Utilization of Digital Manufacturing Tools for Industry 4.0 Implementation

Nadikudi Bhanodaya Kiran Babu

Associate Professor, Mechanical Engineering Department, Sreenidhi Institute of Science and Technology, Hyderabad, India

*Corresponding author: kiran.n@sreenidhi.edu.in

ABSTRACT

Industry 4.0 is one of the foremost that drives the modern industrial revolution with the latest technologies, which comprises smart equipment, machinery and control systems. In this, digital manufacturing integrates the traditional manufacturing systems with the latest digital technologies for modelling, analysis, optimization and automation of manufacturing processes. This study analyses the application of various advanced technological tools for implementation of digital manufacturing. Based on content analysis, combined applications of digital manufacturing tools and advanced manufacturing technologies are framed and various technological trends identified. Integrated and automated machines can do repetitive works and humans can do complicated works through creativity and problem-solving capacity through technological tools. This paper support to identify the digital manufacturing obstacles in implementation and also helps to understand the digital manufacturing within the framework of the nine technological tools and it also recognizes that correlation with other technologies. In digital manufacturing, a huge manufacturing data can be analyzed with the big data analysis and stored in cloud for future use and secured with the cybersecurity technology. Simulation carried out to test digital model before implementation and monitoring with the digital twin technology. Virtual reality integrates the real-world with virtual environments and taking decisions through Internet of things. Robotic system enables to automate works and additive manufacturing technology develops the components from the stored data.

Keywords: Digital manufacturing; Industry 4.0; Internet of things; cloud computing; augment and virtual reality

INTRODUCTION

Industry 4.0, often referred to as the Fourth Industrial Revolution (Figure 1), it represents a transformation characterized by the full computerization of manufacturing processes (Sazzadur Rahman et al. 2023). This Revolution focuses on enhancing the digitalization of manufacturing through three key movements such as connectivity, intelligence, and automation. Industry 4.0 introduces new technological concepts that enhance the expertise of professionals in the manufacturing arena (Rai 2021).

A key achievement of Industry 4.0 is the mechanization of entire manufacturing processes, which optimizes output and efficiency while identifying process limitations even before production begins, leveraging vast amounts of data. This can be achieved by significant changes in design, production, and distribution. The integration of cutting-edge smart technologies into the manufacturing sector marks the beginning of Industry 4.0, emphasizing the role of human participation alongside advanced technologies. As a result, the combination of speed, precision, creativity, and innovation drives more efficient manufacturing operations, enabling businesses to effectively tackle large-scale challenges (Tam´as Kegyes et al. 2021). Industry 4.0 converts the scenario of the manufacturing systems into cyber physical conditions (Rahul Rai et al. 2021) and Artificial Intelligence (AI) is used for decision making (Rai & Sahu 2020), product design and modelling and also inspection (Zhang, 2019) are few examples of advanced technologies implementation for manufacturing sector.

The main pillars of manufacturing for Industry 4.0 comprises interconnectivity, automation, machine learning (ML) and real time data (Dhandapani & Sivaramakrishnan 2019). Interconnectivity deals Industrial Internet of Things (IIoT) with the incorporation of physical and digital systems in which, sensors are connected to the machinery which will collect all the real time data and send to digital

system where the analysis and decision making are taking place (Armengaud et al. 2017; Stocker et al. 2021). Automation through programmed robots to perform the routine manufacturing tasks. Cloud computing is one of the key technologies which enables the storage of manufacturing in the cloud to secure the data. On the other side, cybersecurity makes the data available with the privacy.

A fundamental aspect of Industry 4.0 is the Internet of Things (IoT), which transforms physical devices into digital counterparts. This transformation is typically achieved through the deployment of sensors and models that work together to enhance system capacity. In this context, technology utilizes the IoT to generate outputs and perform necessary maintenance tasks.

AI plays a crucial role in digital manufacturing by offering solutions to various challenges based on its learning capabilities, allowing for adaptive responses without the need to search for answers in every aspect (Alpaydin 2010). One of the primary advantages of AI is its potential to enhance quality control and improve proficiency in arranging tools and machinery for the production of complex parts. Key factors that boost AI capabilities include advanced hardware, sophisticated algorithms, deep learning and reinforcement learning techniques, state-of-the-art data sensors, and large datasets (Pokutta 2016). Reinforcement learning is a technique, where an agent learns by taking actions in an environment and receiving feedback for decision-making optimization. In AI, deep learning is a subset of ML that uses complicated artificial neural networks to process information. In Cyber-physical conditions, AI is integrated into a system that directly interacts with the physical world through sensors and actuators, creating a better environment for real-time decision-making and control mechanisms.

This study explores different kinds of advanced technological tools for implementation for digital manufacturing in the context of Industry 4.0. Many of the digital manufacturing tools are not new, but latest forms of interconnectivity, integration and enhancements have changed the digital manufacturing in different way and opened new challenges and opportunities to explore. With content analysis of technical and scientific papers, various reports, different digital manufacturing roles are assessed to define implementation of tools.
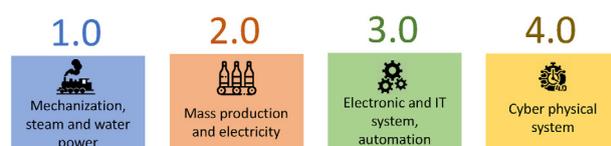

FIGURE 1. Industrial revolutions (Sazzadur Rahman 2023)

DIGITAL MANUFACTURING IN INDUSTRY 4.0

Digital manufacturing is a new emerging digital technology for the new era in manufacturing where the integration of all the areas of manufacturing is connected to the computers. This integration provides a better productivity with sustainability and moving towards new scope of enhancing the manufacturing with better quantity as well as quality. Nowadays, digital manufacturing has become very popular with the development of computer aided models, simulations and analysis. In Industry 4.0 concepts there is a provision of work of both humans and computer integrated computers together to minimize the flaws in manufacturing.

Digital manufacturing can be found in all major areas such as computer integrated manufacturing, flexible manufacturing and design for manufacturing. The transaction of systems and tools can enhance the managerial capacity. This transaction also supervises the information throughout the product life cycle effectively. This improved integration that ultimately encourages decentralized decision-making.

Digital manufacturing tools facilitate simultaneous engineering, allowing for optimization and error prevention, anticipating necessary corrections and generating non-linear cascading effects. In traditional linear project management models, product development typically happens independently of manufacturing and assembly process planning, operations that can create difficulties like reproduction due to assembly, poor ergonomics and unbalanced assembly lines. Regarding inter-organizational integration, many organizations have opted to concentrate on core business functions and decentralize manufacturing operations to enhance flexibility and expedite time-to-market.

Digital manufacturing use of machines with collaboration with advanced computer technologies tends to increase the manufacturing processes. The major benefits anticipated with reduction in wastage by streamline of manufacturing processes results in efficiency enhancement on the other side, improvement in quality and assurance is achieved using data analysis including production monitoring activities. Customization is also possible with rapid prototype and flexible manufacturing techniques. Digital manufacturing systems remove obstacles by fostering agile manufacturing plans that different production process components are connected and integrated within the framework of the manufacturing life cycle, supplier integration enables the anticipated assembly of product processes using digital mock-up tools before the suppliers fully develop respective parts, requiring only

minor adjustments when completed. Ensuring qualitative information sharing among all partners remains a main goal of digital manufacturing and the real-time exchange of information with stakeholders is pivotal for successful manufacturing operations.

The implementation is primarily depending on integration of systems by integration different manufacturing and machines digitally for consistent operations. Secondly modelling and simulating the models using software's to forecast the outcome of production before starting actual manufacturing. Thirdly, digital twins able to create an effective representation of entire system to optimizing the manufacturing operations. The technologies to implement Digital manufacturing, the 2D and 3D models are to be developed through software's in computer aided design domain and then computer aided manufacturing converts the models into data for machines for production. In Additive Manufacturing (AM), printing of prototype components layer by layer from design. AI analyzing the data for the manufacturing, quality and optimization. IoT can provide manufacturing devises and sensors to gather data for manufacturing processes through internet. After understating above elements, it is evitable to support for digital manufacturing to improve the capability of business to sustain in competition.

Digital Manufacturing operates and serving as a crucial integrator of technologies across the entire product life cycle. Industry people universally acknowledge the digital manufacturing processes is revolutionize every facet of manufacturing systems. Isolated production units evolve into a cohesive, automated, and optimized production flow, enhancing efficiency and redefining traditional relationships among suppliers, manufacturers, and customers.

The trends in digital manufacturing includes sustainability in less effect on environment by using high efficiency processes and smart factories after implementing autonomous machines can project decisions on real manufacturing data and collaboration is possible among manufacturers and technology developers. Different challenges encompass cybersecurity by protecting digital data from cyber risks, investment costs for capital money for manufacturing systems setup and maintenance. On the other side, training is need to provide for the workers for understanding latest technologies.

The main nine tools [Figure 2] of technological advancements identified within this framework include: IoT, Cloud computing, Big data and analytics, ML and AI, Autonomous Robots, Digital Simulations, Digital twins, Cybersecurity, Augmented Reality (AR) and Virtual Reality (VR), AM. Each one of these technologies is connected in digital manufacturing at various phases of the life cycle, influencing design, analysis, use and implementation.

FIGURE 2. Digital manufacturing tools in Industry 4.0 (https://www.precicon.com.sg/industry_4/industry-4-0-framework/)

DIGITAL MANUFACTURING THROUGH IOT

The IoT is a crucial component in connecting and enhancing the value of digital manufacturing for the modern industries. The interconnectivity of reliable sensors, devices and machines enables greater real-time visibility of data and communication throughout a plant. This visibility, combined with sophisticated analytics and different data tools helps the managers to extract actionable insights from a huge data storage. The actual role of IoT devices is to provide timely and accurate information. The ability to collect latest information from machinery, devices and sensors unlocks new analytical opportunities for analysers. This enhances result visibility and enabling easier decision-making. IoT sensors furnish critical insights with regard to quality and also costs.

Moreover, final production plans and analyses can be iterated as needed prior to actual manufacturing begins, significantly reduces the manufacturing threats. IoT devices are integral during the ramp-up to operations phase within the life cycle and they play a vital role in integration, automation and decision making. Digital manufacturing tools with IoT synchronize the manufacturing processes and materials. This synchronization process, supported by plant integration and real-time simulation, enhances operational excellence. Additionally, IoT supports forecast maintenance by providing critical information for equipment evaluation, thereby ensuring accuracy and efficiency in production line.

IIoT is a subset of the IoT, where different sensors, software and hardware are integrated with machinery and systems to receive a real-time data. The main use of IIoT is tracking for latest technology applications. IIoT have

applications in inventory management as prevention of holding over or understock in inventory. One effective approach to accomplish this is by implementing shelf-mounted sensors and weighing devices that transmit Inventory data directly to warehouse management system. Establishing this system enables warehouse managers to track inventory levels data, providing them with real-time visibility and enhanced control over stock management.

DIGITAL MANUFACTURING THROUGH CLOUD COMPUTING

This cloud technology plays a critical role in digital manufacturing by enabling the integrated, real-time collection, processing and access of data. Cloud computing enables manufacturing data to be stored in the cloud and accessed via the internet as needed.

Cloud computing is able to offer scalable computing resources and storage solutions that allows industries to leverage business intelligence by utilizing big data analytics. This capability helps organizations consolidate and optimize their manufacturing operations. The advent of cloud computing marks a transformative shift in how information technology services are developed, deployed and maintained for.

Essentially, cloud computing offers scalable and elastic information technology related capabilities as a service to external customers through Internet. It serves as the foundation for various digital manufacturing systems across different life cycle stages, it starts from product engineering and plant design, where the cloud facilitates the collection of data and its availability for real-time simulation, commissioning and operations. For many decades, manufacturers are collecting and storing the manufacturing data for the purpose of enhancing their production rate. However, these collected data generated at higher speeds and huge volumes, it become impossible to handle through conventional storing process. There is necessity to create a storage place where the generated data stored safely and efficiently and able retrieve when there is need. On the other hand, cloud computing provides an opportunity to store and processes huge amount of data on remote servers. So that, the storage infrastructure development is not required at workplace.

According to the National Institute of Standards and Technology (NIST), there are three service models related to cloud computing known as the SPI model: Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS). SaaS provides access to cloud based digital manufacturing tools like computer aided design and finite element analysis through the Internet (Elias Ribeiro et al. 2020).

For instance, Siemens Intosite provides streamlined access to current digital manufacturing information directly from the shop floor. This solution implements the digital factory as a SaaS application, allowing Siemens PLM Software to host the application data on the cloud, enabling customers to access it via web browsers. No need them to invest in new hardware and support (Aldrete 2018). After implementing of these service models there is chance to enable manufacturing companies to reduce costs and allows information technology departments to shift their focus from daily operations to strategic initiatives. Successful utilization of digital manufacturing necessitates a robust data infrastructure for storage, transfer and processing to reduce losses in production. Significant processing power is also vital for analysis and simulations which demand high hardware capacities.

Consequently, establishing sufficient infrastructure becomes a key challenge in leveraging digital manufacturing along with cloud technology emerges as a better suitable solution. A cloud edge-based hybrid scheduling presentation was prepared with (Jian 2021) for prediction and schedule the output. Eventually, cloud computing is converting the facet of manufacturing into digital manufacturing in the fields from management to manufacturing processes.

BIG DATA, ML AND AI IN DIGITAL MANUFACTURING

The manufacturing sector generates large volumes and complex data generated by IoT when compared with other industries. This data arrives from cloud and enterprise applications, sensors and much more in different formats. When this data arrives, there is use of data analytics to convert data into information and dispatched implementable conclusions. Generated huge volumes of data can be analyzed to gain insights and optimization. As the complexity of manufacturing operations increases, so too does the potential value information from big data and analytics. One of the pivotal roles of analytics in digital manufacturing involves correlating information to prove the effect of some variables within the production system, aiding in scenario modeling by linking previously unrecognized factors. Operations managers leverage advanced analytics to interrogate historical process data, identifying different patterns and relationships among discrete steps and inputs in order to optimize critical factors Auschitzky et al. 2014 noted that many manufacturing facilities possess extensive real-time shop-floor huge information alongside the capacity for advanced statistical analysis. A single data source across all applications ensures reliable and actionable real-time insights,

facilitating better communication among partners and across product generations. This correlation also provides the ability to analyze existing patterns, such as resource and process failures, improves predictions within simulation models. For instance, Boeing company is integrated the entire value chain as unified platform, thereby enhancing data and analytics capabilities to make fruitful use of digital manufacturing tools.

AI technologies improve the data analysis, enables forecast analytics for production enhancements and failure prediction. AI can be used for decision making, product design, modelling, inspection and manufacturing processes are few examples of advanced technologies implementation for manufacturing sector. This highlights how AI is applied throughout the manufacturing cycle, which can integration starts from design to the dispatching of manufacturing components. ML provides an opportunity for manufacturing industries to optimize the production cycle and is possible to give service so that the machinery can work independently. This can offer a structured inspection of different opportunities and risks in the manufacturing. ML can use from production planning to payments. Different applications of ML in digital manufacturing are shown in Figure 3. In expert structure, the machine labour support and also the machine maintenance. On one side, direct added value is initiated for the customer when operating the machine, on the other side, the available machine data are used for the development of value-added services.
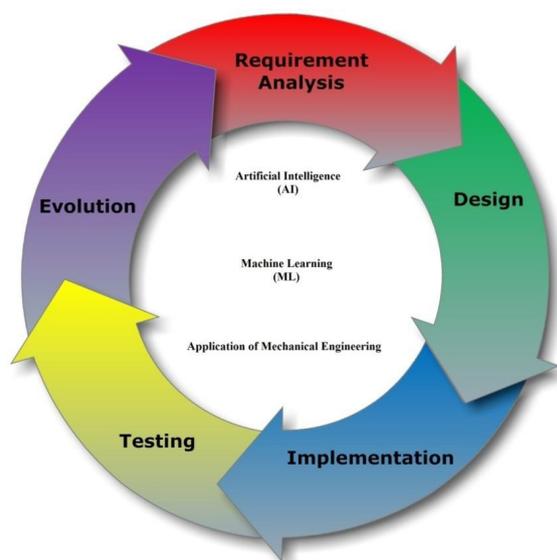

FIGURE 3. ML Applications in digital manufacturing
(Dhandapani & Sivaramakrishnan 2019)

Manufacturing industries with Industry 4.0 utilizes the latest smart digital technology devices to develop intelligent objects. Next level AI and IoT are having

properties such as self-configuration, self-repair and self enhancement (Xu 2018). In predictive manufacturing systems, different technologies were used like data mining, statistics and models are used to transforms the data in to information, and development of predictions in manufacturing systems (Nikolic 2017). In human machine interaction is an integration of AI with human machinery is very critical in development of Industry 4.0 business cycles. Here the target is to achieve better efficiency by attaching human with algorithms in machine with human interfaces (Schaeffer 2017).

ML techniques utilize advanced computational algorithms to analyze huge data sets, while data visualization tools help manufacturers better understand the insights presented by the data. By integrating previously isolated data sets and performing thorough analysis, companies can now discover innovative methods to magnify the processes that significantly impact yield. Big data and AI and ML techniques are often applied to optimize the use of digital manufacturing tools, particularly in the planning stages, encompassing tasks such as line balancing and real-time production management. There are number of ML methods are existing and on the other side, number of manufacturing areas where these methods can be employed (Diez-Olivan 2019; Wuest 2016).

DIGITAL MANUFACTURING AND AUTONOMOUS ROBOTS

Recent advancements in technology have accompany in a new era of advanced robotics, capable of executing both complex and delicate tasks. Autonomous robots belong to emerging category of devices that can be programmed to perform tasks with minimum human intervention to automize routine tasks that's improve production efficiency and safety. Over the past few years, there has been a notable increase in autonomous robots equipped with AI and learn from their environment and to take independent decisions. These robots, powered by state-of-the-art software and sensors, can recognize, analyze, and respond to information from their surroundings and also collaborate with and learn from humans (Rüßmann 2016). One notable area of growth in robotics is the rise of collaborative robots which are designed to operate safely alongside people, thereby reduce workers from repetitive and hazardous duties.

Robot can have features of autonomy, flexibility and cooperation and also have provision to handle complicated tasks and allows workers to focus more on work leads to a significant improvement in shop floor production. In digital manufacturing space, the autonomous robots are to facilitate the design and simulation of hybrid workstations

in this both human workers and robots are work together. Digital manufacturing tools enable the programming of robots in both offline and online modes, mechanization of manual works and simulations of interactions between workers and Robots. Generally, autonomous Robots play a vital role during the plant design and operational ramp-up phases of the life cycle, as they are crucial for plant automation and commissioning. Digital manufacturing tools can identify the potential collisions between the Robot and manufactured products and also can utilize to determine the optimal ergonomic position for workers, based on concurrent simulations of collective job connecting humans and robots.

DIGITAL MANUFACTURING AND SIMULATIONS

The simulation usage reflects advancements in technology and the specific phases of the life cycle in which it is utilized. After arriving of cloud computing and data acquisition has changed the simulation from static to dynamic environments. This connects to the concept of Digital Twins (Elias, 2020) referred simulation as fundamental for digital manufacturing that includes experiments and validity and configures of both existing and new manufacturing facilities. Simulation permits the modeling of processes and providing a chance to replicate the actual system's responses to events occurring over time. In complete digital manufacturing, products, manufacturing processes and materials are simulated digitally before the materials are procured. This method is minimizing the time and cost related to new product development and new process eventually leads to good quality components and at lower costs. For example, dynamic simulations provide a real time change in current ongoing processes, this will give a provision of incorporate a new product into the assembly line.

DIGITAL MANUFACTURING AND DIGITAL TWIN

The concept of a digital twin provides significant potential for enhancing the performance and maintenance of industrial systems. Many big companies are implementing digital twin for monitoring and managing the assets and manufacturing processes. A digital twin works as a virtual representation of a real-world product, machines and processes so that, the companies are able to understand in a better way to analyze and optimize operations via real-time simulation (Dietz & Pernul, 2019; Negri, 2017).

Digital twin executes an online simulation that leverages data from sensors connected to machines. The capability of digital twin to forecast potential issues, enabling proactive measures. For instance, operators can diagnose malfunctions in a part or estimate the lifespan of a product. The ongoing simulation improves the product design and helps ensure equipment uptime. An IIoT system transmits the real time date and a digital twin continuously collects the information, ensuring it remains aligned with the original system throughout manufacturing lifecycle. Digital twins gain a virtual test environment for innovating new components and enhancing performance even before making physical alterations. The applications can be seen in demanding sectors such as aerospace and automotive industries.

DIGITAL MANUFACTURING AND CYBERSECURITY

Cybersecurity in digital manufacturing focuses on ensuring the availability, privacy and integrity of digital data stored in any format. Cybersecurity is very important tool to secure from cyber threats are continuously alarming and can be detected and controlled by adopting firewalls protection for digital manufacturing implementation (Pistorius, 2020). As digitalization and connectivity increase, manufacturing systems inevitably become more susceptible to security vulnerabilities. The security objectives are three different types such as confidentiality, integrity, and availability. Confidentiality relates to preventing unauthorized access to manufacturing data, integrity involves maintaining the accuracy and consistency of the manufacturing data and availability ensures that manufacturing data and resources remain accessible for authorized users only. Wu et al, 2018 emphasize that cybersecurity's primary role in digital manufacturing is to assure the development of security, sharing, and management of all product, process, and resource information in a digital format and also provided a scenario wherein design engineers optimize a product design, but attackers gain unauthorized accessing the Computer Aided Drafting models stored in a cloud, altering its geometrical specifications.

DIGITAL MANUFACTURING AND AR AND VR

The practical application of digital manufacturing can be enhanced by integration of real-world interactions with virtual environments. AR removes the gap between the

digital and physical worlds by overlapping virtual data onto a physical object (Masood & Egger, 2019). For this purpose, the technology uses AR devices, like smartphones, tablets etc. AR technology permits customers to cover virtual data onto real environments in real-time, which enhances user interaction by integrating text, images, sounds, and other data within physical contexts.

In the manufacturing sector, AR has the potential to accelerate assembly processes and enhance decision-making. For instance, AR glasses can project essential data such as layouts and assembly instructions directly onto physical parts, making work procedures faster with efficient (Stocker 2017). The use of AR in digital manufacturing is conceptualizing and modeling ideas, enabling users to visualize digital models through tangible interactions and also involves visualizing existing digital content, which is particularly useful for training, implementation and operational processes. A significant aspect of digital manufacturing focuses on decision-making and production, processes and resource validation. Hence, AR's main role in digital manufacturing is to offer real-time virtual information overlays, promoting swift, right decisions. AR can be implemented across various levels of the life cycle, from process planning through assembly path simulation to replace conventional manuals with augmented virtual information.

VR is rapidly gaining traction across various industries and manufacturing sectors. By enabling workers to virtually engage with the manufacturing processes, VR is enhancing efficiency and minimizing errors. There are various VR applications in the manufacturing sector. It appears that within just a few years, the industry may operate independently of traditional methods, relying heavily on virtual reality. VR applications offer significant benefits for manufacturing, especially considering the vast and complex nature of modern facilities, which consist of machinery operating continuously. Under these conditions, organizing testing, training, and maintenance are challenges, as these activities often pose safety risks to workers and can disrupt the manufacturing process. Moreover, VR simulations can be customized to reflect specific work environments, making them particularly effective for companies with complex or hazardous workflows. Accordingly, VR has already shown success in a variety of safety training scenarios, like firefighting and hazardous materials handling. Furthermore, VR can simulate various manufacturing processes, optimizing the flow of materials and workers on the factory floor. Additionally, VR can be utilized to train employees on new equipment or procedures, ensuring that factory layouts are safe, efficient, and tailored to meet the demands of particular products.

One of the most significant advantages of VR is its ability to revolutionize training for manufacturing personnel. By familiarizing workers with potential hazards and errors, VR applications ensure that employees are well-prepared for real-life challenges on the job. VR is increasingly being adopted for factory floor planning because it allows manufacturers to visualize how a proposed layout will function before any physical modifications are made. VR is rapidly becoming an indispensable tool for safety training. VR can be a valuable tool in product development, particularly within the manufacturing domain. For instance, it enables manufacturers to visualize how a product will perform in real-world conditions and identify potential problems before they arise. Additionally, VR can be used to train new employees in proper inspection and maintenance techniques, allowing them to interact safely with the digital replica of the system. For instance, VR can simulate equipment failures, ensuring that employees are prepared for potential challenges.

Moreover, VR can assist in creating prototypes to test for performance and durability while also training workers in the use of new equipment or processing techniques. This technology allows manufacturers to minimize the need for expensive and time-consuming trial-and-error methods in product development. In near future, use of VR in digital manufacturing increase drastically and becomes a crucial for companies there explores innovative applications of this advanced technologies.

DIGITAL MANUFACTURING AND AM

Beside automation and robotics, AM is a leading technology drives Industry 4.0. AM works on modelling of 3D objects to create physical parts with a 3D printer deposition of materials by layers. This AM technology encompasses a variety of technical tools that convert virtual information into pattern along the successive material deposition layer by layer. Although, it began primarily as a tool for rapid prototyping, AM now presents an extensive array of manufacturing possibilities, ranging from tooling to mass customization across nearly all sectors of manufacturing. This technology allows parts to be stored as digital design files in virtual inventories, enabling on-demand production that is closer to the point of use in manufacturing. This decentralized manufacturing strategy can minimize transportation distances and eventually minimize the costs also, while it simplifies the inventory management by relying on digital files rather than physical components. When there is high complex nature of component then the related manufacturing operations are also become complicated, then their value of digital manufacturing increases proportionally.

TABLE 1. Data collection sources for digital manufacturing tools

Sl. No	Digital Manufacturing Tool	Features	Benefits	Reference
1.	IoT	Sensors are incorporated to provide communication with real time data for the decision making.	This helps to optimize the manufacturing process and reduce downtime.	Mohsen Soori et al. 2023
2	Cloud computing	Sensors are incorporated to provide communication with real time data for the decision making.	The typical large amount of data being stored and analyzed can be processed more efficiently and cost-effectively with cloud	Columbus, 2015, Auschitzky et al. 2014
3	Big data, ML and AI	Large volumes of data generated during manufacturing is analyzed to gain insights, optimize processes and also predict the maintenance needs.	This technology enhances data analysis, enabling predictive analytics for performance improvements and production failures	Dassault Systems, 2017
4	Robotics	Advanced robotics systems are employed to automate repetitive tasks	Improves efficiency and safety in manufacturing environments	Fitzgerald, 2017
5	Simulation	Simulation uses digital models to test changes before implementation.	Reduces the risks commonly associated with new production techniques and equipment's	Ribeiro da Silva et al. 2019
6	Digital twin	Digital twin exhibits the virtual representation of real-world product, machines and processes.	Physical assets help in monitoring, analysis and optimization of manufacturing processes in real-time.	Grieves & Vickers, 2017
7	Cyber security	Cybersecurity ensuring the availability, privacy and integrity of digital data stored in any format	Important tool to secure from cyber threats are continuously alarming and can be detected and controlled by adopting firewalls protection for digital manufacturing implementation	Wu et al. 2018
8	AR and VR	AR and VR technologies permit customers to cover virtual data onto real environments in real-time, which enhances user interaction by integrating text, images, sounds, and other data	The practical application of digital manufacturing can be enhanced by integration of real-world interactions with virtual environments.	Masooda, & Eggera, 2020
9	AM	AM generate components through successive layers ensures the final geometry meets the desired specifications.	A number of online manufacturing platform enables users to upload their 3D files for analysis and Manufacture	Renishaw, 2017

The main advantage of AM in digital manufacturing is able to create prototypes and cost-effectively for physical simulations, aiding digital manufacturing tools in the development and testing of AM files intended for 3D printing. Digital manufacturing significantly benefited from AM by enabling the rapid creation of prototypes in economical way, which are very much essential for physical simulations and analysis. These prototypes facilitate the recognition of potential failures and enable visualization of necessary modifications before they manifest in the final manufacturing processes. This approach significantly reduces both time and price associated with new model development. For example, Renishaw, 2017 discusses the application of digital manufacturing tools that facilitate the creation of ready-to-use AM files. This case highlights the integration of virtual and physical world in 3D design,

testing, analysis software and metal 3D printing. Consequently, these digital manufacturing tools enable the production of more precise printed parts, resulting in reduced lead times and cost savings in materials.

Implementation of digital manufacturing is a challenge, in this a dedicated manufacturing team is required for carrying multiple tasks in quick and flexible manner. Generally, manufacturing industries are not able to implement the agile teamwork is due to it needs much training on latest digital manufacturing tools. Moreover, the manufacturing industry is one, in which more cyberattacks are takes place because of the lack of intellectual property rights and the complexity of supply chains which results lose a lot of money and efforts to prevent. Obstacles can reduce by increasing the awareness of their employees about cybersecurity and protecting their connected machines. On the other side, a careful monitoring the data prevents the organization from cyber-attacks and is the most efficient way to measure organizational goals.

CONCLUSION, FUTURE SCOPE

Digital manufacturing is crucial in propelling the progress of Industry 4.0, utilizing various digital tools and technologies at every stage of the manufacturing life cycle. By exploit these digital technologies, manufacturers can significantly improve productivity and competitiveness in an increasingly complex and fast-evolving market. In this paper, the influence of digital manufacturing in Industry 4.0 was discussed, how the technology development changes the utilization of digital manufacturing in last few years and introduced so many challenges and also opportunities in digital manufacturing domain. This paper gives assistance to define critical success factors and to identify the digital manufacturing obstacles in implementation. It helps to understand the digital manufacturing within the framework of the nine main technologies and it recognizes that correlation with other technologies also exist.

IoT refers to the interconnection of physical manufacturing objects with their digital counterparts, attempting to link with the aim of linking numerous sensor devices through standard technologies. On the other side, cloud computing offers to share, exchange and modify manufacturing data over the internet by connecting various computer systems, that leads to enhanced connectivity and communication, which are needed to safeguarding of manufacturing systems. AI tools are offers to design, modelling and decision making of manufacturing components and processes. As autonomous robots continue to evolve into more flexible and collaborative systems, advancements in automation are expected to progress further.

Simulation is treated as main tool for digital manufacturing, simulating and validation of both existing and new manufacturing processes is possible through this. Digital twin exhibits the virtual representation of real-world product, machines and processes, this can also provide an opportunity to analyze and optimize. Cybersecurity is crucial in protecting sensitive and confidential manufacturing data, making it a significant area. AR enhances the assembly process manufacturing line, so that the decision-making is become easy and simple. AM involves in generation of components through successive layers ensures the final geometry meets the desired specifications.

The future of digital manufacturing is Industry 5.0 revolution, in which the complete integration of machines with humans are taking place to increase the efficiency without compromising production quality. There will be an optimized use of resources and better efficiency will reduce manufacturer costs.

ACKNOWLEDGEMENT

DECLARATION OF COMPETING INTEREST

None.

REFERENCES

Aldrete, S. 2018. What you need to know about Siemens' Intosite cloud-based web app. *Tecnomatix News*. March 6.

Alpaydin, E. 2010. *Introduction to Machine Learning*. Second Edition. The MIT Press Cambridge. Massachustts London. England.

Armengaud, C., Sams., Von Falck, C., List, G., Kreiner, C & Riel, A. 2017. Industry 4.0 as digitalization over the entire product lifecycle: Opportunities in the automotive domain. *In European Conference on Software Process Improvement*. Springer. Cham 334-351.

Auschitzky, E., Hammer, M & Rajagopaul, A. 2014. *How Big Data Can Improve Manufacturing*. McKinsey. Dassault Systèmes.

Columbus L., 2015. 10 Ways analytics are accelerating digital manufacturing. *Forbes*.

Dassault Systèmes. 2017. Boeing and dassault systèmes announce extended partnership. *Dassault Systèmes*.

Dhandapani, C & Sivaramakrishnan, R. 2019. Implementation of Machine Learning (ML) in mechanical engineering application using Artificial Intelligence (AI). *Science, Technology and Development* VIII(X): 93-99.

Diez-Olivan, A., Del Ser, J., Galar, D & Sierra, B. 2019. Data fusion and machine learning for industrial prognosis: Trends and perspectives towards Industry 4.0. *Information Fusion* 50: 92-111.

Elias Ribeiro da Silva., Ana Carolina Shinoharab., Christian Petersson Nielsena., Edson Pinheiro de Limab, C & Jannis Angelisd. 2020. Operating Digital Manufacturing in Industry 4.0: the role of advanced manufacturing technologies. *Procedia CIRP* 93: 174–179.

Fitzgerald J., 2017. Using autonomous robots to drive supply chain innovation. *Deloitte Perspective.*

Grieves, M & Vickers, J., 2017. Digital twin: Mitigating unpredictable, undesirable emergent behavior in complex systems (Excerpt). *B Transdicisplinary Perspect Syst Complex* 85–113. https://www.precicon.com.sg/industry_4/industry-4-0-framework/

Chengfeng Jian., Jing Ping & Meiyu Zhang. 2021. A cloud edge-based two-level hybrid scheduling learning model in cloud manufacturing. *International Journal of Production Research* 59(16): 4836-4850.

Dietz, M & Pernul, G. 2019. Digital twin: Empowering enterprises towards a system-of-systems approach. *Business and Information Systems Engineering* 1-6.

Masood, T & Egger, J. 2019. Augmented reality in support of Industry 4.0 - Implementation challenges and success factors. *Robotics and Computer-Integrated Manufacturing* 1(58):181-95.

Mohsen Soori, Behrooz Arezoo & Roza Dastres. 2019. Internet of things for smart factories in industry 4.0, *a review, Internet of Things and Cyber-Physical Systems* 3: 192–204

Negri, E., Fumagalli, L & Macchi, M. 2017. A review of the roles of digital twin in cps-based production systems. *Procedia Manufacturing* 11: 939-948.

Nikolic., Bojana., Jelena Ignjatic., Nikola Suzic., Branislav Stevanov & Aleksandar Rikalovic. 2017. *Predictive manufacturing systems in industry 4.0: trends, benefits and challenges. Annals of DAAAM and Proceedings* 28.

Pistorius, J. 2020. Industrie 40 – Schlusseltechnologien fur die Produktion: Grundlagen • Potenziale • Anwendungen. Springer Vieweg, Berlin

Pokutta, S. 2016. Machine Learning in Engineering Applications and Trends. *NASA Workshop Machine Learning Technologies and Their Applications to Scientific and Engineering Domains Workshop.*

Rahul Rai., Manoj Kumar Tiwari., Dmitry Ivanov & Alexandre Dolgui. 2021. Machine learning in manufacturing and industry 4.0 applications. *International Journal of Production Research* 59(16): 4773-4778.

Rai, R., Tiwari, M. K., Ivanov, D & Dolgui, A. 2021. Machine learning in manufacturing and industry 4.0 applications. *International Journal of Production Research* 59: 4773–4778.

Rai, Rahul & Chandan Sahu. 2020. Driven by data or derived through physics? A re-view of hybrid physics guided machine learning techniques with cyber-physical system (CPS) focus. *IEEE Access* 8: 71050–71073.

Renishaw. 2017. *Enhancing the Additive Manufacturing Process Chain* 1-4

Ribeiro da Silva E., Shinohara A C., Pinheiro de Lima E., Angelis J & Machado CG. 2019. Reviewing Digital Manufacturing concept in the industry 4.0 paradigm. *Procedia CIRP* 81: 240–245.

Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P & Harnisch, M. 2015. Industry 4.0: *The Future of Productivity and- Growth in Manufacturing Industries*.

Sazzadur Rahman Md., Tapotosh Ghosh., Nahid Ferdous Aurna., Shamim Kaiser, M., Mehrin Anannya & Sanwar Hosen, A.S.M. 2023. Machine learning and internet of things in industry 4.0: A review. *Measurement: Sensors* 28: 00822.

Schaeffer, E. 2017. Industry X.0 Realizing Digital Value in Industrial Sectors. Redline Verlag, Munich, Germany.

Stocker, A., Rosenberger, M., Schmeja, M., & Schneider, G. 2021. Key Success Factors for the Implementation of Digital Technologies in the Context of Industry 4.0. 2021 *IFIP/IEEE International Symposium on Integrated Network Management (IM)*. Bordeaux. France 2. 920-925.

Stocker, A., Spitzer, M., Kaiser, C., Rosenberger, M & Fellmann, M. 2017. Datenbrillengestützte Checklisten in der Fahrzeugmontage. *Informatik-Spektrum* 40(3): 255-263.

Tam´as Kegyes., Zolt´an S¨ule & J´anos Abonyi. 2021. The applicability of reinforcement learning methods in the development of Industry 4.0 applications. *Complexity* 1-31.

Tariq Masooda & Johannes Eggera. 2020. Adopting augmented reality in the age of industrial digitalization. *Computers in Industry* 115: 103112.

Wu, D., Ren, A., Zhang, W., Fan, F., Liu, P & Fu, X. 2018. Cybersecurity for digital manufacturing. *Journal of Manufacturing Systems* 48: 3–12.

Wuest, T., Weimer, D., Irgens, C & Thoben, K.D. 2016. Machine learning in manufacturing: advantages, challenges, and applications. *Production and Manufacturing Research* 4(1): 23-45.

Xu, Li Da., Eric., Xu & Ling Li. 2018. Industry 4.0: state of the art and future trends. *International Journal of Production Research* 56(8): 2941-2962.

Zhang., Binbin., Prakhar Jaiswal., Rahul Rai., Paul Guerrier & George Baggs. 2019a. Convolutional neural network-based inspection of metal additive manufacturing parts. *Rapid Prototyping Journal* 25(3): 530–540.