM's greater emphasis on machines. Connecting sensors, devices, and company assets to the web and one another is foundational to the "industry 4.0" concept[7]. Breaking down production into smaller, more value-focused units that only convey information about the next steps in the process can make adaptation easier and coordination simple[8]. The fourth industrial revolution, or Industry 4.0, as shown in figure:1, has brought about fresh perspectives on manufacturing that have the potential to increase output while decreasing costs.[9]

Germans have launched a program called Industry 4.0, which uses IT to improve production. Mass production in manufacturing didn't become a reality until the widespread availability of cheap, reliable electrical power during the Second Industrial Revolution[10]. In recent years, "Industry 4.0" has arisen as a viable technological framework for enhancing and integrating manufacturing processes at businesses' internal and external levels. The rapid growth of information and communication technologies (ICT) has accelerated the rollout of Industry 4.0[11]. Because of the advancements and breakthroughs made possible by Industry 4.0, numerous practical options will become available to the industrial sectors to meet their growing demands. The "Fourth Industrial Revolution" is a concept that sounds great in principle but comes with many challenges in practice[12]. The idea of Industry 4.0, or the "fourth industrial revolution," promotes using cyber-physical systems in manufacturing to build "smart" facilities. Smart self-properties like self-configuration, self-monitoring, and self-healing are essential for the success of industrial ecosystems[13]. Improvements in productivity and operational efficiency are possible thanks to Industry 4.0. "Industry 4.0" describes using numerous technological and conceptual approaches[14]. The Industrial Internet and the Industrial Internet of Things, cloud-based design and manufacturing, crowdsourcing, and open innovation are some emerging concepts for product creation in the twenty-first century[15]. Figure: 1 shows the revolution from Industry 1.0 to Industry 4.0.

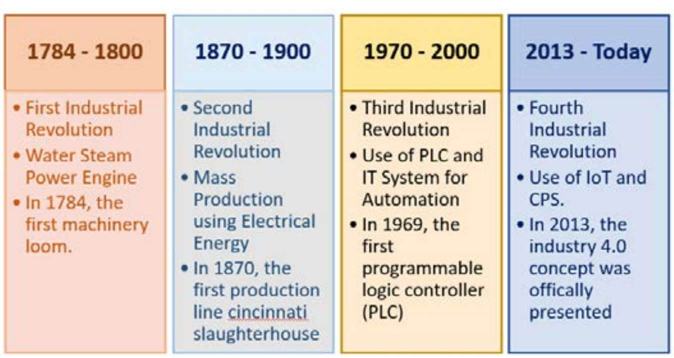

Figure 1. From Industry 1.0 to Industry 4.0

Industry 4.0, fueled by intelligent manufacturing, is the fourth sector to develop due to the industrial revolution[16]. The goal of the Industry 4.0 movement is to make manufacturing more computerized, data-driven, individualized, and eco-friendly. The development of a CPS is essential in the process of developing an innovative and digitally-enabled manufacturing facility[17]. The goal of Industry 4.0 is to create a highly adaptable production model for personalized and digitally enhanced products and services by facilitating real-time interactions between people, products, and devices across the manufacturing process[18]. If factories could receive customer orders, make the goods, and swiftly send them out, the current online shopping paradigm would have to alter radically.[19]

"Industry 4.0" is the fourth significant change in how things are made. It comes after the mechanical, mass production, and digital revolutions[20]. Industry 4.0 has come a long way in the last few years, largely thanks to improvements in connectivity technologies like IoT, AI, ML, big data, cloud computing, and advanced robots. But if the goal of Industry 4.0 is to improve value by connecting supply networks and industrial sites, it looks like people will become more critical shortly.[21] As IoT, cloud computing, automation, and data technologies driven by robotics have improved over the past five years, manufacturers have felt the effects of Industry 4.0. Innovative workplaces can be made by bringing together software, hardware, and people, and "as-a-service" business models can grow.[22] Even small and medium-sized businesses can now utilize what Industry 4.0 offers. Now, companies can hire good people for less money and with less effort.[23] Figure 2 shows barriers of Industry 4.0.

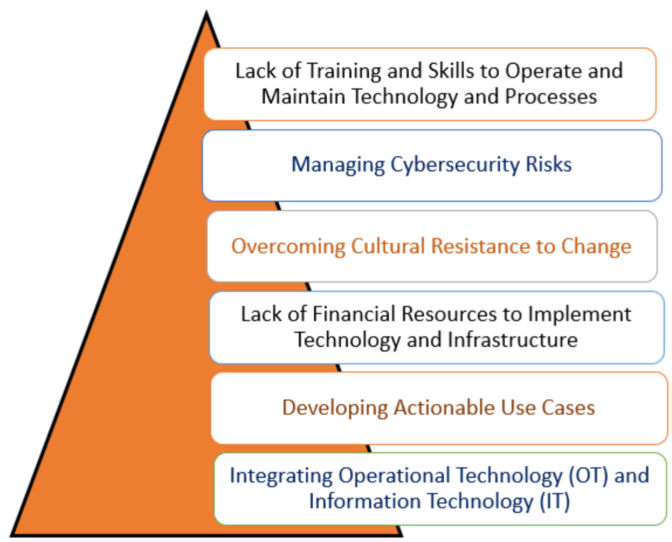

Figure 2. Barriers of Industry 4.0

Industry 4.0 is still having an effect on businesses all over the world. Here are the six essential reasons producers might want to use Industry 4.0.[24]

Optimized Processes: Industry 4.0 uses technologies like sensors, IoT, AI, digital twins, etc., to make factories more efficient. Automation makes more work get done, data analytics helps managers make better, more productive decisions, and tracking tools let quality keep getting better[25]. More money is coming in regarding Industry 4.0 and digital change, and customers are glad. Manufacturers will get the most out of the connected workplace when sensors keep an eye on equipment and when artificial intelligence and field service give customers personalized care and help when needed.[26]

Greater Asset Utilization: Industry 4.0 makes it easier for businesses to get the most out of their assets because it makes it easier for operations to change. Autonomous mobile robots (AMR) can be told to move goods, which frees up human workers to do other tasks that add more value.[27]

Higher Labor and Productivity: When workers are happy where they work, they can focus more on their jobs and get more done. Industrial workers are much safer now than they were in the past because of IoT[28]. A safe and healthy workplace can be maintained by looking at data from cameras in the workplace and on employees often. Because of Industry 4.0, many people who work in production are learning new skills and gaining further information. When a company uses new technologies, the people who work there learn everything there is to know about them[29]. Think about how much more things could get done if people and cobots worked together. They might be more beneficial, flexible, risk-averse, and focused on quality.

Supply Chain Visibility: With the help of sensors linked to the IoT and data analytics, manufacturers can keep an eye on the entire supply chain and industrial process[30]. AI and machine learning can optimize the supply chain in real-time with this information. Some people in the business world still talk about the coming of "Logistics 5.0." Transparency is a long-term investment that can help businesses empower their workers, plan for disruptions, and reduce their environmental effects through a collaboration of digitization and human effort without sacrificing or ignoring their businesses' competitiveness and profitability.[31]

After-sales Service: Shortly, customers can use essential Industry 4.0 technologies, like predictive analytics, virtual reality, and remote monitoring.[32] Even though manufacturers might not immediately feel the effects of IoT connections, their customer service and field support teams will be significantly affected. Customer service is a critical way many businesses set themselves apart, and the use of connected technology in field service is helping to make customers happier.[33] By keeping an eye on their products from afar, makers can figure out when they need to be fixed, which makes customers more comfortable.

Sustainability: Key parts of Industry 4.0, like remote tracking, virtual reality, and prediction analytics, will soon be available to customers[34]. Connectivity through the IoT might not instantly affect manufacturers, but it will significantly impact customer service and field assistance. One way a business can stand out is by using connected technology to make customers happier. Manufacturers might have more satisfied customers if they could check things from a distance to see if they need to be fixed.[35] The major discussion points related Industry 4.0 have been mentioned in the figure 3.

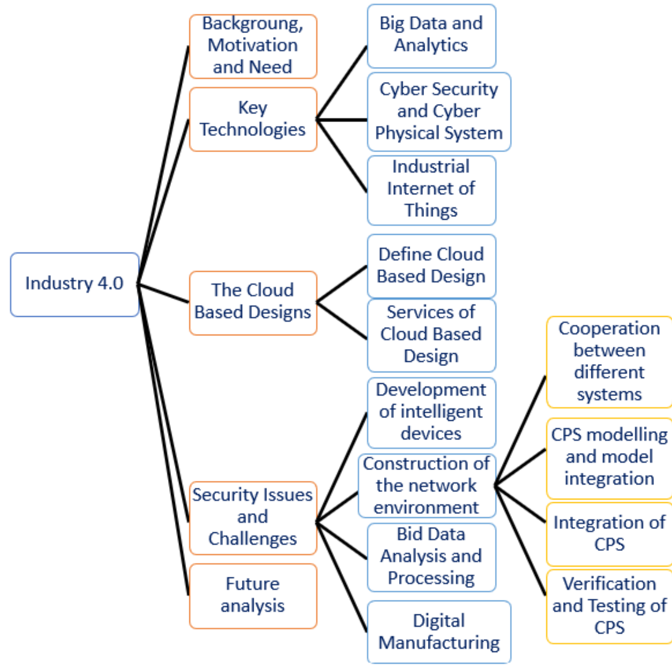

Figure 3. Key points of Industry 4.0 for intrigued analysis

1. Real Progress of Industry 4.0

During the last five years, journals in robotics, electronics, computer science, and production engineering have devoted significant attention to Industry 4.0 and related subjects, including additive manufacturing/3D printing, intelligent manufacturing, and big data.[36] A systematic literature review on Industry 4.0 or some specific technologies (e.g., additive manufacturing) is provided. However, prominent scholars have acknowledged the relevance of Industry 4.0 for management in general and Operations and Production Management (O&PM) expressly. Relatively little consideration has been given to these topics by mainstream O&PM journals, especially to Industry 4.0 technologies' disruption on operations and supply chain management.[37] A few prominent exceptions are represented by the recent attempts to shed light on the link between Industry 4.0 and lean manufacturing, the connection between the IoT and supply chain management, the impact of additive manufacturing on supply chain processes and performances, and the short-term supply chain scheduling in intelligent factories.[38] While there were very few pilot Industry 4.0 projects in the past, the number of applications has significantly increased, both in terms of demonstration and "real" factories, giving rise to more empirical studies. For many companies, Industry 4.0 is still the "next thing" they should focus on - or the trend to which they are currently adopting their strategy.[39] It reflects the fourth industrial revolution triggered and enabled by developments in IT. Key elements include automation, robotization, big data analytics, intelligent systems, virtualization, AI, machine learning, and IoT. It places the well-being of the worker at the center of the production process and uses new technologies to provide prosperity beyond jobs and growth while respecting the production limits of the planet.[40] It complements the Industry 4.0 approach by specifically putting research and innovation at the service of the transition to a sustainable, human-centric and resilient European industry. Calls for a greater emphasis on societal value well-being are as old as capitalism itself, and echoes have been heard ever since think Corporate Social Responsibility, ESG, or the Triple Bottom Line, for example.[41] But putting people and planet rather than profits and growth center stage in the very definition of Industry is new. Never before have we seen such radical emphasis on repurposing the core objectives of Industry.[42]

The concept of Industry 4.0 is several years ahead, of course, but not for very long. It is considered that Industry 4.0 started trending in 2011 when the vision for the Fourth Industrial Revolution was presented at the Hannover Messe fair in Germany.[43] Naturally, the initial idea of Industry 4.0 was also developed primarily for the German industrial automation and intelligent manufacturing market and other countries that are part of the EU and subject to EU legislation. Even though Industry 4.0 became a global trend, it had been perceived as primarily relevant to the European business environment and policies for some time[44]. In this vision, robots, intelligent machines, IoT, AI, and Big Data are still the key to business success. Still, the technological side is balanced with more focus on sustainability, resilience, and enhancement of human talent, supported by increasingly intelligent and efficient devices.[45] Allegedly coined by Klaus Schwab, a German engineer, economist, and founder of the World Economic Forum, the concept of Industry 4.0 describes rapid changes in industries, technologies, and processes fueled by the integration of the latest tech innovations.[46]

Considered by Schwab to be a substantive shift in industrial capitalism, the transition to Industry 4.0 is primarily characterized by the wide adoption of multiple automation technologies, such as artificial intelligence (AI), robotics, large-scale machine-to-machine communication (M2M), Internet of Things (IoT), intelligent automation and interconnection techniques, etc.[47] These technological innovations and specific strategies and approaches to implementing them are central to the Industry 4.0 concept. They are viewed as the key to unprecedented efficiency and productivity growth, which should be the product of this new generation of industrial automation solutions.[48]

2. Need, Motivation, and Background of Industry 4.0

Intelligent factories and future organizations will be formed by integrating many industrial systems, made possible by today's ubiquitous internet connectivity technologies.[49] Disruptive innovation drives the development of the technologies that underpin Industry 4.0. Technologies such as cloud-based design and production systems, IoT, IIoT, and SPD. (Social Product Development) are all included. With these advancements, every primary Industry will have access to many new possibilities for value creation.[50] Adopters of Industry 4.0, however, will face significant challenges and difficulties due to the cybersecurity and data privacy vulnerabilities afflicting current Internet technology. Cybersecurity experts have difficulty getting everyone in an Industry 4.0 company to collaborate and share information.[51] There is a lack of standardized standards and procedures in cybersecurity that are supposed to get everyone on the same page and better coordinate essential goals. Technology and experts from several disciplines come together in an Industry 4.0 environment[52]. For example, operational technologists (OT) and control engineers collaborate in manufacturing. It is also customary for an IT department to employ a system administrator who works with more conventional resources like servers and applications[53]. Regarding the safety of OT assets, a control engineer's top concern is "mission assurance.

Meanwhile, the importance of an IT administrator's "information assurance" task cannot be excessive. Rarely do both goals converge.[54] A control engineer may not prioritize data loss over the safety of people or buildings, while a system administrator would never consider air in their servers' UPSs. Different factors motivate the creation of these cybersecurity artifacts. Conversely, the concepts of Industry 4.0 require that all these systems work together seamlessly.[55] The fundamental objective of this book is to clarify previously discussed requirements, technologies, and other worries associated with Industry 4.0 and cybersecurity. As suggested earlier, stakeholders need a complete picture of the issue[56]. The goal of the new industrial revolution, dubbed "Industry 4.0," is to build an open, intelligent manufacturing platform for use by industrial sector data networks.

3. Key technologies of Industry 4.0

Digital manufacturing, network communication, computer, and automation technology are just some of the numerous fields that make up the adaptable and intricate system known as "Industry 4.0".[57] It uses digital design and simulation, highly automated manufacturing processes, production data management networking, and production process management to access data and the governance rules, mining, analysis, judgment, and decision-making. As an alternative, the CPS provides the framework for Industry 4.0 by integrating computing, communication, and control methods to improve production through real-time sensing intelligent systems, dynamic management, and information services.[58]

Quick decision-making will become the norm thanks to the widespread adoption of data collecting and analysis from various sources, such as company and customer management systems and production equipment and systems.[59] The proliferation of data is outpacing the capacity of conventional data management and storage methods. Products, processes, the value chain, and external sources generate many organized and unstructured data that manufacturers must process[60]. Big data technology seeks to rapidly extract relevant information that may be used for excellent decisions by applying specialized processing modalities to enormous volumes of data. The upcoming generation of CPS production machinery will incorporate enterprise information systems and sensor data[61]. Vast data will be transferred to a cloud computing data center during this process for storage, processing, and ultimately guiding the manufacturing process. Big data and in-depth data analysis could help industrial operations improve efficiency, cut costs, and boost output.[62]

Cyber security for critical industrial systems and production lines is becoming increasingly important due to the growing connection and adoption of industry-standard communications protocols by Industry 4.0[63]. To this end, it is crucial to have communications that can be relied upon and a system that can fully control the identities of both computers and their users. Increased connectivity across the physical, service, and digital sectors can enhance the data quality in industrial systems' design, development, and operation[64]. Cyber-physical systems (CPS) effortlessly combine data processing, transfer, and action with the physical world (natural and artificial systems included). Cloud computing enables real-time data interchange between cyber-physical systems through an intelligently networked set of interconnected nodes. The Digital Shadow of Production is a digital or informational representation of a physical product[65]. Cyber-physical systems are being heavily studied to optimize the current production system and address the vital necessity of real-time-oriented manufacturing operations. The proper CPS sensors will trigger the fault repair methods when a machine malfunctions[66]. It determines how each workstation may be used most effectively by considering the necessary cycle time of task. The 5C architecture allows machines to communicate in the cloud (a machine with a machine or a human with the device). An example of Industry 4.0, the intelligent car, is the result of the convergence of digital and mechanical technologies.[67]

One definition of the "Internet of Things" is the global network of devices with unique identifiers that may communicate with one another using established protocols.[68] There is not just the IoT but also the IoS, the IoMs, the IoP, an embedded system, and the ICT integration (IICT). The Internet of Things is distinguished by its contextual awareness, pervasiveness, and optimization. The ability of an object to quickly adjust to new environmental conditions is often referred to as "context." Modern technologies are connected to more than just a human-machine interface network of operators, as concepts like omnipresence and optimization show[69]. Integrating physical products, human factors, intelligent machines, smart sensors, manufacturing processes, and production lines across organizational boundaries can help make the value chain more intelligent, agile, and networked. Future machinery and industrial operations will rely heavily on data and software. Bright pallets and shelves will power next-generation inventory management in warehouse storage.[70] The technologies for monitoring the whereabouts of cargo shipments have gotten quicker, more accurate, and safer.

4. Cloud-Based Design of Industry 4.0

Technology-wise, the Industry 4.0 Application Center is held together by a backbone of cloud-based IT infrastructure that facilitates collaboration between the various components.[70,71] Organizations need to increase data sharing across locations and companies to achieve response times of a few milliseconds or less with Industry 4.0. Digital production is syncing and exchanging information across various devices via the cloud. As a noun, it can also refer to the factory. Cloud computing uses a shared pool of configurable computing resources (such as networks, servers, storage, applications, and services) that may be instantly provided and delivered with minimal administrative labor or involvement from service providers.[72] When talking about the architecture and operating system that data centers utilize to host and serve software as a service (SaaS) via the Internet, the term "cloud computing" is typically used. "SaaS" is commonly used when promoting these products and services.[73]

The term "cloud" refers to a vast, virtualized pool of resources that multiple users can quickly access and utilize (including but not limited to hardware, software development platforms, and services). By dynamically altering these resources in response to shifts in demand, maximum efficiency can be obtained (called "scaling"). One example of this occurrence is clouded[74]. It's built from a dispersed network of interconnected virtualized servers so that they can be sold and displayed to consumers as a single or group of unified computing resources per agreed-upon service-level agreements. Careful consideration must be given to user experience and corporate strategy while utilizing cloud computing. Cloud computing is a new way of providing information technology services that allow people to use software, data storage, and communication networks hosted remotely and made available via the Internet[75]. It paves the way for many possibilities, including a selection of vendors, discounts for volume purchases, and consumers' autonomy. The phrase "infrastructure management" describes a methodology for controlling and monitoring a distributed system of computers. Whether or not "cloud computing" represents a major paradigm shift is debatable. This innovation is economically significant because it challenges conventional wisdom regarding IT deployment and paves space for new methods.[76] Cloud computing is widely viewed as a game-changing innovation. Another technological advance in the long history of computing, which began with simple binary-digit adding machines and has since seen the introduction of mainframe computers capable of floating-point arithmetic, portable personal computers with graphical user interfaces, the Internet, which enables access to computing resources through decentralized and distributed client-server architectures, utility, grid, and cloud computing, and so on.[77] Cloud Based Design (CBD) is a subgroup focused on design questions. The Collaborative Design Process is a method of design that makes use of Web 3.0 and Web 2.0 technologies (such as social networking sites, wikis, online reviews, and recommender systems) to collect better, visualize, analyze, and use data about product design that is widely dispersed across the Internet and social media.[78] It's commonly believed that the onus of developing and implementing methods falls squarely on design teams. Conversely, CBD may facilitate online collaboration between users, engineers, and other players to produce higher-quality products by incorporating Web 2.0 characteristics into product development. Web 2.0 marketplaces like Amazon and eBay facilitate two-way communication between consumers and providers by sharing and reading product reviews.[79] Clients can now provide input on design iterations quickly.

HaaS makes the CBDM system available to users in the cloud, allowing them access to shared machine tools, complex tooling, and manufacturing processes. Hardware for cloud services might be leased from a third party instead of being purchased outright[80]. Instead of shelling out hundreds of dollars for a 3D printer, cloud customers may use their subscription and a mobile device to print out any needed parts.[81] Engineers and factory floor workers who use manufacturing equipment are two groups that could benefit from HaaS.

SaaS for cloud customers today includes several business-critical software like CAD, CAM, FEA tools, and ERP programs. Thin client interfaces allow cloud users to access and run enterprise and engineering software without paying full software licenses[82]. Dassault Systems and Autodesk's cloud services provide remote access to 3D modeling software and high-performance discrete computing environments, two prominent examples of engineering analysis applications. Software as a Service (SaaS) customers might range from the creative class to the technical and managerial ranks.[83]

Platforms-as-a-service (PaaS) offer both end users and developers of apps access to a service environment and a suite of development tools to help speed up the process of bringing about the required functionality.[84]

Infrastructure-as-a-service (IaaS) is a model for delivering computing resources, such as data storage and powerful server space, over the Internet to end customers.[85] Engineers and upper-level management are two examples of potential users of IaaS. Figure 4 shows cloud-based Design Services.

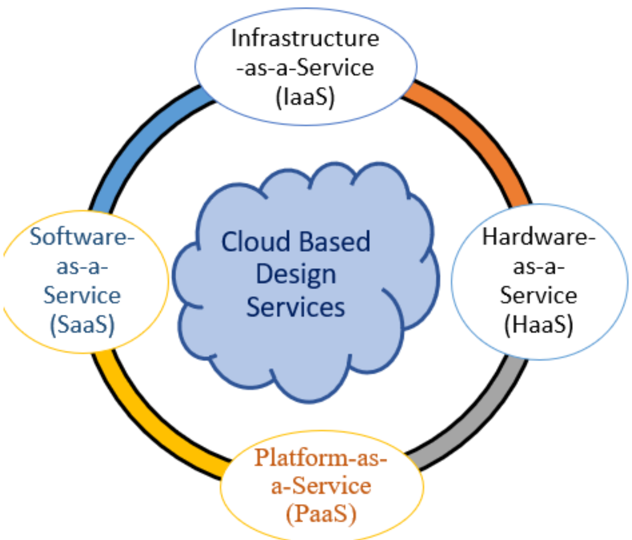

Figure 4. Cloud-based Design Services

5. Issues and Challenges in Industry 4.0

The early adoption of mechanical systems to today's highly automated assembly lines is just two examples of how the industrial sector has benefited from technological developments that have allowed it to respond to and adapt to the requirements and expectations of the market.[86] Embedding, predictability, flexibility, and robustness are challenges under unforeseen conditions. Significant challenges and questions still need answering before the sector can be completely established. The manufacturing industry can now make use of the 4.0 technology.[87]

Intelligent Decision-Making and Negotiation Mechanism: Unfortunately, current system architectures lack the autonomy required by the smart manufacturing system, as evidenced by their reliance on "3C Capabilities" (i.e., communication, coordination, and collaboration) rather than the additional autonomy and sociality capabilities required by the intelligent manufacturing system.[88]

High-Speed IWN Protocols: IWN networks are now superior to odd networks in production environments. However, they are limited in dealing with extensive data or frequent, intensive communication.[89]

Manufacturing Specific Big Data and Analytics: It is difficult to guarantee the quality and integrity of data in a manufacturing system.[90] When different data repositories have different semantics and significant differences in the annotations of data objects, it becomes increasingly difficult for advanced data analytics to merge them.

System Modeling and Analysis: Representing systems as self-organized manufacturing systems can assist in minimizing dynamical equations and lead to a more effective control model[91]. The research on intricate designs is ongoing.

Cyber Security: Protecting critical industrial systems, production lines, and system data from cyber security attacks has never been more critical than it is now, thanks to the increased interconnectedness and widespread usage of industry-standard communications protocols that are hallmarks of Industry 4.0.[92]

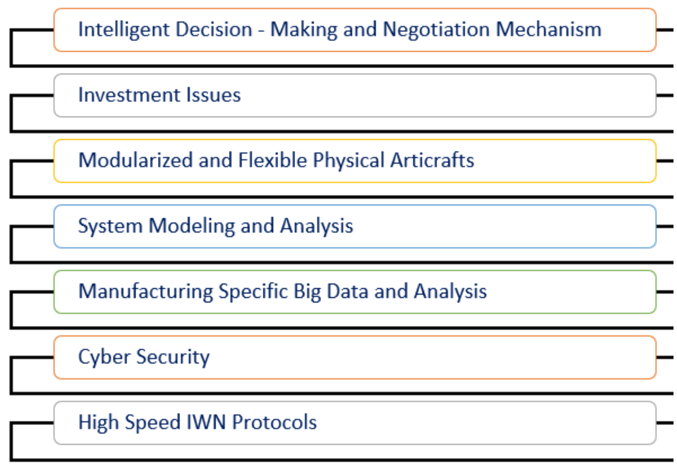

Figure 5. Issues in Industry 4.0

Modularized and Flexible Physical Artifacts: Multiple machines, such as those used for machining and testing, must process a product, assure uniformity, and provide distributed decision-making.[93] Therefore, an innovative, modular, and adaptable conveying device that can accommodate quick shifts in production paths is urgently required.

Investment Issues: It is common to wonder how best to invest in emerging technology industries. A small or medium-sized business's initial cost to adopt Industry 4.0 is. Prices might be increased when a company assumes all of Industry 4.0's principles.[94]

The employment of artificial devices (such as robots) and reduced human labor can make factories more intelligent than ever with the help of Industry 4.0 technology.[95] However, because each factory requires one-of-a-kind device settings, developing a smart device for usage in an Industry 4.0 facility can be time-consuming and costly. Figure 5 shows issues in Industry 4.0

5.1 The Construction of the Network Environment

A CPPS platform built on CPS technology is the most typical definition of the network environment when discussing Industry 4.0[96]. The following four elements are examples of CPS issues progressing on the CPPS platform development project.

5.1.1 Cooperation between different systems

Information network systems enable data transmission between physical devices and provide ubiquitous communication access.[97] A cooperative model between the material and the information network system must be developed for qualitative and quantitative analysis. It is also crucial to consider the interplay between various computer and network systems.[98] The safety, dependability, and object orientation standards in hardware differ significantly from those of general-purpose computers. Therefore, the dynamics of the physical design and those of each discrete and sequential, reconfigurable computer system and the amorphous system of information networks need to be explored.[99]

5.1.2 CPS modeling and model integration

Bringing together digital and material processes is central to the CPS model. Thus, it must demonstrate this behavior before it can be taken seriously.[100] Physical infrastructure, software and hardware platforms, network models, additional scheduling software, network delays, power utilization, and other factors are all functional and non-functional parts of a CPS model. Second, the CPS has its peculiarities that need to be considered, given that it uses various computing models and combines computational and physical elements.[101] Logical time, as utilized by the computational process, is discrete in contrast to the continuous physical time used by the biological approach. Compared to the physical world's emphasis on position, shape, shape, and other such properties, the computing world employs terminology like messages, exceptions, and interrupts to describe events. Using different computer simulations can make establishing a standard framework for CPS modeling challenging.[102] Considering the context, a new CPS modeling language is required. CPS modeling and model integration continue to provide difficulties.

5.1.3 The integration of CPS.

When creating a CPS, combining a wide range of components and implementing many different approaches is essential. One difficulty is creating a flexible user interface compatible with many features and allowing for quick and straightforward experimentation with new configurations.[103] Second, each discipline uses its models, languages, and methodologies, making establishing connections across a CPS's numerous systems challenging. Modeling, simulation, analysis, synthesis, and developing a wide range of computing and communications subsystems are only some tasks that require a comprehensive toolchain to design and develop CPS.[104]

5.1.4 Verification and testing of CPS.

The complex behavior of the CPS is necessary for the system to function correctly due to the interdependence of its numerous components[105]. To ensure the CPS is built for various purposes, it must undergo extensive, rigorous validation and testing before use. The CPS suffers from a lack of standardized criteria and testing methodologies.

5.2 Big Data Analysis and Digital Manufacturing

Extensive and complex data will continue to be produced by the devices, systems, processes, materials, software, products, and services that comprise Industry 4.0[106]. The advent of big data has sparked worries about data privacy and security in large corporations. Industrial ample data research and applications are just starting, so there is much room for development in hardware and software.[107]

Digital manufacturing seeks to streamline production by incorporating computer modeling, simulation tools, and the World Wide Web.[108] Challenges relating to management, standards, and other forms of technology will appear throughout the deployment. Network security is becoming more of a problem in digital manufacturing as the barriers between the real and virtual worlds continue to blur.[109] Several issues must be resolved to guarantee network security and combat cyber espionage to prevent hackers and other cybercrimes caused by the infringement.[110,111] Figure:6 shows the challenges of Industry 4.0.

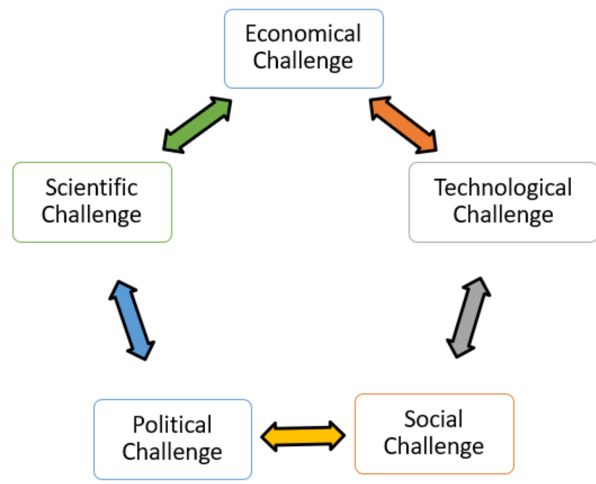

Figure 6. Challenges of Industry 4.0

Conclusion and Future Work

Industry 4.0, the fourth industrial revolution, was the main topic of the presentation since it allows for cost-effective, intelligent, efficient, and individualized production. Miniaturized sensors, faster processing, enhanced machinery, and decreased data storage and transmission costs have all contributed to the possibility that machines and things could soon communicate and learn. Miniaturized sensors, increased processing power, enhanced equipment, and lower data storage and transmission costs all contribute to the eventual goal of machine and thing-to-machine communication and learning. The nine pillars of Industry 4.0 are laid out, and the difficulties and worries that will arise from implementing it are highlighted. New research fields should be found as industry 4.0 usage rises, such as transparent and well-organized industrial management and supply chains, data collecting from production lines optimized for efficient machines, energy conservation, and enhanced maintenance schedules.

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Conflict of Interest Statement

Authors declare no conflict of interest is there for publication of this work.

References

1. R. Rosati, L. Romeo, G. Cecchini, et al. From knowledge-based to big data analytic model: a novel IoT and machine learning based decision support system for predictive maintenance in Industry 4.0. *J. Intelligent Manufacturing*. **2023**, 107–121.
2. T.A. Van Nguyen, D. Tucek, N.T. Pham. Indicators for TQM 4.0 model: Delphi Method and Analytic Hierarchy Process (AHP) analysis. *Total Quality Management and Business Excellence*. **2023**, 220–234.
3. J. Antony, O. McDermott, D. Powell, M. Sony. The evolution and future of lean Six Sigma 4.0. *TQM Journal*. **2023**, 1030–1047.
4. A. Saihi, M. Awad, M. Ben-Daya. Quality 4.0: leveraging Industry 4.0 technologies to improve quality management practices – a systematic review. *Int.l J. Quality Reliability Management*. **2023**, 628–650.
5. A. Raj, A. Jeyaraj. Antecedents and consequents of industry 4.0 adoption using technology, organization and environment (TOE) framework: A meta-analysis. *Annals of Operations Research*. **2023**, 101–124.
6. A. Prashar. Quality management in industry 4.0 environment: a morphological analysis and research agenda. *International Journal of Quality and Reliability Management*. **2023**, 863–885.
7. M. Bildirici, Ö.Ö. Ersin. Nexus between Industry 4.0 and environmental sustainability: A Fourier panel bootstrap cointegration and causality analysis. *J. Clean. Prod.* **2023**, 386, 135786.
8. M.A.M.S. Lemstra, M.A. de Mesquita. Industry 4.0: a tertiary literature review. *Technol. Forecast. Soc. Change* **2023**, 186, 122204.
9. V. Modgil, P. Singh, S.K. Sharma. Steady State availability analysis of a Physical System : Sole lasting system of Shoe Industry. *J. Integr. Sci. Technol.* **2014**, 2 (1), 22–26.
10. B. Ding, X. Ferràs Hernández, N. Agell Jané. Combining lean and agile manufacturing competitive advantages through Industry 4.0 technologies: an integrative approach. *Production Planning and Control*. 2023, pp 442–458.
11. S. Bag, L.C. Wood, A. Telukdarie, V.G. Venkatesh. Application of Industry 4.0 tools to empower circular economy and achieving sustainability in supply chain operations. *Production Planning and Control*. 2023, pp 918–940.
12. S. Pandey, R.K. Singh, A. Gunasekaran. Supply chain risks in Industry 4.0 environment: review and analysis framework. *Prod. Plan. Control* **2023**, 34 (13), 1275–1302.
13. A. Kumar, S. Choudhary, J.A. Garza-Reyes, et al. Analysis of critical success factors for implementing Industry 4.0 integrated circular supply chain–moving towards sustainable operations. *Production Planning and Control*. 2023, pp 984–998.
14. S. Qahtan, K. Yatim, H. Zulzalil, et al. Review of healthcare industry 4.0 application-based blockchain in terms of security and privacy development attributes: Comprehensive taxonomy, open issues and challenges and recommended solution. *J. Netw. Comput. Appl.* **2023**, 209, 103529.
15. M. Ryalat, H. ElMoaqet, M. AlFaouri. Design of a Smart Factory Based on Cyber-Physical Systems and Internet of Things towards Industry 4.0. *Appl. Sci.* **2023**, 13 (4), 2156.
16. L. Pinciroli, P. Baraldi, E. Zio. Maintenance optimization in industry 4.0. *Reliab. Eng. Syst. Saf.* **2023**, 234 (0), 109204.
17. H.A. AlMalki, C.M. Durugbo. Evaluating critical institutional factors of Industry 4.0 for education reform. *Technol. Forecast. Soc. Change* **2023**, 188, 122327.
18. J. Antony, M. Sony, O. McDermott, S. Furterer, M. Pepper. How does performance vary between early and late adopters of Industry 4.0? A qualitative viewpoint. *Int. J. Qual. Reliab. Manag.* **2023**, 40 (1), 1–24.
19. A.A. ForouzeshNejad. Leagile and sustainable supplier selection problem in the Industry 4.0 era: a case study of the medical devices using hybrid multi-criteria decision making tool. *Environmental Science and Pollution Research*. 2023, pp 13418–13437.
20. R. Pozzi, T. Rossi, R. Secchi. Industry 4.0 technologies: critical success factors for implementation and improvements in manufacturing companies. *Production Planning and Control*. 2023, pp 139–158.
21. N. Tsolakis, T.S. Harrington, J.S. Srai. Digital supply network design: a Circular Economy 4.0 decision-making system for real-world challenges. *Production Planning and Control*. 2023, pp 941–966.
22. D. Pandya, G. Kumar. Applying Industry 4.0 technologies for the sustainability of small service enterprises. *Service Business*. 2023, pp 37–59.
23. J. Antony, M. Sony, O. McDermott. Conceptualizing Industry 4.0 readiness model dimensions: an exploratory sequential mixed-method study. *TQM Journal*. 2023, pp 577–596.
24. A.J. Dal Forno, W.V. Bataglini, F. Steffens, A.A. Ulson de Souza. Industry 4.0 in textile and apparel sector: a systematic literature review. *Research Journal of Textile and Apparel*. 2023, pp 95–117.
25. M. Daneshmand, F. Noroozi, C. Corneanu, F. Mafakheri, P. Fiorini. Industry 4.0 and prospects of circular economy: a survey of robotic assembly and disassembly. *International Journal of Advanced Manufacturing Technology*. 2023, pp 2973–3000.
26. K.M. Qureshi, B.G. Mewada, M.K. Buniya, M.R.N.M. Qureshi. Analyzing Critical Success Factors of Lean 4.0 Implementation in Small and Medium Enterprises for Sustainable Manufacturing Supply Chain for Industry 4.0 Using PLS-SEM. *Sustainability*. 2023, p 5528.
27. M. Kumar, R.D. Raut, S. Jagtap, V.K. Choubey. Circular economy adoption challenges in the food supply chain for sustainable development. *Business Strategy and the Environment*. 2023, pp 1334–1356.
28. S. Kusi-Sarpong, H. Gupta, S.A. Khan, et al. Sustainable supplier selection based on industry 4.0 initiatives within the context of circular economy implementation in supply chain operations. *Production Planning and Control*. 2023, pp 999–1019.
29. S. Werbińska-Wojciechowska, K. Winiarska. Maintenance Performance in the Age of Industry 4.0: A Bibliometric Performance Analysis and a Systematic Literature Review. *Sensors* **2023**, 23 (3), 1409.
30. F. Alkaraan, M. Elmarzouky, K. Hussainey, V.G. Venkatesh. Sustainable strategic investment decision-making practices in UK companies: The influence of governance mechanisms on synergy between industry 4.0 and circular economy. *Technological Forecasting and Social Change*. 2023, p 187122187.
31. J. Serey, M. Alfaro, G. Fuertes, et al. Pattern Recognition and Deep Learning Technologies, Enablers of Industry 4.0, and Their Role in Engineering Research. *Symmetry*. 2023, p 535.
32. Y. Yang, T. Gai, M. Cao, et al. Application of Group Decision Making in Shipping Industry 4.0: Bibliometric Analysis, Trends, and Future Directions. *Systems* **2023**, 11 (2), 69.
33. J. Reyes, J. Mula, M. Díaz-Madroñero. Development of a conceptual model for lean supply chain planning in industry 4.0: multidimensional analysis for operations management. *Production Planning and Control*. 2023, pp 1209–1224.
34. S. Tissir, A. Cherrafi, A. Chiarini, S. Elfezazi, S. Bag. Lean Six Sigma and Industry 4.0 combination: scoping review and perspectives. *Total Quality Management and Business Excellence*. 2023, pp 261–290.
35. S.K. Gupta, A. Khang, P. Somani, C.K. Dixit, A. Pathak. Data Mining Processes and Decision-Making Models in the Personnel Management System. In *Designing Workforce Management Systems for Industry 4.0*; CRC Press, Boca Raton, **2023**; pp 85–104.
36. M.R. Ejaz. Implementation of Industry 4.0 Enabling Technologies from Smart Manufacturing Perspective. *Journal of Industrial Integration and Management*. **2023**, 149–173.
37. H. Mansour, E. Aminudin, T. Mansour. Implementing industry 4.0 in the construction industry- strategic readiness perspective. *International Journal of Construction Management*. **2023**, 1457–1470.

38. Z. Lei, S. Cai, L. Cui, L. Wu, Y. Liu. How do different Industry 4.0 technologies support certain Circular Economy practices? *Industrial Management and Data Systems*. **2023**, 1220–1251.
39. O. Yavuz, M.M. Uner, F. Okumus, O.M. Karatepe. Industry 4.0 technologies, sustainable operations practices and their impacts on sustainable performance. *J. Cleaner Production*. **2023**, 387135951.
40. L. Athanasopoulou, H. Bikas, A. Papacharalampopoulos, P. Stavropoulos, G. Chryssolouris. An industry 4.0 approach to electric vehicles. *International J. Comp. Integr. Manufacturing*. **2023**, 334–348.
41. W. Zayat, H.S. Kilic, A.S. Yalcin, S. Zaim, D. Delen. Application of MADM methods in Industry 4.0: A literature review. *Computers and Industrial Engineering*. **2023**, 2023109075.
42. H. Nouinou, E. Asadollahi-Yazdi, I. Baret, et al. Decision-making in the context of Industry 4.0: Evidence from the textile and clothing industry. *Journal of Cleaner Production*. **2023**, 2023136184.
43. L. Melnyk, O. Kubatko, O. Matsenko, Y. Balatskyi, K. Serdyukov. Transformation of the human capital reproduction in line with Industries 4.0 and 5.0. *Problems and Perspectives in Management*. **2021**, 480–494.
44. T.A. Kurniawan, C. Meidiana, M.H. Dzarfan Othman, H.H. Goh, K.W. Chew. Strengthening waste recycling industry in Malang (Indonesia): Lessons from waste management in the era of Industry 4.0. *J. Clean. Prod.* **2023**, 382, 135296.
45. W. Kim, H. Jang, B. Gerelmaa, G. Khongorzul. A study on the internal and external factors influencing smart plant construction in perspective of fourth Industrial revolution (Industry 4.0). *J. Integr. Sci. Technol.* **2021**, 9 (1), 37–44.
46. M. Ghobakhloo, M. Iranmanesh, M.E. Morales, M. Nilashi, A. Amran. Actions and approaches for enabling Industry 5.0-driven sustainable industrial transformation: A strategy roadmap. *Corporate Social Responsibility and Environmental Management*. **2023**, 1473–1494.
47. L. Liu, W. Song, Y. Liu. Leveraging digital capabilities toward a circular economy: Reinforcing sustainable supply chain management with Industry 4.0 technologies. *Computers and Industrial Engineering*. 2023, p 178109113.
48. A. Raja Santhi, P. Muthuswamy. Industry 5.0 or industry 4.0S? Introduction to industry 4.0 and a peek into the prospective industry 5.0 technologies. *Int. J. Interactive Design and Manufacturing*. **2023**, 947–979.
49. Y. Kazancoglu, Y.D. Ozkan-Ozen, M. Sagnak, I. Kazancoglu, M. Dora. Framework for a sustainable supply chain to overcome risks in transition to a circular economy through Industry 4.0. *Production Planning and Control*. **2023**, 902–917.
50. A. Khang, S.K. Gupta, C.K. Dixit, P. Somani. Data-Driven Application of Human Capital Management Databases, Big Data, and Data Mining. In *Designing Workforce Management Systems for Industry 4.0*; CRC Press, Boca Raton, **2023**; pp 105–120.
51. B. Alhayani, A.S. Kwekha-Rashid, H.B. Mahajan, et al. 5G standards for the Industry 4.0 enabled communication systems using artificial intelligence: perspective of smart healthcare system. *Applied Nanoscience (Switzerland)*. 2023, pp 1807–1817.
52. M. Golovianko, V. Terziyan, V. Branytskyi, D. Malyk. Industry 4.0 vs. Industry 5.0: Co-existence, Transition, or a Hybrid. *Procedia Comput. Sci.* **2023**, 217 (0), 102–113.
53. A. Khang, B. Jadhav, S. Birajdar. Industry Revolution 4.0. In *Designing Workforce Management Systems for Industry 4.0*; CRC Press, Boca Raton, **2023**; pp 11–34.
54. G. Zhang, Y. Yang, G. Yang. Smart supply chain management in Industry 4.0: the review, research agenda and strategies in North America. *Annals of Operations Research*. 2023, pp 1075–1117.
55. V. D'Angelo, F. Cappa, E. Peruffo. Green manufacturing for sustainable development: The positive effects of green activities, green investments, and non-green products on economic performance. *Business Strategy and the Environment*. 2023, pp 1900–1913.
56. T.-D. Bui, J.-W. Tseng, M.-L. Tseng, K.-J. Wu, M.K. Lim. Municipal solid waste management technological barriers: A hierarchical structure approach in Taiwan. *Resour. Conserv. Recycl.* **2023**, 190, 106842.
57. K.L. Whittingham, A.G. Earle, D.I. Leyva-de la Hiz, A. Argiolas. The impact of the United Nations Sustainable Development Goals on corporate sustainability reporting. *BRQ Business Research Quarterly*. **2023**, 45–61.
58. S.A.R. Khan, Z. Yu, K. Farooq. Green capabilities, green purchasing, and triple bottom line performance: Leading toward environmental sustainability. *Business Strategy and the Environment*. 2023, pp 2022–2034.
59. A.K. Barapatre, R. Sadiwala. Energy and resources management for Multiple Access in Massive IoT network. *J. Integr. Sci. Technol.* **2023**, 11 (3), 518.
60. A. Rejeb, K. Rejeb, S. Zailani, Y. Kayikci, J.G. Keogh. Examining Knowledge Diffusion in the Circular Economy Domain: a Main Path Analysis. *Circular Economy and Sustainability*. **2023**, 125–166.
61. C. Semeraro, A.G. Olabi, H. Aljaghoub, et al. Digital twin application in energy storage: Trends and challenges. *J. Energy Storage*. **2023**, 58106347.
62. Y. Shang, Y. Lian, H. Chen, F. Qian. The impacts of energy resource and tourism on green growth: Evidence from Asian economies. *Resources Policy*. **2023**, 81103359.
63. S. Hägele, E.H. Grosse, D. Ivanov. Supply chain resilience: a tertiary study. *International Journal of Integrated Supply Management*. **2023**, 52–81.
64. M. Saini, E. Sengupta, M. Singh, H. Singh, J. Singh. Sustainable Development Goal for Quality Education (SDG 4): A study on SDG 4 to extract the pattern of association among the indicators of SDG 4 employing a genetic algorithm. *Education and Information Technologies*. **2023**, 2031–2069.
65. A. Ebekozien, C. Aigbavboa, M. Aigbedion. Construction industry post-COVID-19 recovery: Stakeholders perspective on achieving sustainable development goals. *Int. J. Construction Management*. **2023**, 1376–1386.
66. D.P. Maganga, I.W.R. Taifa. Quality 4.0 transition framework for Tanzanian manufacturing industries. *TQM Journal*. 2023, pp 1417–1448.
67. M.M. Mijwil, K.K. Hiran, R.D. al. Advancing Construction with IoT and RFID Technology in Civil Engineering: A Technology Review. *Al-Salam J. Eng. Technol.* **2023**, 2 (2), 54–62.
68. S. Luo, N. Yimamu, Y. Li, et al. Digitalization and sustainable development: How could digital economy development improve green innovation in China? *Business Strategy and the Environment*. **2023**, pp 1847–1871.
69. S. Nasrollahi, A. Kazemi, M.H. Jahangir, S. Aryaee. Selecting suitable wave energy technology for sustainable development, an MCDM approach. *Renewable Energy*. 2023, pp 756–772.
70. 1Z.A. Adhoni, D. Lal N. Framework, semantic and standard approaches in multi-clouds to achieve interoperability: A survey. *J. Integr. Sci. Technol.* **2022**, 10 (2), 67–72.
71. M. Kubli, S. Puranik. A typology of business models for energy communities: Current and emerging design options. *Renewable and Sustainable Energy Reviews*. 2023, p 176113165.
72. S. Goubran, T. Walker, C. Cucuzzella, T. Schwartz. Green building standards and the United Nations' Sustainable Development Goals. *Journal of Environmental Management*. 2023, p 326116552.
73. S. Abbate, P. Centobelli, R. Cerchione. The digital and sustainable transition of the agri-food sector. *Technological Forecasting and Social Change*. 2023, p 187122222.
74. Y. Cheng, K. Zhu, Q. Zhou, et al. Tourism Ecological Efficiency and Sustainable Development in the Hanjiang River Basin: A Super-Efficiency Slacks-Based Measure Model Study. *Sustainability (Switzerland)*. 2023, p 6159.
75. Y. Dou, L. Sun, J. Ren, L. Dong. Opportunities and future challenges in hydrogen economy for sustainable development. In *Hydrogen Economy*; Elsevier, **2023**; pp 537–569.
76. A. Di Vaio, S. Hasan, R. Palladino, R. Hassan. The transition towards circular economy and waste within accounting and accountability models: a systematic literature review and conceptual framework. *Environment, Development and Sustainability*. 2023, pp 734–810.

77. J.G. Vargas-Hernández, K. Pallagst, J. Zdunek-Wielgołaska. Urban Green Spaces as a Component of an Ecosystem. In *Sustainable Development and Environmental Stewardship*; Springer International Publishing, Cham, **2023**; pp 165–198.
78. S. Zhang, M.K. Anser, M. Yao-Ping Peng, C. Chen. Visualizing the sustainable development goals and natural resource utilization for green economic recovery after COVID-19 pandemic. *Resources Policy*. 2023, p 80103182.
79. N. Manjubaashini, G. Radha, S. Balakumar. A comprehensive review on functionalized Hydroxyapatite nanostructures based gas sensors for environmental pollutant monitoring. *J. Mater. Nanosci*. **2022**, 9 (1), 47–60.
80. Z. Wang, Y. Deng, S. Zhou, Z. Wu. Achieving sustainable development goal 9: A study of enterprise resource optimization based on artificial intelligence algorithms. *Resources Policy*. 2023, p 80103212.
81. A. Tlili, R. Huang, Kinshuk. Metaverse for climbing the ladder toward 'Industry 5.0' and 'Society 5.0'? *Service Industries Journal*. 2023, pp 260–287.
82. G. Tian, W. Lu, X. Zhang, et al. A survey of multi-criteria decision-making techniques for green logistics and low-carbon transportation systems. *Environmental Science and Pollution Research*. 2023, pp 57279–57301.
83. J. Alves, T.M. Lima, P.D. Gaspar. Is Industry 5.0 a Human-Centred Approach? A Systematic Review. *Processes* **2023**, 11 (1), 193.
84. F. Mneimneh, H. Ghazzawi, M. Abu Hejjeh, M. Manganelli, S. Ramakrishna. Roadmap to Achieving Sustainable Development via Green Hydrogen. *Energies*. 2023, p 1368.
85. D. Singh, S. Sinha, V. Thada. A novel attribute based access control model with application in IaaS cloud. *J. Integr. Sci. Technol.* **2022**, 10 (2), 79–86.
86. C.M. Galanakis. The "Vertigo" of the Food Sector within the Triangle of Climate Change, the Post-Pandemic World, and the Russian-Ukrainian War. *Foods* **2023**, 12 (4), 721.
87. D. Ivanov. The Industry 5.0 framework: viability-based integration of the resilience, sustainability, and human-centricity perspectives. *International Journal of Production Research*. 2023, pp 1683–1695.
88. M. Sadiq, T.Q. Ngo, A.A. Pantamee, et al. The role of environmental social and governance in achieving sustainable development goals: evidence from ASEAN countries. *Economic Research-Ekonomska Istrazivanja* . 2023, pp 170–190.
89. S. Biswas, A. Sanyal, D. Božanić, A. Puška, D. Marinković. Critical Success Factors for 5G Technology Adaptation in Supply Chains. *Sustainability (Switzerland)*. 2023, p 5539.
90. I. Bolis, T.F.A.C. Sigahi, A. Thatcher, P. Saltorato, S.N. Morioka. Contribution of ergonomics and human factors to sustainable development: a systematic literature review. *Ergonomics*. 2023, pp 303–321.
91. D.G. Broo, J. Schooling. Digital twins in infrastructure: definitions, current practices, challenges and strategies. *International Journal of Construction Management*. 2023, pp 1254–1263.
92. D.B. Rathore. Future of Textile: Sustainable Manufacturing & Prediction via ChatGPT. *Eduzone : international peer reviewed/refereed academic multidisciplinary journal*. 2023, pp 52–62.
93. X. Chen, M. Wang, B. Wang, et al. Energy Consumption Reduction and Sustainable Development for Oil & Gas Transport and Storage Engineering. *Energies*. 2023, p 1775.
94. M. Attaran, B.G. Celik. Digital Twin: Benefits, use cases, challenges, and opportunities. *Decis. Anal. J.* **2023**, 6, 100165.
95. A. Kusiak. Smart Manufacturing. In *Springer Handbook of Automation*; Springer, **2023**; pp 973–985.
96. W. Xian, K. Yu, F. Han, et al. Advanced Manufacturing in Industry 5.0: A Survey of Key Enabling Technologies and Future Trends. *IEEE Transactions on Industrial Informatics*. 2023.
97. G.O. Botchway, O.J. Bradley. The diffusion of the sustainable development goals (SDGs): an examination of preparer perceptions. *Sustainability Accounting, Management and Policy Journal*. 2023, pp 289–312.
98. S.A. Ahmad, G.A. Sulaiman. the Role of Attributes Based Costing Technology in Achieving Sustainable Development Goals. *International Journal of Professional Business Review*. 2023, p 8.
99. S.K. Pathak, V. V. Tyagi, K. Chopra, et al. Energy, exergy, economic and environmental analyses of solar air heating systems with and without thermal energy storage for sustainable development: A systematic review. *Journal of Energy Storage*. 2023, p 59106521.
100. Y. Truong, S. Papagiannidis. Artificial intelligence as an enabler for innovation: A review and future research agenda. *Technological Forecasting and Social Change*. 2022, pp 816–37.
101. C.L. Karmaker, A.B.M.M. Bari, M.Z. Anam, et al. Industry 5.0 challenges for post-pandemic supply chain sustainability in an emerging economy. *International Journal of Production Economics*. 2023, p 258108806.
102. O. Oloruntobi, K. Mokhtar, N. Mohd Rozar, et al. Effective technologies and practices for reducing pollution in warehouses - A review. *Cleaner Engineering and Technology*. 2023, p 2023100622.
103. N. Shehata, D. Egirani, A.G. Olabi, et al. Membrane-based water and wastewater treatment technologies: Issues, current trends, challenges, and role in achieving sustainable development goals, and circular economy. *Chemosphere*. 2023, p 320137993.
104. A. Shrivastava, K. Murali Krishna, M. Lal Rinawa, et al. Inclusion of IoT, ML, and Blockchain Technologies in Next Generation Industry 4.0 Environment. *Materials Today: Proceedings*. 2023, pp 3471–3475.
105. V.A. Wankhede, S. Vinodh. Benchmarking Industry 4.0 readiness evaluation using fuzzy approaches. *Benchmarking An Int. J*. **2023**, 30 (1), 281–306.
106. J. Rosak-Szyrocka, J. Żywiołek, M. Shahbaz. Quality Management, Value Creation, and the Digital Economy; Routledge, London, **2023**.
107. L. Prost, G. Martin, R. Ballot, et al. Key research challenges to supporting farm transitions to agroecology in advanced economies. A review. *Agron. Sustain. Dev.* **2023**, 43 (1), 11.
108. F.S. Hafez, B. Sa'di, M. Safa-Gamal, et al. Energy Efficiency in Sustainable Buildings: A Systematic Review with Taxonomy, Challenges, Motivations, Methodological Aspects, Recommendations, and Pathways for Future Research. *Energy Strategy Reviews*. 2023, p 45101013.
109. A. Sawangwong, P. Chaopaisarn. The impact of applying knowledge in the technological pillars of Industry 4.0 on supply chain performance. *Kybernetes*. 2023, pp 1094–1126.
110. J. Antony, O. McDermott, M. Sony, et al. Benefits, challenges, critical success factors and motivations of Quality 4.0–A qualitative global study. *Total Quality Management and Business Excellence*. 2023, pp 827–846.
111. R. Singh, S. Kalas, K. Bamarah, A. Singh, R. Kumar. Challenges for Indian Machine Tool Small and Medium Enterprises (SMEs). *J. Integr. Sci. Technol.* **2018**, 6 (2), 25–32.