Additive Manufacturing: Concepts and Technologies

Pimal Khanpara and Sudeep Tanwar

Abstract

Industry 4.0, the recent industrial uprising, encourages the inclusion of smart manufacturing systems and sophisticated IT. In this fresh motion, additive production (AM) is regarded an important component. An extensive analysis of AM techniques with both its contributions to Industry 4.0 is provided in this paper. The analysis focuses on three key elements of AM: latest progress on material science, operation growth, and design consideration enhancements. The paper's primary goal is to identify and demonstrate its prospective applications of present information (and technological developments) on AM. Industry 4.0 is the modern move toward smart automation of technology. In this current time, the use of Additive Manufacturing's modern abilities in the domain of IT integration plays a major role in the competitiveness of the industrial domain. This paper provides a fundamental understanding of Industry 4.0's role of 3DP technology. As can be seen, there is no uncertainty that 3DP technology is going to contribute to the upcoming significant industrial era. Due to its multifaceted features, time and price savings, Additive Manufacturing performs a significant part in Industry 4.0, being critical to process effectiveness and decreasing entanglement, permitting quick prototyping and extremely decentralized manufacturing procedures. A large number of manufacturing sections are now embracing AM. Future intelligent plants communicate all procedures via the Internet of Things, integrating higher pliability and individualization of production procedures.

Keywords

Additive manufacturing · 3D printing · Smart factory · Industry 4.0 · Smart materials · Computational geometry · Production process

1 Introduction

There is a need to digitize and intelligentize manufacturing procedures for today's industrial sectors. The production sectors are now shifting from mass manufacturing to custom manufacturing. The fast developments in technology and applications for agricultural manufacturing assist to boost efficiency [1, 2].

A manufacturing chain is the method of converting raw materials into commodities. Nevertheless, to transform the accessible funds into products such as architecture, scheduling, production and distribution, many measures are required. Recently, as additive manufacturing (AM) or 3D printing (3DP) technology has altered its measures, it appears that the production chain process has shifted. Customized products with hard geometries can be constructed and printed using additive technology. Therefore, markets can be proffered without needing businesses to reserve or generate products at a high cost [1].

The word Industry 4.0 constitutes the fourth industrial revolution described as a fresh stage of organisation and restrict over the whole product life cycle value chain; it focuses on increasingly individualized client needs. Industry 4.0 is still innovative but a practical idea which involves: Internet of Things (IoT), Cloud-based Manufacturing (CBM), Industrial Internet (II), and Smart Manufacturing (SM). Industry 4.0 is concerned about the rigorous inclusion of people into the manufacturing system to continually enhance and concentrate on value-adding and waste prevention operations [3].

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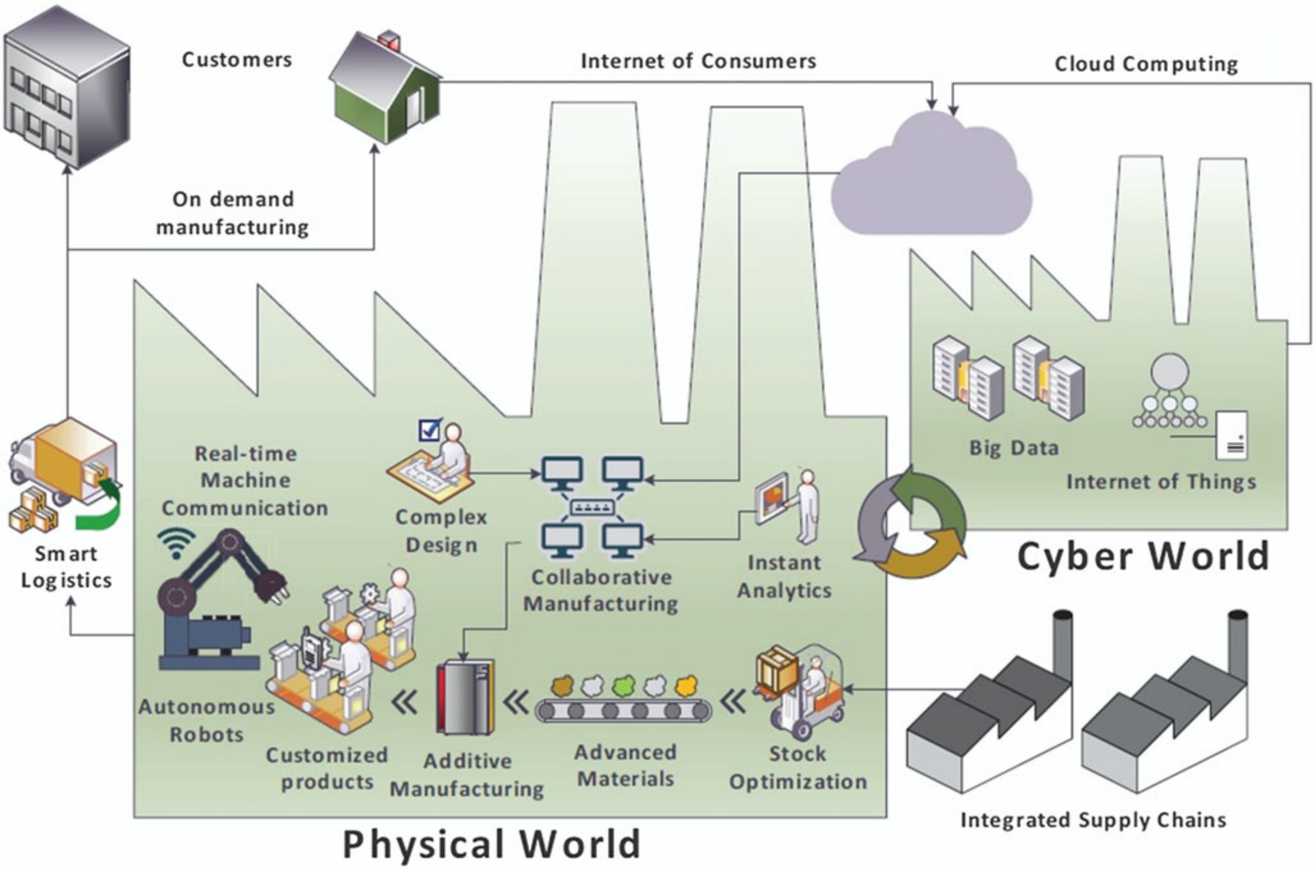


Fig. 1 Illustration of smart factories in Industry 4.0 [5]

The fourth industrial revolution, Industry 4.0 is the latest motion on smart computing technologies. The use of contemporary production abilities in the framework of incorporating fresh data techniques in this fresh age performs a major part in financial competitiveness [4]. As shown in Fig. 1, Industry 4.0 provides profitable cooperation between cyber and physical devices with the aim of constructing intelligent plants by redefining the position of individuals.

The basic virtual world ideas of smart factories include Cloud computing, Internet of Things (IoT), Big Data, etc., while its physical domain involves independent robots and Additive Manufacturing [2, 6–25].

With regard to cyber-physical devices, IoT is defined as the notion of using computer networks or enhanced cellular links to collect data from physical artifacts. The information obtained from the goods, machines or manufacturing lines is a significant quantity of statistical data to be shared and evaluated. Other data sources are layout documents, order of clients, distribution of providers, information linked to inventory and logistics. Overall, this big amount of information is described as Big Data, which in Industry 4.0 is another significant concept. Furthermore, cloud computing, which is linked to the handling of all accessible data, can also be regarded one of the most important concepts in the implied manufacturing environment. All of these cyber techniques assist guarantee that current data is used effectively for potential intelligent manufacturing [2].

On the other side, the capacity of the current production technologies limits the physical portion of the intelligent machines. This makes the AM one of Industry 4.0's essential parts. Because of the need for mass customization in Industry 4.0, it is necessary to develop non-traditional production techniques. Due to its capacity to produce sophisticated items with advanced characteristics (fresh fabrics, forms), AM can thus become a main technology for manufacturing tailored goods. AM is presently being used in multiple sectors such as aviation, biomedicine and production, thanks to enhanced consumer quality [3]. While there are still some questions about its applicability in mass manufacturing, owing to the latest technological advances, the use of AM in the sector is on the increase. It can give a way to substitute standard production methods in the upcoming age as an emerging technique to produce precise and reinforced complex items with enhanced production velocity.

Existing production systems' capability confines the intelligent factories' physical portion. Due to the need for mass customization in Industry 4.0, fresh non-conventional production techniques are constantly being created. AM is

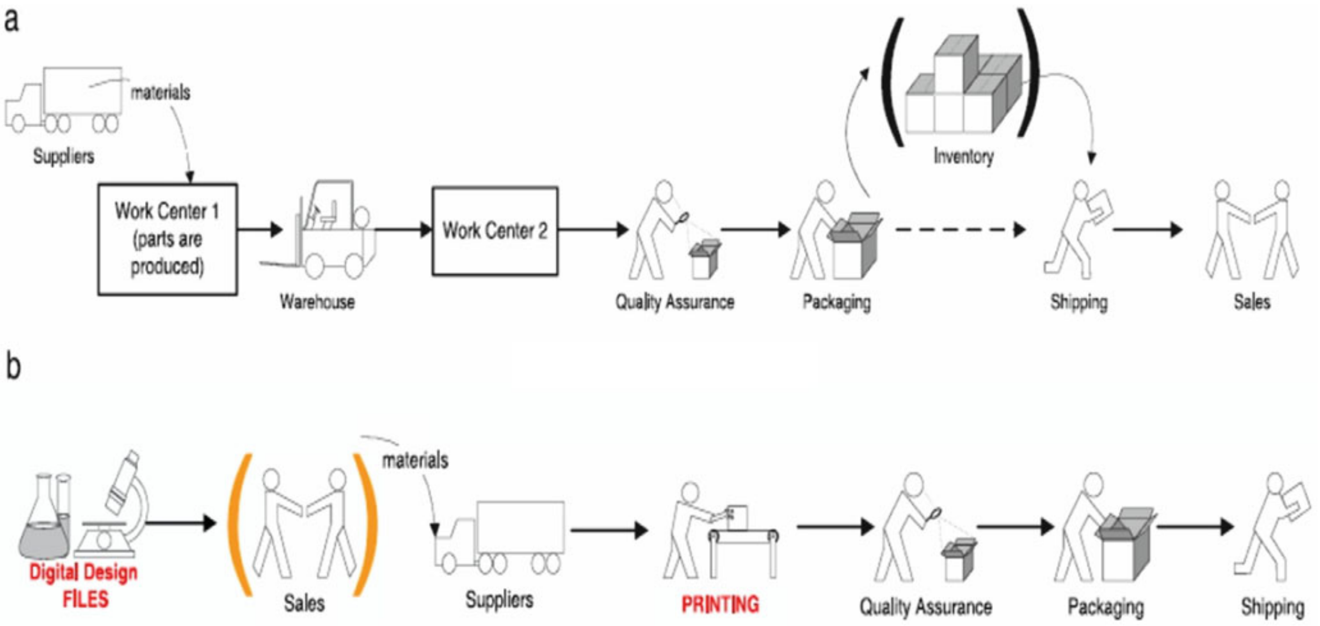


Fig. 2 Classic and 3DP procedure [27]. (**a**) The classic procedure. (**b**) The 3D printing procedure

considered a main technology for production of custom products [26] due to its capacity to produce sophisticated items with advanced characteristics. Figure 2 illustrates a comparison between standard business method and 3DP method:

In comparison of conventional manufacturing and additive manufacturing, the overall benefits of additive manufacturing are the product development and growth skills. Though there are some constraints, businesses are increasingly using AM to get advantage of the many prospective advantages such as complexity-free production. In traditional production [28], a straight connection exists between complexity and production expenses.

High production and tool-making expenses often significantly restrict designs meant for traditional manufacturing. The higher design flexibility through AM makes it possible to integrate the assembly of components into a single unit, thus lowering the necessary configuration job and expenses. In addition, implementation capacities [26] do not need to be compromised.

3DP emerges as a technology that allows for a broad range of fresh applications. Basically, the accessible equipment, manufacturing velocity and resolution of the 3DP procedures should be regarded for each particular implementation [29]. Nowadays, there are devices that enable the production of 3D forms by diverse methods: extruder (fused filament), chemical agent (binder) or laser (sintering/fusion), technically recognized as additive manufacturing (AM), with several benefits [30].

Industry 4.0 is the latest step towards technology intelligent automation. In this current time, the use of AM's advanced IT inclusion abilities plays a significant part in the industrial economy's competitiveness. In this sense, this paper tries to offer the fundamental knowledge Industry 4.0 and 3DP technology.

This paper reviews Industry 4.0's latest physical literature to assist AM scientists classify/sort basic expertise in the sector. AM is the primary range of this paper because of its important position in Industry 4.0. The paper is organized as follows: first, the enhancement in material science will be addressed. In the following section, AM's novel methods are described in detail, specifically metal additive processes and hybrid procedures, while the next chapter describes AM's design associated problems. Lastly, the last segments contain potential AM-related expectations and findings.

2 Materials

Materials are essential for scientific comprehension AM technology advancements. New materials appropriate for 3D printing applications are of great concern to researchers in this sector. Although there are a big amount of metal/polymer components are accessible for AM [26], as demonstrated in Fig. 3, certain products attract attention in this field. Therefore, it is necessary to discuss in detail the characteristics of potential materials which are likely to be evolved in the era of Industry 4.0 and to identify their potential uses.

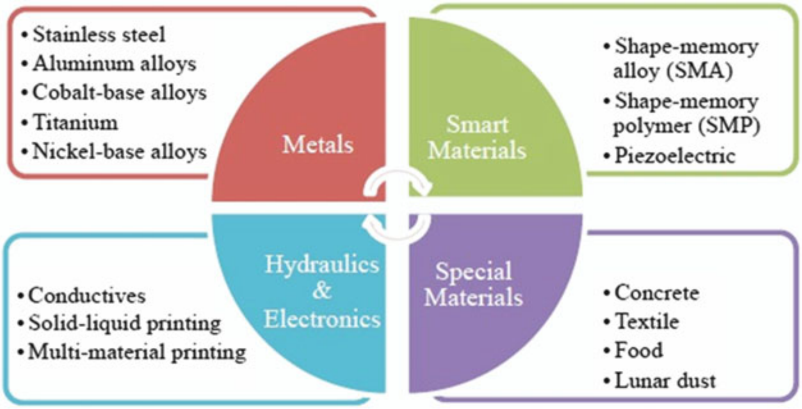


Fig. 3 Materials used in additive manufacturing [3]

Design flexibility, mass customization, minimization of waste and the capacity to produce complicated constructions are the primary advantages of additive manufacturing. The present situation of growth of 3DP products involves, among many others, concrete [31], the use of wood, metal alloys, metal composites, polymer composites, and ceramic composites. The 3DP technology includes a broad variety of products used in a wide range of sectors (including jewelry, aerospace, dentistry, automotive, petroleum and gas, orthopedic printed electronics, and [32] tooling). Figure 3 presents an outline of the most frequently used products in AM.

The elements deemed to fuel the additive price of manufacturing are metal costs, labor costs, machine costs, and cost of energy consumption. Material expenses for methods of laser sintering are a significant percentage of the expenses of additive production. The labor cost would be 2–3% and less than 1% of energy consumption [5].

2.1 Metal Additive Manufacturing

Because of the favorable mechanical characteristics of metals, they are probably the most usual substances in engineering. As an effect, the 3D printing trade is looking for fresh options for producing metallic parts that can replace their traditionally manufactured equivalents. Fresh enlargements in 3D printing technology boosts the efforts in the vital study industry: Metal Additive Manufacturing (MAM). AM techniques have freshly made it possible to produce many metallic components using stainless steel, aluminum, titanium, etc. as the key element of the method [30]. Most company electronic 3D printers use metal powders, while other appropriate fabric compositions [26] have also been investigated for MAM.

In addition, the microstructure arising from AM affects the mechanical characteristics of the components, such as tensile/fatigue behavior. Consequently, problems relating to microstructure, stage structure, and thermal therapy have lately drawn the attention of the AM study community [29]. For example, Lee et al. [30] explored certain mechanical characteristics of parts manufactured using a laser-based MAM method, showing the mechanism of cracking. On the other side, much remains to be developed as the manufactured components have not yet fulfilled the standards of the industry. Some problems that need to be addressed include favorable costs, pace of manufacturing, improved tensile/fatigue/hardness behavior, improved ground performance, and homogeneous microstructure [31]. MAM is likely to become a main player in Industry 4.0 development in the fresh age as soon as it overcomes these present obstacles through advances in both material engineering and MAM procedures.

Because of the advantages this method provides, Metal AM has started to receive attention in the areas of aviation, petroleum and gas, marine, automotive, production instruments and medical applications. Each portion generated by AM can be distinctive and manufactured in an overly less time, making it possible to customize mass. AM also lowers the demands for installation by incorporating the amount of parts needed for installation into a sole component. It lessens general weight, time of manufacturing, the amount of necessary production procedures, the demands for price and equipment, and optimizes the mechanical characteristics needed [32].

Recently, one of the highly investigated fields is the additive production of intelligent materials and structures. Smart materials are objects that can alter their form or characteristics under the impact of internal stimulation. As a reaction to internal stimulation implemented by incorporating intelligent products, the AM-made parts can alter their form or characteristics over moment (the fourth aspect). This leads to a latest concept called 4D-printing (4DP), which includes structural changes over period [33].

2.2 Smart Materials

Intelligent materials have been recognized as those resulting from externally exposed circumstances that alter their form or material characteristics. They were also categorized as 4D printing products due to their evolving characteristics over moment.

The implementation of smart materials to the AM sector offers advantageous characteristics such as reconfiguring the printed framework and achieving the required material characteristics in moment. Generally speaking, Shape Memory Alloys (SMA) and Shape Memory Polymers (SMP) are used as 4D printing material to generate functional components of soft robotic systems, self-developing designs and regulated continuous folding applications [5].

For their fundamental characteristics of super-elasticity and heat shape restoration, shape memory alloys are considered. In applications varying from biomedical embeds to micro-electromechanical systems, some SMAs such as nickel-titanium have been widely used. SMPs are too susceptible to internal stimuli such as light, moisture, and heat gradient as another branch of intelligent products. Because of SMP's biocompatibility, there is increasing interest in its medical engineering applications [34]. SMP materials are also used in the apparel sector and jewelry applications were digital light processing is required [31]. Piezoelectric fabrics are also considered to be another notable option for 3D printing. 3D nanofabrication of such products can be explored in conjunction with the power conservation and actuation purposes [33]. All these industries are likely to use AM in the era of Industry 4.0 with further changes in the performance of manufactured components.

One of the latest application domains for intelligent materials is soft robotics, where researchers have observed that the functional parts with electro-active polymers can be enabled externally to modify their rigidity in a supervised way [34]. Hong et al. [35], for instance, described the self-folding/unfolding function of 3D printed SMPs as effective origami and proved the restrict ability of effective multi-material hinges. One key application of active hinges [32] is the self-opening satellite parts caused by an inner stimulus. Likewise, Khoo et al. [36] explored multi-material printing made up of hydrophilic polymer where forced deformations produce 3D shape self-evolution when exhibited to water. The outcomes of such explorations will pave the road for research into self-assembled forms. As a prospective result, smart products can be attainable for acute scenarios such as deep sea or space tour by triggering them by water or UV light, respectively.

To outline, 3D printing technique can speed up intelligent materials implementation. Potential applications would be structures of self-assembly, compact settings, stimulus-activated systems in severe settings, and programmable components that will be easily used in the coming age. However, further study on intelligent components requires to be carried out on fresh combinations of components, creative production procedures and changes in layout.

2.3 Printable Hydraulics and Electronics

Hong et al. [35] explored an experiment in multi-material AM, where the research presents printable hydraulics that concurrently produced strong and fluid products. Modeling of fused deposition, called Fused Deposition Modelling (FDM) with various nozzles was used to manufacture strong structures composed of stiff, versatile components and simultaneously fill the liquid. As a result, hydraulically actuated operating systems such as smooth robotic grippers were produced for installation in just one phase without further measures. Thus, 3D printing can provide an easy way to manufacture immediate robotics and ready-to-use functional devices.

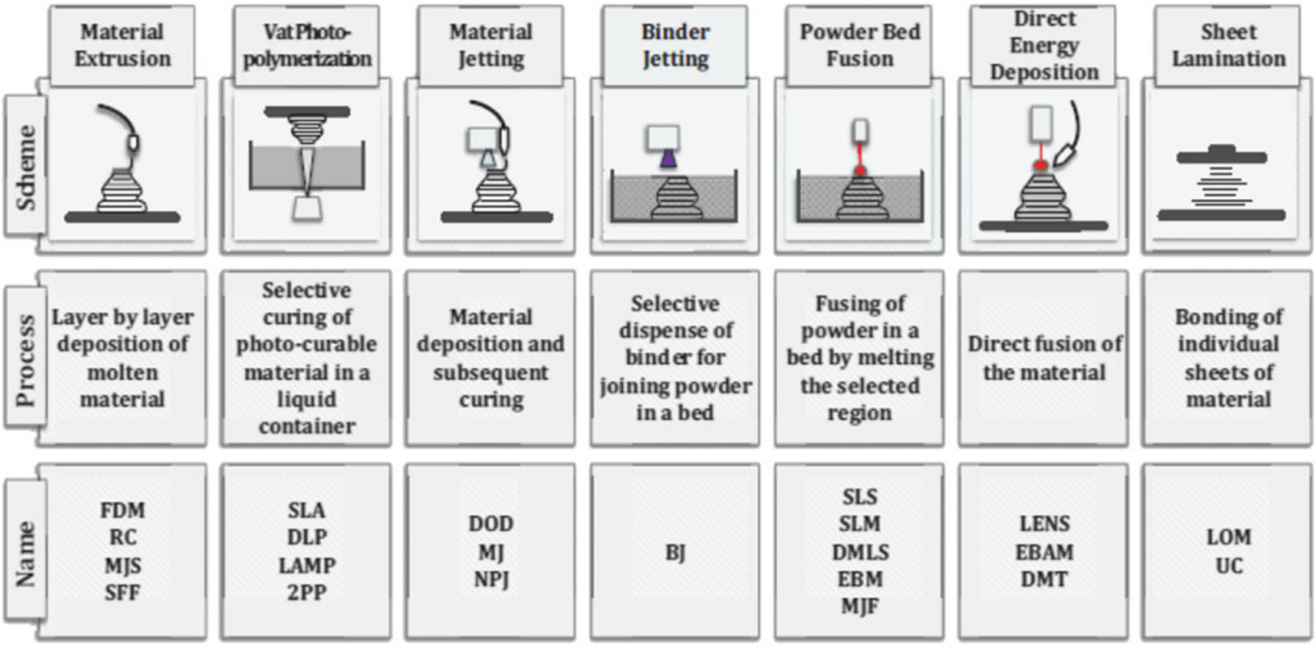
The implementation of conductive drugs for AM in this fresh age allows for the incorporation of digital circuitry into the printed item. As a result, complete circuit integration into the associated item (so-called integrated electronics) becomes a significant subject. Pham et al. [37]'s research focused on one instance of smart digital integrated apps where LEDs and digital PCBs are integrated in an electronic gaming dice (3D printed). In another job, Cooper [38] researched 3D printing (for recovery reasons) of tailored items housing digital equipment. In a modern research on 3D printed operational parts, further examples of printed equipment such as quad-copters, stretchable tactile detectors and micro batteries are stated [39]. Such work findings show the potential of AM to manufacture intelligent items for flexible areas.

In summary, together with its electronics, AM offers possibilities to manufacture goods. In the Industry 4.0 age, the loading effectiveness of electronic devices may be improved, allowing more creative models to be produced with multi-material printing technique in just one phase.

2.4 Space Materials and Applications

In the previous sub-sections, an overall perspective on new AM products has been summarized. In this section, extra AM components are to be addressed shortly, which are probable to be used in the upcoming age. The latest debate on additive building focuses on building potential houses and infrastructure.

As a result, in civil engineering implementations, inquiries into concrete and other particular materials shape the foundation for printing technology [40]. As a distinct part, the fabric production innovations have increased the AM procedures in the apparel and jewelry sector. In the fashion sector, some of the benefits of AM include a fast development method (i.e. brief manufacturing time) and decreased packaging and transport costs [41]. Another exceptional material for 3D



	Material Extrusion	Vat Photo-polymerization	Material Jetting	Binder Jetting	Powder Bed Fusion	Direct Energy Deposition	Sheet Lamination
Scheme							
Process	Layer by layer deposition of molten material	Selective curing of photo-curable material in a liquid container	Material deposition and subsequent curing	Selective dispense of binder for joining powder in a bed	Fusing of powder in a bed by melting the selected region	Direct fusion of the material	Bonding of individual sheets of material
Name	FDM RC MJS SFF	SLA DLP LAMP 2PP	DOD MJ NPJ	BJ	SLS SLM DMLS EBM MJF	LENS EBAM DMT	LOM UC

Fig. 4 Commonly used procedures in additive manufacturing [5]

printing is the food industry's consumable components. Using the extrusion-based AM methods, diverse applications with required ground texture and multiple nutritional content have recently been studied. While the process efficiency, permanence, and serviceability difficulties of the consumable products have not yet been achieved; AM may have a future in meat manufacturing [42]. Today, the use of this technique in space exploration is an uncommon subject. That is, some surveys researching Moondust's 3D printing to construct space colonies [43] discuss the practability of building habitations and infrastructure on the Moon with AM technology advances [44]. In addition, making excellent use of Mars' insitu assets as 3D printing material has been suggested for potential investigation projects to decrease the Earth's carried resources [45].

To sum up, some unique products and related procedures are shortly indicated with their consequences for the building sector, food, clothing, and even aviation sector. AM offers excellent opportunities to be investigated in the upcoming age, boosting competitiveness across a broad range of sectors.

3 3DP Processes

Three-dimensional printing has recently been outlined as it demonstrates a huge commitment to execute nearly all structural components of Computer-Aided Drafting (CAD). Various distinct methods are accessible for 3D printing, including, among others, Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS), Stereo Lithography (SL), Photopolymerization (PPT) [37]. Figure 4 demonstrates the procedures most frequently used in AM.

Novel AM procedures with a significant focus on those linked to MAM and hybrid production are described in this section. Although there is a substantial increase in the amount of creative AM procedures, they belong to the firmly-established basic techniques depicted in Fig. 4. With the technical advances in AM, more improved procedures are likely to be created. Most of these procedures, however, are created to print custom products such as metals that are usually used for non-industrial purposes.

Specific AM procedures have lately faced the need for substantial engineering applications in the framework of Industry 4.0. Since metals are the most popular product in the sector, significant thought has been given to the problem of MAM in this new era [31]. In fact, the future of production is anticipated to lead the sector to combine the use of these procedures. This fresh common sector, recognized as hybrid production, provides a manner to exercise subtractive techniques accompanying additives in order to manufacture stronger goods with higher ground performance, fatigue resistance, etc. [46]. Today, the increasing interest in hybrid production contributes to different combinations of production procedures beyond standard AM procedures.

3.1 Processes for Metal Manufacturing

Because of the comprehensive use of metallic components in almost every engineering field, MAM plays a crucial position for Industry 4.0. MAM procedures therefore dominate other kinds of techniques of printing. Four basic methods can be used to achieve AM of materials: (1) powder bed fusion, (2) direct power deposition, (3) fabric jetting, (4) binder jetting. The first two kinds are the industry's most prevalent ones. Powder-based techniques such as Selective Laser Sintering/Melting (SLS/SLM) and Electron Beam Freezing (EBM) use a power source to warm the content in a bath, named after the source used [47].

On the other side, during the processing of mixed metal, immediate power processing methods such as laser engineering net form (LENS) use heat power for boiling. Furthermore, there were also indirect MAM techniques accessible in which the molding for steel components and casting is immediately achieved [36]. Wire and arc additive production (WAAM) is a new metal AM method that is defined in conjunction with wire feeding as an integral arc welding process [48]. Due to its supremacy in manufacturing very big parts and its ability to shape all weldable materials, recent WAAM apps have been introduced in the aviation sector.

Nano Particle Jetting (NPJ) is a recently patented MAM process in which heated metal nanoparticles are thrown into a special liquid medium to construct extremely thin layers of the produced component [49]. Innovators of this fresh method argue that NPJ allows the finest surface finish among the existing MAM techniques to deliver elevated precision without deteriorating production velocity. In addition, NPJ is to deliver virtually the same metallurgical characteristics of strong counterparts and provide better production circumstances through the elimination of dangerous dust. Another innovative method proposed by Markforged [50] is Atomic Diffusion Additive Manufacturing (ADAM), where thick steel sections are printed layer by layer using the steel dust attached to a metal binder.

Progressive removal of the metal binder and sintering produces the finished item, resulting in outstanding mechanical features owing to the simultaneous sintering of the whole portion. Similarly, a new MAM technique called Single Pass Jetting (SPJ) has lately been announced by Desktop Metal Company [51]. A continuous binder jetting activity in the SPJ method causes steel oxide formation and compaction. The printing head's bi-directional motion makes the method 100 times quicker than standard laser-based metal additive techniques. The firm claims that SPJ provides the first 3D printer with its competitive manufacturing price per part estate that is competent of mass production.

Despite innovations in MAM, comprehensive study is still ongoing to solve challenges such as absence of system stability/repeatability along with restricted component size, elevated unit price, and bad completed product mechanical characteristics. Researchers have lately scrutinized optimization of parameters, searching for accurate sintering activities, and appropriate powder compounds, etc. [52] to identify remedies for these issues. Furthermore, study fields such as in-process surveillance and inspection have become very important in removing the obstacle for potential metal production [53]. Because MAM is inevitable for Industry 4.0's intelligent plants, the evolution of new procedures and associated techniques is likely to accelerate in the foreseeable future.

The fundamental concept of the SL method is photopolymerization, which is the method of converting a fluid monomer or tissue into a solidified tissue by adding ultraviolet light that functions as a catalyst for the responses; this method is also known as ultraviolet curing. Like pottery, powders can also be placed in the liquid [39].

Prometal is a 3DP method for the construction and death of injection instruments. This is a method based on powder that uses stainless steel. The method of printing takes place when a fluid binder is spurted into metal dust in jets [37]. SLS is already a 3DP process where a carbon dioxide laser beam [41] is used to sinter or fuse a powder.

FDM is a 3DP method where a slender metal filament carries a device where it is melted by a print head and is typically 0.25 mm thick. Materials used in this method include polyphenylsulfone (PPSF), polycarbonate (PC), PC-ABS blends, Acrylonitrile Butadiene Styrene (ABS), and medical-grade PC-ISO. The primary benefits of this method are that there is no requirement for chemical post-procedures, no cure resins, less costly machines and equipment that result in a more cost-effective procedure [45]. The drawbacks are that the resolution on the z axis is small relative to other additive production processes (0.25 mm), so if a clean surface is required a finishing method is needed and it is a slow method that sometimes takes days to construct big complicated components [44]. Few designs allow two methods to save time; a completely thick mode and a small mode that saves time but clearly reduces the mechanical characteristics [43].

Electron Beam Melting (EBM) is a method that uses an elevated voltage electron laser beam, typically 30–60 KV, to melt the dust. The method requires place in a large void room to prevent problems with oxidation as it is designed for the construction of steel components. The method is very comparable to SLS other than this. EBM can also process a wide range of pre-alloyed materials. One of the potential applications of this method is exterior space production as everything is accomplished in a large vacuum room [54].

Polyjet is an AM method that produces physical designs using inkjet techniques. The inkjet head rotates in the x and y axes depositing a photopolymer that is healed after each layer is finished by ultraviolet lamps. The density of the coating obtained in this method is 16 μm, resulting in elevated transparency of the manufactured components. The components that this method produces, however, are softer than others, such as stereolithography and selective laser sintering. A gel-type plastic is used to support the characteristics of the overhang and this material is thrown water after the method is completed. Multiple color components can be constructed with this method [46].

It is worth noting that multi-material extrusion in 3DP is receiving recognition owing to a broad range of opportunities provided, motivated in particular by the mercantile accessibility of a broad range of untraditional filament components. As a consequence, it is feasible to print designs that are not restricted to artistic reasons, but can now also give higher features and hence adapted for its function with mechanical efficiency [47].

It is shown that the use of AM methods is beneficial for components that have a large purchase: fly percentage, have a complicated structure, have a large price of solid-based raw material used for machining, have poor machining speeds and are hard and costly to process. For a conventional aerospace-Titanium alloy over a spectrum of purchases, the particular price of material unloaded by additive production technologies needed to provide a 30% saving over standard machines from strong methods is projected: fly ratios [50].

3.2 Hybrid Manufacturing Processes

Hybrid procedures describe the mixture of additive-and subtractive manufacturing (SM) procedures that are implemented sequentially or incorporated in mode, including adequate fastening and components orientation control [50]. This method is used for both enhancing dimensional precision and speeding up the manufacturing method as a whole. In addition, hybrid methods can be used to solve the issue of producing complex fields where a single production method (subtractive or additive) is not sufficient [53].

In the last century, scientists have developed hybrid approaches to create goods with chosen engineering attributes [55]. Hagel [56] have recently created a hybrid fast prototyping scheme in which FDM was used as an additive method in which the extruder was intended to move from AM to SM without compromising workspace. In a comparable research, CNC machining in regards to the deposition angle of the FDM is accompanied by the FDM method in order to obtain reduced ground roughness of the item and not reduce its surface morphology [57]. On the other side, for metals, a hybrid method composed of EBM and quick CNC machining has suggested improving system efficiency [58]. In their research, together with adequate process scheduling, milling is used as SM technique. Similarly, in order to achieve required surface finish, Rayna et al. [59] implemented a mixture of selective laser melting with accuracy milling. Hybrid deposition and later micro-rolling (recognized as HDMR) have also been used to manufacture components of steel planes with exceptional mechanical properties [60].

The problem of further enhancing hybrid manufacturing efficiency is strongly linked to sophisticated process scheduling, layout and production integration. A structure suggested by Chen et al. [60] implements the mix of AM/SM and test procedures. In this context, an algorithm is designed to arrange manufacturing operations/sequences with appropriate parameters while optimizing manufacturing time and resource utilization [61]. Related ideas are introduced in a notable implementation in which the hybrid method was used by incorporating material and consecutive machining to reuse current products [62]. Following the Fourth Industrial Revolution, future advancement on hybrid systems may come from IT innovations and the effective use of accessible data. As a result of both fresh hybrid procedures and efficient system scheduling, manufacturing demands are probable to be fulfilled with the enhanced performance of the item.

4 Additive Manufacturing in Industry 4.0

Industry 4.0 provides cybernetic and physical devices, as shown in Fig. 1, to collaborate profitably with the objective of constructing smart plants, redefining the function of humans. There are many meanings to the word Industry 4.0. It aims to define the smart plant, with the Internet of Things interconnecting all procedures. In this sector, the first developments engaged the inclusion of higher flexibility and production process individualization [50].

Industry 4.0's paradigm is fundamentally described in three aspects: (1) horizontal inclusion throughout the whole value development network, (2) end-to-end engineering throughout the entire consumer life cycle, and (3) vertical integration and networked production systems [58]. Industry 4.0 encourages the inclusion of smart manufacturing systems and sophisticated IT. In this, production is regarded as an important ingredient [39].

In Industry 4.0, the application of 3DP technology will be crucial for system effectiveness and decreased complexity, premising for fast prototyping and extremely decentralized manufacturing procedures: the product model could simply be off to the nearest 'printing' place for the customer, removing the need of intermediate manufacturing, storage and warehousing measures [52]. Table 1 shows an overview of the significant innovations and anticipated development in Industry 4.0 for the different factors of value development:

Table 1 Major developments and growth in Industry 4.0

Equipment	Highly automated machine equipment and robots will be used to characterize the production machinery. The machinery will be prepared to adjust flexibly to modifications in the other variables of value development, e.g. the robots can collaborate on joint assignments with the workers [58]
Human	Current production workers face an elevated danger of being largely automated. Thus, the number of employees will reduce. More information on this research will include the remaining production employment as well as more short-term and hard-to-plan tasks [63]. Workers are progressively required to track automated machinery, are incorporated into decentralized decision-making, and are engineering operations as part of end-to-end engineering [53]
Organization	From a certain point onwards, a central instance cannot manage the growing organizational complexity of the production scheme. Consequently, decision-making will be moved from a key example to decentralized cases. The decentralized cases will regard local decision-making data autonomously. The choice itself will be made by employees or machinery using artificial intelligence methods [53]
Process	Additive production techniques, also recognized as 3D printing, can be progressively implemented in value creation procedures, as additive production expenses have fallen quickly over the past few years by concurrently expanding in terms of velocity and accuracy. This enables more complicated, heavier and lighter geometries to be designed as well as the implementation of additive production to greater amounts and bigger product scales [64]
Product	The goods will be produced in batch size which is in accordance with the customer's person requirements [51]. This mass item customization integrates the client into the value chain as soon as feasible. As a part of fresh company designs, the physical item will also be mixed with fresh facilities providing features and access to the client rather than brand ownership [63]

5 Industrialization of 3DP Technology

Industrial businesses are now facing increasingly complicated difficulties in the creation of products. Customers are asking for creative, separately customized goods at a fair cost with elevated consumer quality. Furthermore, the financial lifetime of goods reduces, forcing businesses to shorten their business time and their growth cycles [64]. Competition in fertile economies is increasing through globalization. Foreign business imitators create it more difficult for businesses to retain market stocks that have been achieved [60]. A fresh manufacturing technique, the AM [46], provides one alternative to boost creativity and shorten time to market.

AM innovation is gradually becoming the key technology at present [64] and there is increasing agreement that 3DP systems will be a fresh significant technological revolution [60]. Figure 5 demonstrates potential Industry 4.0's 3DP operation:

Some 3DP technology implementations in different manufacturing sections are mentioned below:

5.1 Pharmaceutical Sector

In the 4.0 pharmaceutical sector, 3DP is anticipated to be an extremely innovative technique. The primary benefits of 3DP in specific are the manufacturing of limited drug batches, each with custom dosages, forms, dimensions and discharge features. Producing individualized medicines thus becomes a fact. In the short duration, 3DP could be expanded over the drug manufacturing stage from pre-clinical implementations and clinical testing to first-line medical care [59]. Exploring the changing technologies of the pharmaceutical industry 4.0 supports sustainable value creation, leads to a more efficient, better and customized pharmaceutical industry and, in the long go, provides competitive benefits for pharmaceutical businesses. To merge potential activities and pharmaceutical governance throughout the entire life cycle, a more viable pharmaceutical supply chain should be developed [61].

5.2 Biomedicine

Human bodies' 3DP is one of the world's recent developments in today's medical sector. Using present bio-printing technique, human bodies can be printed straight from neurons. In today's globe, many science and education institutions have invested millions of funds to remove the boundaries of body imprinting. The researchers' objective is to effectively substitute a human body. Various devices and equipment are sought around the globe during the method of organ production. With this technique, the most printed bodies are brain, cartilage, hair, heart and bone cells, etc. The reproduction of living bodies (print organ life), processing settings and post-processing (such as autoclaving) are some of the main difficulties in these techniques. Advances in this field obviously indicate that scientists are very near to the future, where it is possible to replace the human body with the printed organ [32]. 3D printing has shown feasibility in various medical applications, inclusive of the production of eyeglasses, custom prosthetic devices and dental embeds [62]. 3DP is also common with the capacity to print porous scaffolds with manufactured shape, restricted chemistry, and interconnected porosity. Some of these inorganic biodegradable scaffolds have been shown to be ideal for bone tissue technology [65]. 3D printing is a powerful tissue engineering tool that enables 3D cell growth within complex 3D biomimetic architectures [66].

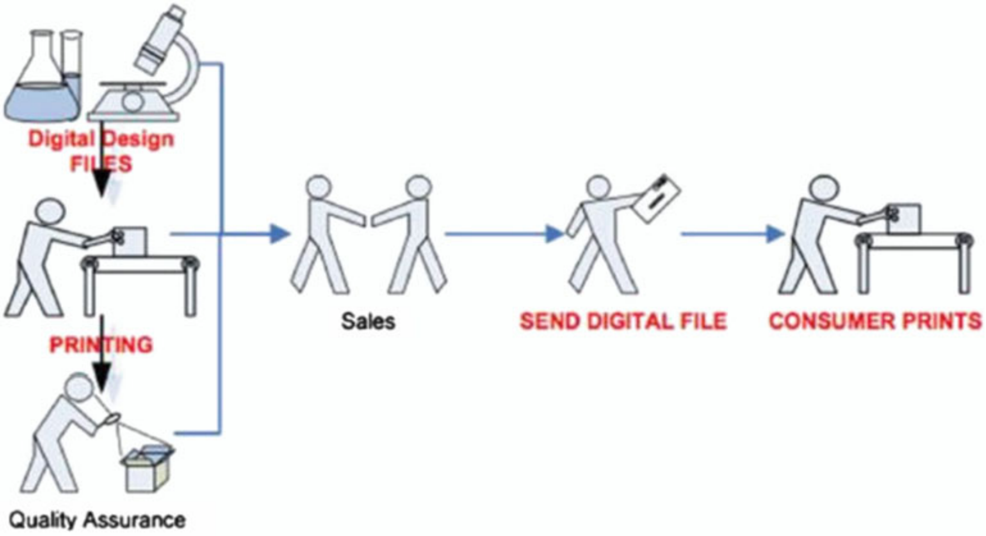


Fig. 5 Future 3DP procedure [1]

5.3 Food Industry

Because of its many benefits like tailored food models, individualized nutrition, streamlined supply chain and extending accessible food content, 3DP food has been extensively researched in the food sector in latest years. However, three primary elements should be regarded in order to achieve a precise idea: material characteristics, system parameters and techniques of post-processing, with unique regard to rheological characteristics, attachment processes, thermodynamic characteristics, techniques of pre-treatment and production powders. Furthermore, there are three primary difficulties in food 3DP: (1) printing precision and precision (2) process efficiency and (3) manufacturing of multicolored, multiflavored goods [67].

5.4 Fashion Industry

3DP has a large number of benefits over conventional production procedures, including a forwarded construction method, reduced production time, and reduced stock, warehousing, shipping, and shipping expenses. This paper describes the five kinds of 3DP techniques with high opportunities for fashion implementation, including stereolithography, selective laser sintering, mixed deposition modeling, PolyJet, and binder jetting [68].

5.5 Electrical Parts

3D printing is a distinctive technology that can provide a large degree of liberty to customize practical goods that integrate electrical elements such as detectors in wearable apps. In the manufacture of such devices and detectors, the accessibility of cheap, secure, electrically conductive material will be crucial before the complete potential of 3D printing can be realized for tailored goods integrating electrical components. To date, there is still a lack of 3D printable conductive filaments with adequately elevated conductivity to produce practical devices for mixed deposition modeling [69].

5.6 Casting Industry

Applying 3DP foundry moulds technology allows for a significant speed of work at prototype castings, allowing for a decrease in the cost of foundry-mold production. A shell mould can be produced and then complemented with cheaper molding material to decrease production expenses. The foundry mould making technique in three-dimensional printing method provides enormous capacity for production. For this reason; further study on its implementation for multiple non-ferrous alloy cast components is recommended [70, 71].

There is an increasing agreement, therefore, that 3D printing techniques are playing a significant part in the industrial technological revolution. History has shown that technological revolution is a pitfall for many companies without appropriate company model development. In the era of 3DP, the issue is then complied by the reality that the implementation of these techniques took place in four consecutive stages (fast prototyping, fast tooling, electronic manufacturing and house manufacturing) corresponding to a distinct stage of 3DP participation in the production process [61].

5.7 Design Related Issues

Engineers and developers have little experience and inadequate understanding about AM's capacities and constraints as a comparatively fresh production technique. Industry 4.0's evolving digitalization has developed possibilities for overcoming design-related obstacles to new manufacturing techniques. The advances on the latest computer instruments for simulation, visualization and immediate assessment are immediately linked to contemporary manufacturing. The design associated problems are to be shortly discussed in this section.

Industry 4.0's cyber technology advances provide developers with improved computing assets, which then contribute to increased productivity and effectiveness in AM. Design for Additive Manufacturing (DfAM) has lately been implemented as one of the additional design instruments to optimally select system parameters (such as price, time, performance, accuracy and CAD limitations).

In reality, DfAM is split into two sections that focus on solutions to a particular layout structure and techniques for improving particular product functionality [65]. The former offers a wide view for inexperienced developers to choose the finest alternatives in AM's design and production phases. For example, Salonitis suggested a particular DfAM technique for designing fresh goods (or reforming an current one) in which client wants, functional specifications, layout parameters and system factors are assessed simultaneously [66]. In a comparable research, another DfAM structure, in which production and installation problems are regarded in the early phase of item growth, offers developers with appropriate choices of materials and processes [67]. On the other side, the later method (i.e. DfAM's second category) provides superior goods for a specific purpose at the cost of giving less attention to other variables in effect [68]. The goal-specific approach is primarily focused on topology optimization (TO) as part of the second branch. It is described as a technique to obtain the finest geometry/shape feasible while meeting certain demands. For instance, product quantity optimization while minimal compliance with components has been studied frequently [72]. There are several novel TO apps for reduced weight-to-stiffness ratio [33]. The use of TO in ideal thermal transfer of buildings manufactured through AM [69] is an exciting objective-specific design implementation. Similarly, in comparison to hybrid AM [70], the techniques such as Solid Isotropic Material with Penalization have lately been explored. In such techniques, IoT and Big data plays an important role [73–78].

Other layout optimization research focused on parameters such as slice density, CAD model geometric data, part construction orientation, and support structures [79, 80]. CAD software problems have drawn a good deal of concern from scientists in latest years among the parameters mentioned. For example, in favor of new electronic file kinds recognized as AM File Format (AMF) and 3D Fabrication Format (3MF) [56], drawbacks originating from STL file format have been studied. Similarly, Junk and Kuen studied the use of open-source CAD technology projects [65]. Several cutting algorithms and effective system scheduling methods were also suggested, such as the one that capitalizes on inhomogeneous interior coherence to minimize printer head movements [66].

As the industrial and academic study group gains knowledge through effective implementation of new computing techniques and new design methodologies, the significance of design-related problems will be significantly increased. Consequently, in the near future, AM's limitations and capacities can be handled more efficiently.

6 Drawbacks and Future Directions

Industry 4.0 has drawn the attention of both academics and sector over the past century as it is regarded as the significant paradigm change in potential manufacturing. AM, as a main innovation in the framework of the upcoming revolution, provides excellent possibilities for future innovations in this fresh age, provided that in the near future some present obstacles are overcome. In this section, along with supplementary suggestions, some predictable projections about AM and its probable disadvantages are to be mentioned.

Because of the significant drawbacks to its velocity, precision, repeatability, and price of manufacturing, AM may not be chosen in standard industrial facilities, particularly for mass production of periodic components. However, in the manufacture of complex and tailored items, it still has superiorities over standard production techniques. In reality, AM offers a wide variety of production opportunities in terms of content (polymers to metals), size (nanoscale to big components), and functionality (self-assembly for optimum thermal transfer) [67]. The resistance of the produced components is another AM deficiency that can be fostered by new materials/processes that cause improved microstructures and development of the correct design/topology. In addition, hybrid production makes it possible to compensate for certain disadvantages, such as the ground performance of the product, as well as offering possibilities for repairing/repairing current components.

Decentralization can become feasible as a potential anticipation by spreading the workload across factories/machines through the efficient use of cloud services [79]. Another direction for AM in the future is the problem of sustainability, where AM can perform an important part in decreasing waste capital and decreasing power usage by using just-in-time manufacturing [80]. In addition, it is expected that 3D printing and electronic production will affect society. First, it is necessary to redefine the position of employees in the sector in such a way that they undertake management/design/analysis employment rather than being employees. Second, platforms such as do-it-ourself and motion of manufacturers promote the involvement of customers in the planning and production stage [68]. For example, by converting the school into a tiny hands-on workshop with an affordable 3D printer, learners can design their own goods.

In the Industry 4.0 age, there are several common areas of research on additive production: fresh material compounds for enhanced microstructures, creative design frameworks for appropriate parameter estimates, enhanced CAD services for optimization/simulation/modeling reasons, fresh AM/hybrid procedures along with real-time system monitoring and inspection, etc. The primary suggestion is the study community, sector, and governments working together to resolve all these present obstacles on AM. In addition, AM's being comparatively fresh innovation involves issues in the sector of standardization, needing some job on suitable certification [72].

7 Conclusion

Cyber-physical inclusion promotes high-efficiency intelligent factories that are able to manufacture tailored goods of high quality. On the one hand, IT progress has accelerated the shift to the upcoming manufacturing age. Indeed, the presence of the Fourth Industrial Revolution relies heavily on AM's capacities. These problems have been summarized in this article in three particular subjects, namely problems of materials, procedures and layout.

More interdisciplinary study attempts are probable to be spent in the future. On the other side, there will be a remarkable redefinition of the position of developers, warehouses and clients as the production company will be spread to many distinct places such as tiny workplaces or households. In other words, with personal-and tailored manufacturing, the present obstacle of mass manufacturing on site will be overcome.

No doubt 3DP techniques will lead to the next significant manufacturing revolution. The Additive Manufacturing performs a major significant role in Industry 4.0 due to its versatility, reduction in time and expenses, being crucial for system effectiveness and decreasing its complications, enabling fast prototyping and extremely decentralized manufacturing procedures. AM is currently taking benefit of more and more manufacturing sections. Future intelligent companies have all their procedures interconnected through the Internet of Things, integrating higher flexibility and production procedures individualization.

As a particular perspective, there is a tendency towards the availability of fresh products for AM such as intelligent metals and metallic constituents in order to attain the necessary features. Another common tendency is to create functional parts/machines in just one manufacturing phase. Due to the possibilities offered by the new AM techniques, only the imaginations of the people limit the design-and manufacturing difficulties.

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