Exploring benefits of 3d printing technology in Industry 4.0

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***Abstract*— This paper reviews the advancement which has taken place due to the adaptation of 3d printing technology in Industry 4.0. Chuck Hill originally popularized 3D printing technology at the beginning of the 1980s. The key improvements brought by 3D printing technology are energy efficiency, ease of manufacturing, and little to no human participation. This paper discusses the benefits that came along with the adoption of 3D printing technology in modern manufacturing technology or Industry 4.0. The fourth Industrial Revolution, or Industry 4.0, is the term of the current trend in intelligent automation technologies. Utilizing contemporary manufacturing technology while incorporating cutting-edge information technologies is crucial in the present day. When manufacturing any component, manufacturers constantly focus on three key factors: Efficiency, Reliability, and Quality. The 3D printing technology is the cutting edge that provides in all three of these critically important areas. This article provides an overview of the advantages of 3D printing technologies, the applications of these technologies, and finally, the role that these technologies play in the fourth industrial revolution.**

Keywords*— *3D Printing, Industry 4.0, Automation, Energy Efficiency, Reliability.

I. INTRODUCTION

The additive manufacturing technique that is utilised in the 3D printing technology results in the formation of 3D models in a format that is based on layering. With the advancement of this technology, different processes with the key major application have been developed. These technologies include powder bed fusion, inkjet printing, fused deposition modelling (FDM), and contour crafting (CC). The first 3D printer that was used commercially relied on a process called stereolithography (SLA) as the method of manufacturing. The process of 3D printing, which has evolved over time and now employs a wide variety of methods, materials, and tools, has the potential to alter the procedures for manufacturing and logistics. One example of an industry that has made substantial use of additive manufacturing is the construction industry. Prototyping and the biomechanical professions are two more examples. Despite the many advantages of 3D printing in the construction industry, such as less waste, greater design freedom, and increased automation, the technology has only lately begun to gain popularity. [1].

The motivation for writing this paper was obtained by reviewing existing trends in industrial manufacturing, although research in the field of 3D printing technology is studied on a wide scale, the key advantages which Industry 4.0 thrives on i.e. environmental effect caused by the use of this technology, ease of production, smart manufacturing and integration with IoT were not majorly highlighted from the existing research work, we aim to cover all this key areas.

A new industrial stage has been designated as Industry 4.0. This stage is characterised by the construction of Cyber Physical Systems (CPS) through the integration of information and communication technologies (ICT), most notably the Internet of Things (IoT), with manufacturing operations systems. [2] The fourth iteration of the industrial revolution is commonly referred to as Industry 4.0. Both the beginning of the fourth industrial revolution, also known as Industry 4.0, and the beginning of the digital transformation of business both began at the beginning of the 21st century [3]. The beginning of the 21st century also coincided with the beginning of the digital transformation of business. The promise that was held for the so-called "fourth industrial revolution" has been more than fulfilled, and the revolution itself has been a huge success. Since the term "Industry 4.0" was first introduced to the public in 2011, global corporate leaders and governments have been paying attention to the digital transformation that is required by Industry 4.0 [4]. The interaction of networked computers, intelligent machines, and smart materials with one another as well as their surroundings in order for them to communicate with one another and, ultimately, make decisions with the assistance of very few humans is a defining characteristic of Industry 4.0. [5].

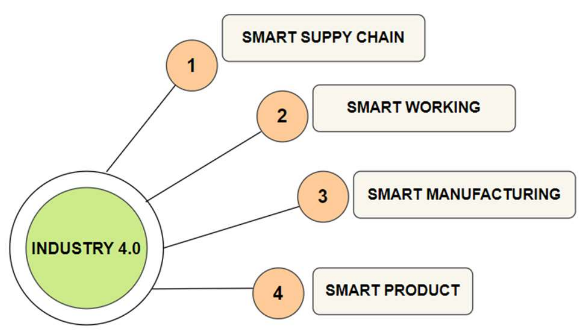

Fig 1-IOT Framework

The four key elements of Industry 4.0 are contained in the first layer (front-end technologies) and each one stands for a different subset of technologies: Smart Manufacturing [6], Smart Products [7], Smart Supply Chain [8], and Smart Working [9]. The connection and intelligence of the frontend technologies are believed to be part of the second layer (base technologies) (e.g. IoT and analytics). We next determine trends in the uptake of these two layers of technology in the examined organizations and unravel the relationships between them using a cluster analysis [10]. We identify a hierarchy of

Industry 4.0 technology layers as an important finding, show the levels of adoption of various technologies, and discuss how these adoption levels affect how the Industry 4.0 concept will be put into practice. These findings are assembled in a framework that provides a conclusive illustration of the maturity of Industry 4.0 implementation in the sample under investigation [11].

II. RESEARCH METHODOLOGY & METHODS

3D Printing Process There are four key processes in the 3D printing process: creating a three-dimensional model, pre-processing, prototyping, and post-processing [12]. Three-dimensional model: The additive manufacturing technology is directly driven by the 3D CAD data model. Designing the product's 3D CAD data model should thus be the initial step in the additive manufacturing process. Currently, STL is the data file format that many software programs accept. To replicate the original solid model and the original 3D data model, several small triangular planes should be employed [13].

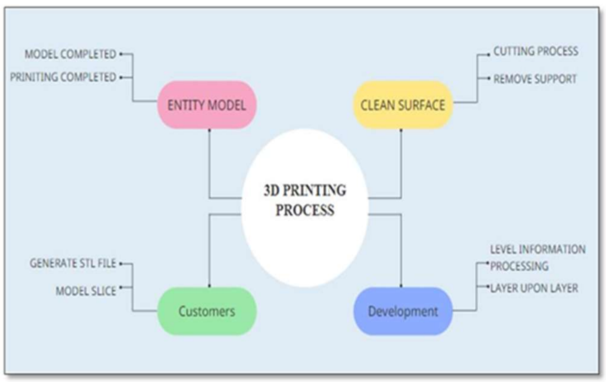

Fig 2 - Flow chart 3D printing process

Pre-processing: choose the proper moulding direction and cut the 3D model in the direction of the moulding height with a series of planes spaced equally apart to collect the 2D contour data of the cutting layer. The better the moulding precision, the longer the moulding process takes, and the less efficient the moulding is, the shorter the spacing height [14]. Prototyping: A forming head is used, controlled by a computer, to execute a two-dimensional scanning movement according to the cross-sectional contour information of each layer. The materials from each layer are then layered and bonded to create the final three-dimensional solid. A nozzle or a laser head might be the forming head [15]. Posttreatment: The goal of post-treatment is to enhance product strength and lowering product surface roughness. Repair, grinding, posturing, peeling, polishing, and coating are all steps in the procedure [16].

2.2. Types of 3D printer Different 3D printing methods have been created, each with a specific purpose. The different types of the major 3D printing process are binding jetting, Stereolithography (SLA), Fused Deposition Modeling (FDM), Electron Beam Melting (EBM), and PolyJet. There are no arguments about whether machines or technologies work better since each one has a specific use. Modern 3D printing technologies are being employed to create a wide range of items rather than just prototypes. Binder jet 3D printing: Binder jet additive manufacturing (AM) technique, also known as binder jet 3D printing or binder jetting, has several benefits over conventional metal additive methods. Large-scale constructions are easily constructed, and build timeframes are frequently quick. To prevent the accumulation of residual stress in the completed component, powder layers are bound together during processing rather than thermally fusing them. The variety of certified metal powder feedstocks for binder jetting has to be expanded as the demand for this efficient technique rises [17].

Advantages- The fact that the binder jetting process takes place at room temperature means that thermal variables, which might lead to component deformation, are not an issue. This is the primary advantage of using binder jetting. As a direct consequence of this, the build volumes of bindery jetting machines are among the highest of any 3D printing method. Sand casting moulds are often fabricated using the largest equipment available, which measures 2200 millimetres by 1200 millimetres by 600 millimetres. Using metal binder jetting systems, it is possible to create multiple components at the same time. These systems are larger than DMSL and SLM systems, despite the fact that they are smaller (they can measure up to 800 x 500 x 400 mm).

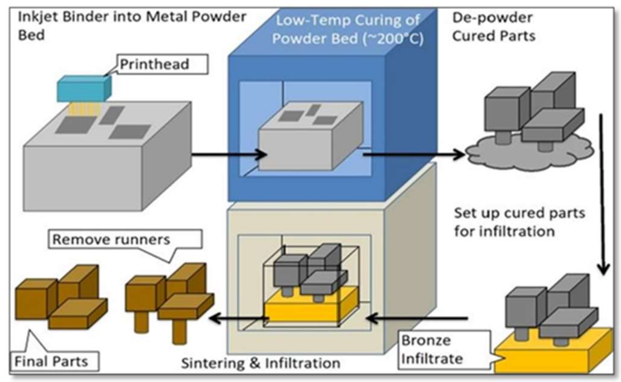

Fig 3- Binder Jet 3D Printer [18]

Disadvantages- Due Accuracy and tolerance are the primary concerns with binder jetting, and it can be difficult to make accurate projections because of component shrinkage that occurs throughout the postprocessing steps. For instance, as a result of infiltration, the metal components of smaller objects may shrink by up to 2%, while the metal components of larger things may shrink by more than 3%. The friction that occurs between the furnace plate and the bottom surface of the object during the sintering process might cause the object to deform. Additionally, the object will shrink by an average of 20%. The component can become softer as a result of the sintering heat, and portions of the component that are not supported may bend as a result of the weight of the remainder of the part. Although these concerns may be handled in the design, taking into account nonuniform shrinkage may prove to be more difficult. Casting patterns, aerospace components, prototypes, full-color decorative objects, cores and moulds, jewellery, and other applications are all possible with this material.

Stereolithography (SLA): One of the most well-known and widely implemented techniques for additive manufacturing is known as stereolithography, which is also referred to as SLA 3D printing on occasion. It accomplishes this by focusing a powerful laser beam on a reservoir of liquid resin, which causes the resin to solidify and construct the required three-dimensional shape. Simply explained, this technology uses a low-power laser and photopolymerization to convert photosensitive liquid into layer-by-layer 3D solid polymers. [19].

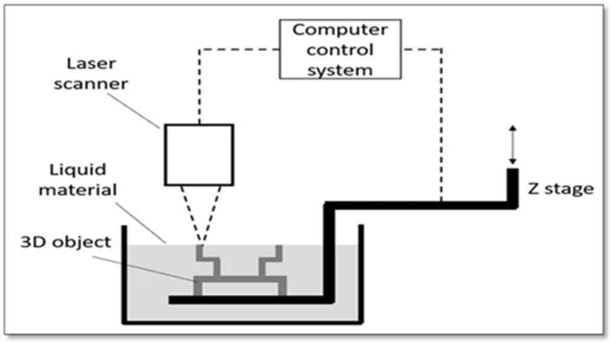

Fig 4- Stereolithography [20]

Advantages- One of the most accurate methods of 3D printing currently available is called SLA. It is possible to make prototypes with intricate geometrical patterns and features that are exceedingly complex (such as thin walls, sharp angles, etc.). These prototypes can be as detailed as desired. It is possible to have layers as thin as 25 µm, while theminimum feature sizes range from 50 to 250 µm. SLA offers the tightest dimensional tolerances of any fast prototyping or additive manufacturing method, with tolerances of +/- 0.005″ (0.127 mm) for the first inch and an additional 0.002″ for each additional inch. The prints have smooth surfaces [21].

Disadvantages- Printing typically requires a significant amount of time. During the construction process, support structures are necessary for slopes that are excessively steep and overhangs. These components run the risk of falling apart whenever printing or curing processes are being performed on them. Because of their brittle nature, resins are not suitable for use in mechanical testing or in the creation of functioning prototypes. The majority of the time, SLA only provides hues and materials in the range of black, white, grey, and translucent. Because resins are typically protected by intellectual property rights, it can be difficult for printers made by various manufacturers to swap them out. Uses include: Rapid Tooling, Jigs, and Fixtures. • Casting patterns as well as moulds. • Snap-fit assemblies and designer models for customization. • Optics, as well as covers that are see-through. • Models to scale and for presentation.

Modelling via Fused Deposition Thermoplastic material that has reached its melting point is employed, and then the molten material is pushed out in order to layer by layer construct a three-dimensional model. As the design progresses, each layer can be interpreted as a horizontal cross section of the overall structure. Following the completion of one layer, the nozzle of the printer is lowered in order to add the subsequent layer of plastic to the design. Once something has been made, the components that supported its creation can be removed. [22].

Advantages: Increased production speed is one of the key advantages that comes with using FDM for 3D printing. It is possible to construct an entire object using 3D printing in a matter of minutes or hours, which reduces the amount of time needed for lead times and speeds up the process of prototyping. FDM makes it possible to print larger objects than ever before, and because the architecture of the printers is so easily scalable, the cost-to-size ratio of the objects that can be printed is surprisingly low [23]. Disadvantages The use of fused deposition modelling for 3D printing comes with a number of important limitations, one of the most significant being the lowest achievable resolution. Because FDM has a layer height that is relatively high compared to other 3D printing methods, it is not recommended for use in the manufacturing of components that contain minute details.

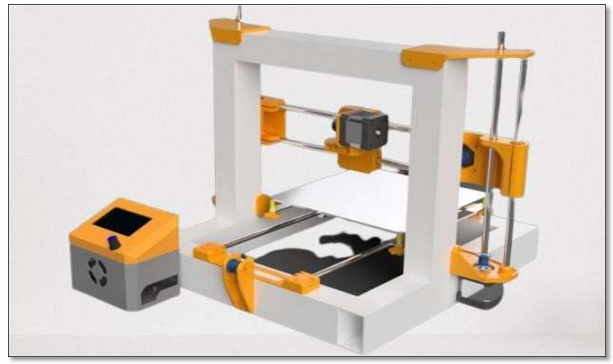

Fig-5 FDM type 3d printer

Additionally, the end items are likely to have rough surfaces and will need post-processing in order to have a smoother finish. This is something that must be taken into consideration. Epoxy adhesion, gap filling, and vapour smoothing are all processes that can improve the appearance of a part; however, each of these processes also adds time to the production process. Epoxy adhesion is one of the processes that can improve the appearance of a part. Because of this, FDM printers are not the best option for the manufacturing of products that require smooth finishes or a high resolution because they cannot produce these qualities. Some of the applications are Functional Testing Engineering and Concept Models. Rapid Manufacturing; Low-volume Production of Complex Parts; Rapid Manufacturing; Tools, Jigs, and Fittings; Rapid Manufacturing; Rapid Manufacturing.

Electron Beam Melting (EBM): In the process of electron beam melting, sometimes known as EBM for short, a powdered metal is melted by a strong electron beam. This method is commonly referred to by its acronym alone. The process of printing in three dimensions is also referred to as electron beam melting in some circles. When layers of powdered metal are melted by an electron beam, a stream of electrons is formed. These electrons are guided by a magnetic field as they are produced. This causes an electron stream to be produced, which can then be used for a variety of applications after it has been produced. The application of this technique will, in the end, result in the manufacture of a product that satisfies all of the requirements outlined in a CAD model to an exceptional degree. The manufacturing process is carried out within a vacuum chamber to eliminate the possibility of any oxidation taking place, which would put highly reactive components in jeopardy if it did take place. [24].

Advantages of EBM- • Reduced tooling and setup costs; • Minimal material waste • Reduced residual stress owing to increased process temperature • Reduced oxidation due to vacuum environment • Geometric flexibility for engineers designing engineered products [26]. Disadvantages of EBM- • There are few commercially available materials. • Has a surface smoothness similar to that of sand casting • Requires complete comprehension to reap the full rewards of the technique [27]. Application- • Aerospace • Automotive • Défense • Medical Applications • Petrochemical.

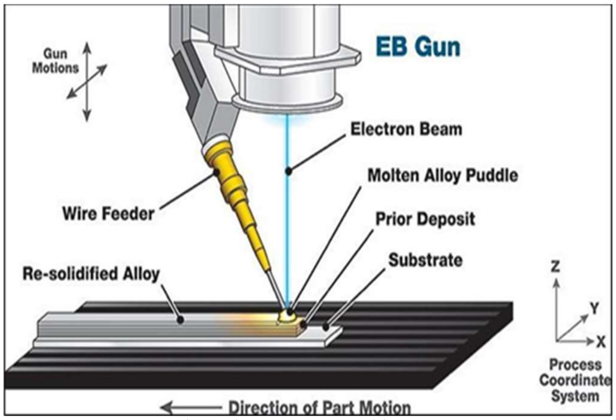

Fig-6 Electron Beam Melting [25]

Polyjet:The robust form of 3D printing known as PolyJet is able to produce smooth and accurate tools, prototypes, and components that can be used in manufacturing. Because of its extraordinarily fine layer resolution and accuracy, which may go down to 0.014 mm, it is able to make thin walls and challenging forms out of the widest spectrum of materials that is now imaginable using any technique. This ability allows it to compete with 3D printing in terms of both versatility and production capacity. When compared to more conventional manufacturing methods, this is a huge advantage. [28].

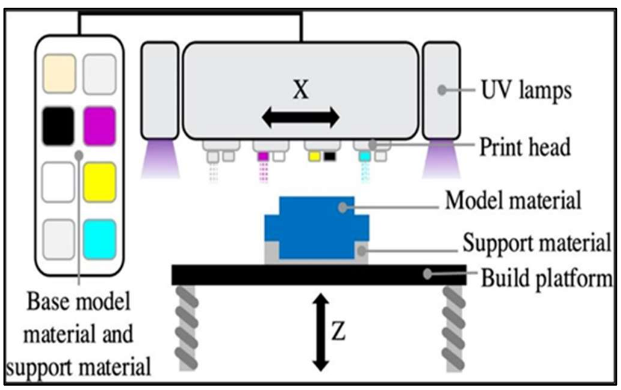

Fig-7 Polyjet [29]

Advantages- • Design slick, minute prototypes that reflect the aesthetics of the finished product. • Create precise moulds, fixtures, jigs, and other production equipment. • Achieve detailed details, complicated forms, and delicate characteristics. • For unequalled efficiency, combine the greatest selection of hues and materials into a single design [30]. Disadvantages- • Surface quality changes due to the support material (surfaces without support are shiny and smooth; those with support are drab and rougher) • Cost is rather costly in comparison to other 3D printing methods. • Sharp edges are frequently somewhat rounded in Polyjet [31]. Application- • Product presentation and form-fit testing. • The prototyping of intricate pieces. • Overmolding. • Rubber-like, flexible models. • slippery or supple surfaces.

2.3. Environmental Effect Numerous factors, including idea evaluation, equipment upkeep, and environmental considerations, must be taken into account while developing manufacturing processes [32]. Although industrial methods have an impact on the environment, clean manufacturing of Green products and products with minimal environmental effects are crucial themes in the development of industrial processes [33]. However, all manufacturing procedures use resources, require energy, and discharge toxins. The same holds with AM technology [34]. Energy consumption-The and effective use of energy are regarded as major aspect in the examination of the environmental effects of the manufacturing process. The most significant environmental impact of AM methods seems to be electrical energy. While this does not hold for the manufacturing of samples, AM in mass production uses more electrical energy than injection molding [35]. Interestingly, several factors affect energy usage. Material: At the moment, many materials may be used in AM techniques. Different energies are needed in manufacturing using AM methods because varied materials have different densities and heat capabilities. As a result, using low-temperature materials requires less energy [36].

Table no. 1 [37]

Process	Material	Machine	Energy (KWh/kg)	Ref.
PBF	Metallic powder	EOSINT M250	710	[38]
	Polyamide	Vanguard HiQ	15	[39]
		EOSINT P760	40	[40]
VP	Epoxy resin	SLA 250	33	[41]
		SLA 3000	41	
		SLA 5000	21	
FDM	ABS plastic	FDM 1650	346	[42]
		FDM 2000	116	
		FDM 8000	23	

Build volume: By utilising this feature, users have the ability to determine the maximum number of discrete components that can be manufactured simultaneously by a certain 3D printer. According to previous research [43], printers that possess the ability to engage in parallel manufacturing and simultaneously print many components are regarded as having higher energy efficiency. The phenomenon of increasing the thickness of the layers. Achieving a reduced layer thickness is considered a fundamental requirement in the pursuit of producing surfaces of superior quality. One potential approach to attaining this objective is to employ a slower printing speed, which necessitates a greater amount of energy. Additionally, a low layer thickness leads to printed components having more layers overall, which raises energy usage [44]. Process speed: Different process speeds are possible with AM methods. In addition, other factors like material and thickness have an impact on printing speed. In all AM techniques, the lengthier process uses more energy, whereas quick printing uses less energy [45,46].

Waste materials- The usage of diverse waste materials through recycling methods facilitates the development of innovative components. In order to integrate recycled materials into additive manufacturing (AM) processes, one viable approach involves the recycling and utilisation of polymeric waste. A diverse range of polymers demonstrates the ability to undergo recycling procedures and afterwards be reintegrated into practical applications. Examples of such polymers are high density polyethylene (HDPE) and low density polyethylene (LDPE). In addition to low-density polyethylene (LDPE) and high-density polyethylene (HDPE), high stiffness polymers such as polypropylene (PP), polylactic acid (PLA), and acrylonitrile butadiene styrene (ABS) are also undergoing recycling processes. The efficacy of recycling these resources for filament production has been established [47,48]. The implementation of recycling practises holds promise in significantly reducing annual expenses amounting to millions of US dollars. This is achievable through the repurposing of filaments for 3D printing, which may be efficiently utilised in the production of polymeric structures.

TABLE 2. NO OF RESEARCH PAPER STUDIED

Sr. No	Field of research	No. of papers
1	Industry 4.0	9
2	3D printing introduction	8
3	3D printing Process	4
4	Binder jet 3D printing	3
5	Stereolithography (SLA)	3
6	Fused Deposition Modeling (FDM)	2
7	Electron Beam Melting (EBM)	3
8	Polyjet	3
9	Environmental effect introduction	2
10	Energy consumption	9
11	Waste material	2
12	Air pollution	3
	Total	51

The identification number for resin is used to classify the various types of waste plastic. In light of the numerous applications for AM processes and the growing demand for 3D printing technology, a recycling code for goods that were manufactured using 3D printing should be provided. In point of fact, if detailed printing is done, there may be concerns if the volume of plastic waste made by other MA processes rises. This is because other MA activities produce waste in the form of waste plastic. The process of recycling that is suggested for use with AM technology is illustrated in Figure 8. Before being chopped into flakes, the recycled material in this instance is first sorted according to the resin code. In some filament extruders, the flakes can serve as a potential source of raw material. In order to ensure the filaments' quality, it is necessary to evaluate them according to certain technical criteria. [49-55].

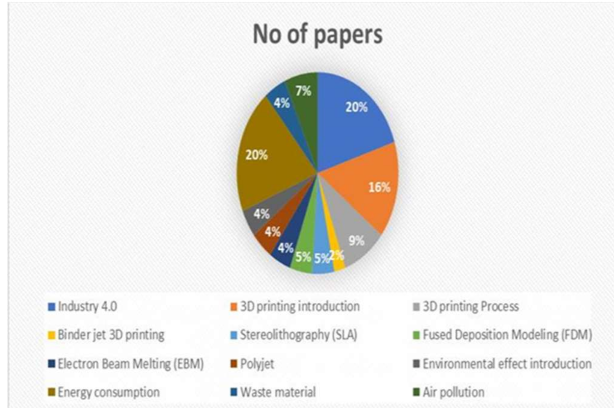

Fig 8. Pie chart presentation of Research Paper studied

Air pollution- Over the course of the past few decades, there has been a discernible rise in the significance of the problem of air pollution on a global scale. The impact of additive manufacturing (AM) on air pollution can be broken down into two broad subdomains: (a) the air pollution that is produced by AM processes, and (b) the use of AM in manufacturing to reduce air pollution. The creation of components from raw materials is one of the major contributors to pollution caused by industrial processes [51,52]. The activities involved in manufacturing are directly responsible for 19% of the world's total emissions of greenhouse gases [53,54]. As a result, it is necessary to make use of the most advanced and applicable technology available in order to reduce the amount of air pollution that is caused by these operations. The different industrial operations contribute different levels of air pollution. Because of this, there is a growing concern regarding the impact that AM technologies have on the quality of the air. [56-62].

III. Result and Discussion

With increasing popularity of 3D printing in industry 4.0, it has become crucial to choose correct method for manufacturing, we have presented various process in this paper which manufacturer can choose from, we have also covered crucial aspect of environmental effect due to the processFor the purpose of this study on 3D printing and its place in Industry 4.0, a literature review of around fifty technical articles, which included research papers and review papers, was carried out. The papers came from a variety of journals, conferences, and publications. This work fills a gap in the existing literature that we discovered after evaluating more than 50 other papers. The gap concerns the effects of the environment on a variety of processes, materials, and after effects. Additional research might be conducted on the subject of the integration of different 3D printing processes with the internet of things, the difficulties associated with automation, and the search for eco-friendly alternatives to the polymers that are now in use.

Conclusion

This article covers the breakthrough that the 3D printing technology has brought to industry 4.0. It focuses mostly on the following topics: an introduction to 3D printing; an introduction to Industry 4.0; the 3D printing process; different types of 3D printers; and the environmental effect. We have covered all of these topics in the context of 3D Printing technology along with classification of the effects produced by each type of 3D printer, advantages, disadvantages, and application. Since industry 4.0 primarily focuses on less waste, smart production, and environmental effects, we have covered all of these topics in the context of 3D Printing technology. This is because industry 4.0 is primarily focused on reducing waste. The environmental effects are categorised according to the types of materials used in production, the requirements for post-processing, and the effects of air.

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