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Role of Additive Manufacturing, Augmented Reality, Internet of Things in building Industry 4.0

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Abstract

As the current world is running at great speed, competition among is at an absolute level. The demand for the customized product is increasing in every sector, and this demand will get fulfilled by new types of technologies like Additive Manufacturing (AM), Augmented Reality (AR), Internet of Things (IoT), Big Data Analytics (BDA), Cyber-Physical System (CPSs), Digital Twin, Artificial Intelligence (AI) and Machine Learning (ML), etc. The combination of all these technologies will lead to a sustainable and smart manufacturing system and arises the concept of Industry 4.0 i.e., the Fourth Industrial Revolution. In this paper, we will mainly focus on concepts of Industry 4.0, Additive Manufacturing, Augmented Reality, and Internet of Things. We will also discuss the integration of modern technologies with the help of some case studies.

Keywords: Additive Manufacturing, Augmented Reality, Internet of Things, Industry 4.0

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1. Introduction

As time is passing, the growth of industries is taking place exponentially as new types of machines; new types of technologies are emerging. Machines are always grateful and have done amazing things for us but we are in the middle of a revolution in which machines are becoming intelligent. The demand for customized and complex in design product are increasing. Through time, we have seen many revolutions. At the end of the 18th century, First Industrial Revolution has been started in Great Britain, in which we have seen mechanized tools and steam power which significantly improved the industrial output. In the 19th century when Second Industrial Revolution started, assembly lines, mass production, electricity comes into the picture. The productivity increased by the assembly line and a certain amount of automation was there due to the integration of machines and electricity. The Third Industrial Revolution started in the ’70s of the 20th century to overcome the slowdown in technical advances, caused by the two global wars. The Third Industrial Revolution brought more advanced machines, started the widespread use of computers and telecommunications into the production process which causes more advanced control over automation. As the consumer’s choices became volatile, more flexibility in the production system is required so that producers can respond properly and quickly to their requirements. This gives birth to the Fourth Industrial Revolution. Integration of new technologies has been taking place for enhancing automation, mass customization, increasing connectivity, and self-monitoring. Modern computers can analyze and diagnose problems without human intervention [1]. All four industrial revolutions are shown in Fig. 1. This Industry 4.0 or the Fourth Industrial Revolution is the smart manufacturing of the future which consist of two environments, first is Virtual Environment which consists of Cyber-Physical Systems, Internet of Things, Big Data Analytics, etc. while the second is the Physical Environment which consists of Autonomous Robots and Additive Manufacturing [2]. With these two environments, the development of industries occurs and finally, Industry 4.0 came.

The birth of Additive Manufacturing occurred because there are distinct types of demand of customers and to meet this demand or to fulfill their expectations, there are lots of companies/industries which are doing research and development. This means competition is high

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among them to occupy the market. For that case, conventional manufacturing methods are needed to be developed or updated.

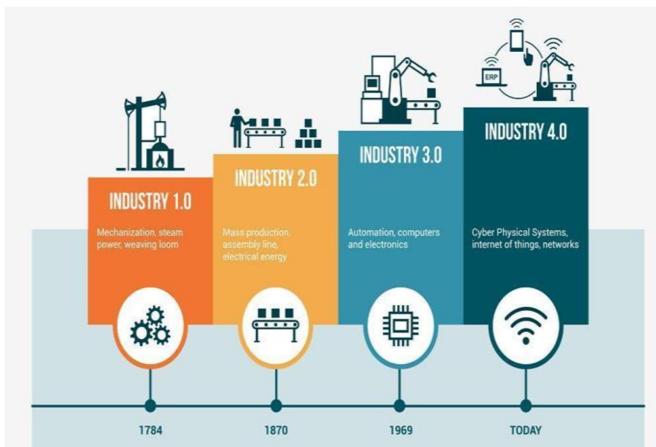

Fig. 1. The Four Industrial Revolutions

Additive Manufacturing is the technique that helps them in doing smart manufacturing. Additive Manufacturing has seen strong growth over the period time. In 2014, it has a market worth over 4 billion USD and this figure is expected to rise up to 23.33 billion USD by 2026 [3]. Further, the use of modern technologies like Augmented Reality and Internet of Things are also increasing day by day. Augmented reality is mostly similar to Virtual Reality except for the difference that in Virtual Reality, the user is completely cut off from the real world while in Augmented Reality; the user sees virtual objects, pictures, characters superimposed on the real world. It acts as a bridge over the gap between the real and digital world. Augmented Reality strengthens the connection between human operator and manufacturing environment by assisting the user in their work task and hence reduced human health workload. The future of Augmented Reality is also very promising. A huge market growth from 0.2 billion USD in 2016 to 48.7 billion USD in 2021 has been predicted by The International Data Corporation [4]. Internet of Things is also an advanced technology that is used to modify a non-digital system into a cyber-physical system. Since in this new era, data is the new oil, this technology proves to be extremely helpful in gathering real-time data and utilizing it efficiently. At its core, Internet of Things is connecting things via network [5].

This paper is divided into 9 sections. In the 2nd section, the paper methodology has been discussed. In the 3rd, 4th, 5th, and 6th sections, Industry 4.0, Additive Manufacturing, Augmented Reality, and Internet of Things have been discussed respectively. In the 7th section, the interconnection between technologies has been discussed with the help of case studies. In the 8th section, there is discussion on this paper and future scope and in the 9th section, the conclusion has been given.

2. Methodology

The study had been done by reviewing previous year literature papers on given keywords. Further, the case study which is used is being studied in depth.

3. Industry 4.0

Industry 4.0 is the platform that provides immerse flexibility for meeting mass customization. Industry 4.0 is the era of digital advancement and interconnectivity and it appears in the form of cyber-physical systems. This cyber-physical system is the integration of intelligent machines, production lines, human actors, within organizational boundaries. Industry 4.0 consists of several modern technologies like Cyber-Physical systems, augmented reality, Additive manufacturing or 3D Printing, Cloud Computing, Big Data Analytics, Internet of Things, Cyber Security, and AI and ML as shown in Fig 2. Implementation of all these technologies requires a large investment for companies [6]. Implementation of Industry 4.0 in a manufacturing industry improves its productivity, product quality and hence, it will improve its global competitiveness and will stand out in the market [7]. Interoperability, Virtualization, Decentralization, Real-time capability, Modularity, Information Transparency, and Technical Assistance are the design principal of Industry 4.0 and have been discussed in [1]. Industry 4.0 uses multiple technologies which gives rise to smart factories under which goods are made as per customer requirements. For research and development project purposes on Industry 4.0, many universities tie up with industries.

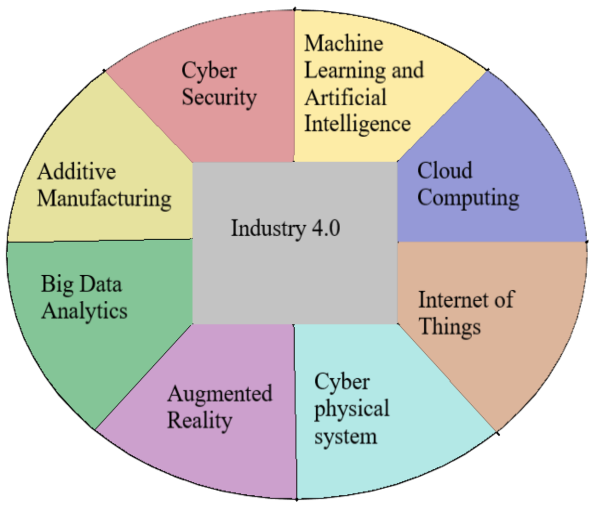

Fig. 2

According to [6], prerequisites required for Industry 4.0 are: Large internet network capacity, machine-to-machine communication, cyber-attack security system, access to real-time data through sensors, sufficient financial resources, and qualified employees. Industry 4.0 related technologies also help in improving the sustainability and supply chain structure in various industries [8]. A study had been done in [9], for finding out the enablers for the sustainability of Industry 4.0 and have found that supply chain, environmental, and information technology are the main casual enablers and are more dominant while economic and social are effect enablers and have less influence on sustainability. Further, with Industry 4.0 and modern technologies, the design and production challenges are only restricted by an individual's imagination. A simplified diagram for Industry 4.0 is shown in Fig. 3.

4. Additive manufacturing

Additive Manufacturing or 3D Printing or Rapid Prototyping or Stereolithography or Automated Fabrication, all are different names of Additive Manufacturing only [10]. Additive Manufacturing, invented in the year 1987, is a computer-controlled fully automated process in which a three-dimensional physical model is created by adding material layer by layer from a digital model without the use of any type of tool [11]. Each new layer has some thickness which is deposited on the previous layer and hence a pile of 2D layers forms a 3D object. It can be easily understood as the formation of Pyramids occurred, big stones one by one can be assumed as molten metal drop, and that is deposited drop by drop, layer by layer. The original application of Additive Manufacturing is Rapid Prototyping [12]. This technology was used only for making prototypes of the new products. However, by the time engineers and designers understood its potential that it can be used for much more than prototyping.

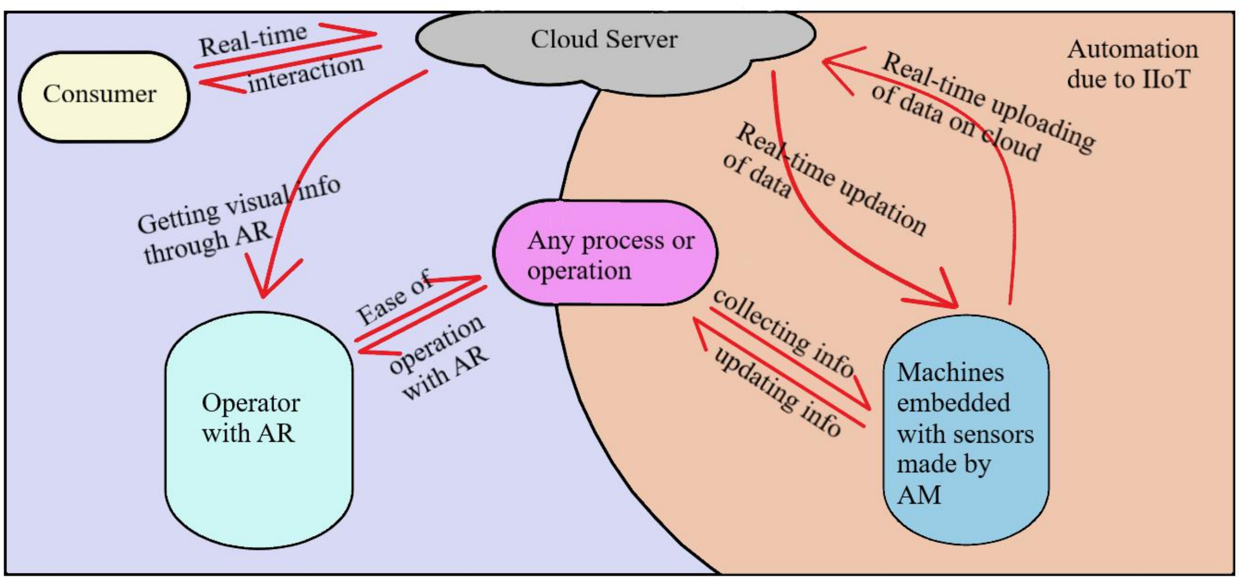

Fig. 3 Simplified form of Industry 4.0

Soon, development in the materials, its accuracy, finishing occurred and since then it can be used as a general production machine. According to [6], prerequisites required for Additive Manufacturing are: Evaluate the characteristics of parts to be produced, consider its technical capability, consider the manufacturing time, consider its security against cyber attacks, Have skilled labor, and have its parts files scanned in 3D.

- *Processes*

There are various processes of Additive Manufacturing which are differing by what type of materials are used, how the layers have been created, and how the layers are going to make bonds with each other. There are seven main types of AM processes and they are Vat Photopolymerization [13], Powder Bed Fusion [14], Material Extrusion [15], Material Jetting [16], Binder Jetting [17], Sheet Lamination [18], and Direct Energy Deposition [19]. All these processes are shown in Fig. 4. When only metal wire and powders are used, then it is called Metal Additive Manufacturing. It is divided into three categories:

i) Wire Feed System
ii) Powder Feed System
iii) Powder Bed System.

It is expected that by 2025, the aerospace, automotive, and medical industries will be responsible for 51% of the Additive Manufacturing market [21]. The projected additive manufacturing market size between 2016 to 2027 has been shown in Fig. 5 [22]

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IMAGE	CATEGORIES	TECHNOLOGIES	CHARACTERISTICS
	Vat polymerization	Stereolitography (SLA) Direct Light Processing (DLP) Continuous Liquid Interface Production (CLIP)	High build speed Good part resolution High cost for supplies and materials
	Material extrusion	Fused Deposition Modeling (FDM) Fused Filament Fabrication (FFM) Atomic Diffusion AM (ADAM)	Inexpensive Multi-material Low surface finish and resolution
	Material jetting	Polyjet Multijet Printing (MJP)	Multi-material High surface finish Low strength material
	Binder jetting	Multijet fusion (MJF) Single-pass Jetting (SPJ)	Full-colour objects Require infiltration during the process Wide material selection High porosity
	Powder Bed Fusion (PBF)	Selective Laser Sintering (SLS) Selective Laser Melting (SLM) Direct Metal Laser Sintering (DMLS)	High accuracy Fully dense part High strength Powder recycling Support requirement
	Direct Energy Deposition (DED)	Laser Engineered Net Shape (LENS) Electron Beam AM (EBAM) Laser Metal Deposition with wire (LMD-w) Wire Arc AM (WAAM)	High deposition rate compared to PBF Repair of damaged part Functional graded part Require post processing
	Sheet lamination	Laminated Object Manufacturing (LOM) Ultrasonic AM (UAM)	High surface finish Low material, machine, processing cost Decubing issues

Fig. 4. AM technologies classification according to the American Society for Testing and Materials (ASTM) [20]

- *Material*

Different types of materials can be printed with the help of 3D printing like metals, glasses, ceramic, elastomers, thermosetting and thermoplastics, composites, polymers, high entropy alloys. Different types of hybrid materials can also be formed like polymer-metals, polymer-ceramic composite, metal-ceramic composites, and polymer-metal-ceramic composites [23].

The raw material which is used in different types of AM processes can be in liquid form or powdered form. Currently, the knowledge of different types of material to make a sustainable and defect-free product is limited but research is going on. Some examples of materials that we can manufacture with the help of 3D printing efficiently are Aluminum, Titanium, Stainless steel, etc [2]. Current research material for Additive Manufacturing in the future has shown in Fig. 6. From Additive Manufacturing, we can get a wide range of complex geometries [24], sustainable production, reduction in manufacturing cost, reduction in scrap and lead time [25], eliminates fixture and setup time, creates whole product without tooling, no need of assembly lines which decreases supply chain cost [26], highly optimized performance, and lightweight product [27]. The most promising area for Additive Manufacturing is the manufacturing of spare parts since it is only competitive for low production volume or low annual demand patterns [28]. Some of the disadvantages of AM are low productivity, low product quality, non-uniform mechanical properties [29]. We also get dimensional limitations in AM process. For producing larger parts, we generally produce parts in small sizes and then combined them with welding or by other joining techniques [32]. As the AM has shown its potential, various industries are taking benefit of this technique to make their components lighter in weight and stiffer. The aerospace industry is taking huge advantages from this technique in designing components of spacecraft, space shuttle, satellites, astronaut's costumes, etc. [23]. Companies like GE, NASA, Airbus, SpaceX, Boeing, and Rolls Royce are using this technique. By using AM, Boeing has made its aircraft lighter which in turn consumes less fuel and saves a huge amount of money. Airbus has reduced 10 kg of weight in one of its brackets used in aircraft [27]. AM has an enormous amount of applications that are only restricted by our imagination.

AM is using in various industries like Aerospace, Biomedical, Nuclear, Robotics soft sensors and actuators, Electronics, Jewelry, Underwater devices, Automobiles, etc. It has limitless applications [23]. For increasing the strength and stiffness, different types of reinforcements are there, like Epoxy resin [30], which is filled in the inner voids designed by Topology Optimization. For increasing the strength and stiffness, different types of reinforcements are there, like Epoxy resin [30], which is filled in the inner voids designed by Topology Optimization. In the bio-medical field, as there is a demand for customized components, AM can

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be a very useful and lifesaving process. Artificial organs, tissues, bones substitution can be made with the help of AM [24]. Reduction in construction time, minimizing cost for improved affordability, waste reduction, and increment in design flexibility, are some of the benefits that AM is giving to the construction industry [31].

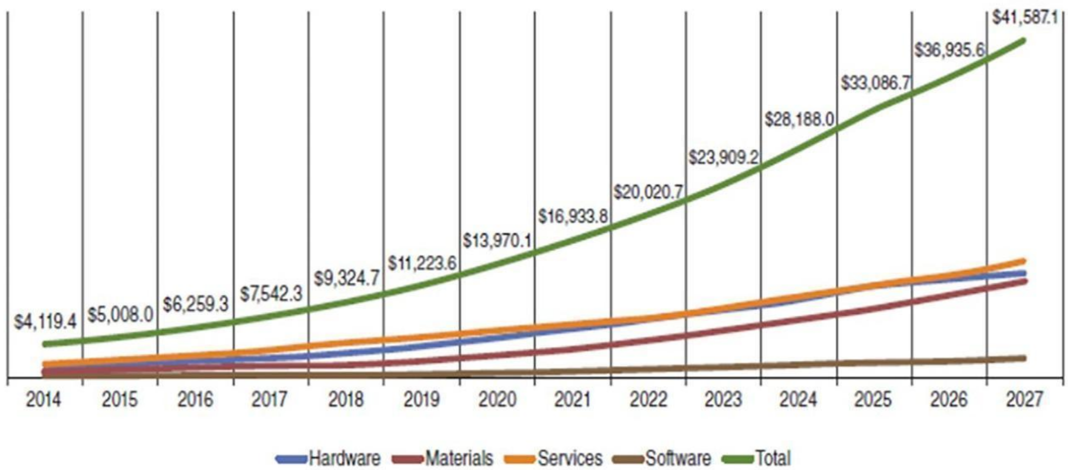

Fig. 5. The projected AM market size between 2016 to 2027 (billion USD) [22]

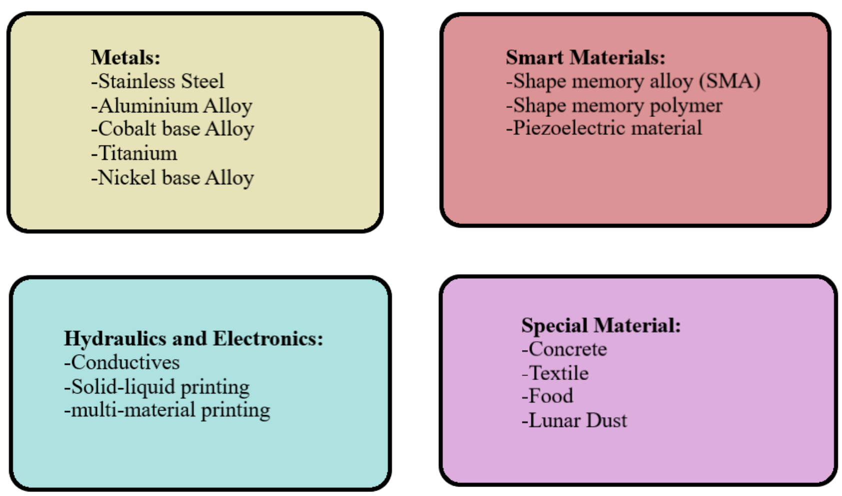

Fig. 6. Current research material for Additive Manufacturing in the futur

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5. **Augmented reality**

Augmented reality is one of the key technology for digital transformation and is not only confined to the industrial areas but can also be applicable in the non-industrial areas [33]. According to Azuma [34], there is a slight variation between augmented reality (AR) and Virtual reality (VR). In Virtual reality, the user is completely inside of a virtual synthetic world and is completely cut off from the real world, while in augmented reality the user experiences a combination of real-world and virtual things.

Those virtual things or objects are superimposed on the real world. The user sees the real world through various types of devices like Microsoft HoloLens or Oculus Rift. The user is augmented by providing additional information with the help of a computer and AI algorithm. It can be simply understood by a common application of AR as the insertion of additional information during a live broadcast of a news channel like the latest headlines, running stock market strip, etc. Therefore, AR is the real-time integration of the 3D real world and 3D virtual objects. Chien et al. [35] say AR is a technology through which virtual and real-world images are combined with the help of a computer. AR is not just confined to the feeling of sight but can also be applied to all detects like hearing, contact, smell, etc. The digital layer created by the AR system stimulates the user's sensory perception that includes vision, hearing, touch, taste, or smell. But majorly visual interactions of AR are more used compare to other sensory stimuli [39].

In the education field [36], AR used in schools and colleges helps in promoting student collaboration during a task and improves physical task performance. Researchers also get benefited from AR to understand the various phenomena as it provides analysis in a wide range of topics like working of a catalyst in a chemical reaction, properties of a mixture, tribology condition, etc. AR is found to be helpful in increasing the curiosity level of young minds [37]. According to [6], prerequisites required for Augmented reality are: consider the operator's work environment, have its file scanned, have detailed process mapping, have an ergonomic study of operator functions, have software that is suitable for using AR hardware, and, plan what data can be shared.

Generally, AR application displays two types of content, Static and Dynamic. Under Static content, text, visuals, or 3D models are there which does not change their appearance during user interaction. While Dynamic content shows a continuous flow of information like a video or animation [37]. It is important to note that the selection of tasks is important for AR applications. If the nature of work is manual and the user is inexperienced or the user is a trainee or unskilled for a particular manual work, the user will found the AR application very helpful compared to others. Manual processes can be Assembly/Disassembly, maintenance, monitoring, quality control, process simulation, planning, training, and facility layout [38].

One should avoid the usage of AR applications in a fully automated process [38]. Basic components of AR application are: i) Visualization Technique: Under this, various types of hardware devices come through which user can interact with AR application like Head Mounted Display (HMD), Hand Held Display (HHD), Monitor, Projector, and Auditory/Olfactory devices. ii) A camera. iii) A tracking system: helps to place digital objects or symbols accurately in the physical world with the help of a marker. iv) A user interface [40]. HMD devices are more used in AR applications compared with other devices because it give flexibility and freedom for movement of both hands. But if HMD is used for a longer duration, it can cause discomfort and visual fatigue [40]. In the case of HHD, we can get more reliability, responsiveness, and agility compared to all other devices.

But these types of devices cannot be used in manufacturing operations where the use of both hands is required like assembly/disassembly operation. It can be time-consuming if the operator uses only one hand while working [38]. An operator using an HHD device is shown in Fig. 7. Monitors and projectors can be installed easily and have a low cost but it is not always possible to install them. Sometimes there vision got block by other objects in the manufacturing environment.

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Fig. 7. Operator using HHD device [39]

According to Azuma [34], there are three basic characteristics of an AR system. They are: i) Combines real and virtual world: it can be done with the help of sensors like camera, GPS, gyroscope, ii) Interactive in real-time: it can be done employing the user interface like touch screen, microphone, hand gesture, earphone, etc., iii) Visualization in 3D: this is done by using special graphic software and hardware like HMD, HHD, monitor, projector, etc. AR can be used in Design and Manufacturing applications, assembly operations, maintenance, Logistics operation, Warehouse operations, through-life engineering services, etc [39]. Application related to the Medical, Engineering, Simulation, Route planning, Entertainment, and Military field has been discussed in [41].

5. Internet of Things

Internet of Things is one of the key driving factors behind the transformation of all technology which comes under Industry 4.0 [42]. In 1999, Kevin Ashton comes up with a term called Internet of Things. He found that one of the main key enablers for Internet of Things was Radio

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Frequency Identification (RFID) technology. It is a type of microchip or a tag with an antenna for identifying and tracking of the target. IoT is generally used for collecting the real-time data of machines, in production lines, supply chains, factories with the help of sensors and actuators so that by proper evaluation of data, one can predict the future [43].

According to [6], prerequisites required for IoT are: Own and use RFID technology, use electronic product code, high-speed wireless network, and capacity, have machine-to-machine communication protocol, have an information security system to mitigate cyber-attack and have streaming events on the fly. Generally, IoT uses four-layer [44] as shown in Fig. 8. IoT gives the ability to the machines and devices to communicate with one another without human intervention. This results in an increase in efficiency, increase in productivity and quality. Since the human intervention is minimum, therefore it also has a less human-made error.

IoT layers:

1. Sensing layer - facilitates integration of sensors and actuators
2. Networking layer - enables transfer of information on wired or wireless network
3. Service layer - integrated different service and application
4. Interface layer - display information to the users

Fig. 8. Layers of IoT [44]

IoT can be applied in almost every field like aerospace and aviation industry, medical and healthcare, manufacturing process, supply chain, transformation Agriculture, Defense, etc [45]. Industrial Internet of Things is a further application of IoT under which sensors, types of equipment, and people are interconnected to the process and to the internet. With IIoT, we can do mass customization, improve safety, reduce cost and lead time [5].

6. Combination of technologies

All these latest technologies can not form Industry 4.0 individually but their integration can do that.

- *Additive manufacturing - Augmented reality*

It has been revealed in an article, by the American Society of Engineering Education, that one of the major weaknesses among eligible employees for Industry is lack of practical experience. Latest technologies like Augmented Reality, Virtual Reality, Mixed Reality are helping employees in learning and training.

In machining operations, QR codes are embedded in modern machines which in which tutorial videos are there, can be scanned by AR multimedia. Even though a process is very easy, some training is required to perform it error-free. If we are using a sophisticated 3D printer, some training will be required to operate it otherwise carefree operation may damage the components of a 3D printer. For analyzing how much Augmented Reality application is useful in performing a task on a Fused Deposition Modeling (FDM) 3D printer, a study has been conducted [46]. In this study, 40 students of different branches were divided into 4 groups with an equal amount of students and have never used 3D printing. Here, the type of AR application used is Head Mounted Display (HMD). After completing the study it has been found that AR helps in better understanding and remembering of the process since AR superimposes additional 3D information on the real-world screen. This shows that AR helps in the self-learning process. This study also shows that the better and more informative type of AR application is, the more helpful it is in remembering and understanding. Another type of study has been done in [47] in which authors try to find out practical implications of an iOS application in industrial processes. Here, the type of AR application used is a Hand Held Display (HHD). After completing the study, it has been found that AR helps in making the working more efficient, reduction in time has also been achieved and users tend to work with fewer mistakes. This study shows that users can adapt to this technology quickly. Also, AR has a high potential shop floor production process.

- *Additive manufacturing - Internet of Things*

Under this system, real-time handling of the manufacturing system is done with the help of an interconnected environment that contains "networks of networks". In this type of system, customized products can be designed, developed, and delivered. We can transform a conventional system into a cyber-physical system by implementing IoT into it. Cyber-physical systems have a great potential application in design, process, and maintenance process. AM machines and components are embedded with sensors and actuators which helps in sharing the real-time data to a human-machine interface like smartphone, laptop, etc. This type of interface shares the data with the cloud platform and the data made available throughout the cloud platform. This data can be accessed from anywhere in the world irrespective of the distance between the user and AM machine or component [47]. Some of the 3D printed IoT enabled smart devices are: (i) Smart pillbox for material adherence, (ii) IoT enable wearables for detection of body temperature, (iii) Novel loop antenna printed for electronic wearables, (iv) 3D printed smartglasses [47].

In a digital manufacturing system, data is exchanged between the manufacturer and end-user in real-time. The benefit from this is that the user can alter the specifications according to its requirements just by changing the cloud data. The information will simultaneously be updated in AM machine and will be applied before printing. This stops excessive use of material and reduces the delivery time. This type of high automation in the production line will increase the robustness and reliability of the process. The error becomes less and the repeatability of the product also increases since it is not affected by the experience and capabilities of the user [25]. AM also plays an important role in making smart IoT devices embedded with sensors. Conventionally, the sensors were just fixed on the surface by some joining process ur fitted in a groove. But as AM provides a wide variety of designs and enables highly customized products, AM process can be used for making an intelligent product in which a sensor is embedded inside the product. The same type of work is done in [48] where authors were successful in producing a metallic passive and wireless smart component. They embedded an acoustic wave SAW sensor inside the component by using Laser Powdered Bed Fusion AM technique. Though some types

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of problems were coming like a sudden change in interlayer cooling time due to material change, adding electronic devices into the high-temperature process could damage it, but all these problems can be eliminated by further research.

7. Discussion and future scope

As we can see from the past that the difference between consecutive 1st, 2nd, 3rd, and 4th industrial revolution was around 100, 70, and 30 years respectively. It can be estimated that the next industrial revolution is on its way and can knock on the door in 20-25 years. And the 5th industrial revolution can be the collaboration of humans with cyber-physical systems, forming a Human-cyber-physical system [38]. It is also seen from the previous time that those countries who take part in the industrial revolution and implement it, grow exponentially like Germany, USA, etc. Printing of smart materials and 4D (3D+time) materials is also a hot topic of research in Additive Manufacturing. These materials are responsive to external stimuli like heat, magnets, electricity, light, gas pressure, etc. These 4D materials can be used in Humanoid robots, which can be well mixed between humans. Further research can be done to increase the speed of additive manufacturing so that it can become a conventional machine process. Various types of research have been carried out in Augmented reality too. Smart glasses can assist humans in various day-to-day work. We can assume their future application in cars windshields, helmets, etc. But as we have seen that Augmented reality has more potential where the work is manual and Industry 4.0 is all about automation, so other technologies like Additive Manufacturing and Internet of Things are more dominant, compared to Augmented reality in the field of Industry 4.0. Internet of Things required embedded sensors and fast internet. More types of components should be made by embedding sensors in them by the use of AM technologies so that they can transmit real-time data and predictions can be made. Further, sometimes it is hard to accept any new technology by people by the fear of job loss. It is true that by implementing Industry 4.0 technologies, more automation will occur causing less need for manpower. But if we see past industrial revolutions, new technologies have arisen jobs in new fields. Similarly, the fourth industrial revolution will open new fields of employment like Cybersecurity, as everything is going to be automated there is a need for security from hackers. These types of jobs will demand new skills and knowledge.

8. Conclusion

In this paper, we have briefly discussed Industry 4.0, Additive Manufacturing, Augmented Reality, and Internet of Things. Further, we had also discussed their integration in building Industry 4.0 more sustainable. Some case studies are also been discussed. As we have seen, Industry 4.0 is nothing but an increase in automation, and Internet of Things is making everything digital, there is a need for security from the different types of cyberattacks. Like in the case of Additive Manufacturing, as the whole component or part is produced with the help of STL file format by using CAD software, there is a need for the security of component's Blueprints. Similarly, in Augmented Reality and Internet of Things, security is needed as they work with the help of internet and thus can be hacked, revealing personal information, location, or any type of important document can also be leaked. Thus, with the emerging of Cyber-Physical systems, Cybersecurity can be a big field and is the need of an hour.

From all this study, it can be concluded that more integration should be done of these technologies. It will automatically take us on a more sustainable way of manufacturing.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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