



Additive manufacturing: expanding 3D printing horizon in industry 4.0

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Abstract

Additive Manufacturing (AM) technology enables the production of personalized goods at reduced development costs, shorter lead times, lower energy consumption during manufacturing, and decreased material waste. AM will be consolidated as a leading technology in numerous sectors in the near future due to the maturity of the technology, the wide range of possibilities afforded by 3D printing, and the institutional push. One of the most important aspects of Industry 4.0 is 3D printing. It may be used to fabricate complicated parts and allows companies to cut inventory, develop on-demand items, create smaller localized manufacturing conditions, and even shorten supply chains. AM is expected to increase rapidly in the future because of its above stated remarkable “performance record.” According to a report published the AM market is predicted to produce US\$2 trillion worth of components and end products by year 2030. Hence integration of smart technology and production systems or indirectly one can say that AM is promoting Industry 4.0 and it plays a pivotal role in solving some of the 4th industrial revolution’s most important needs. AM is a future paradigm for futuristic production systems, and Industry 4.0 will leverage its potential to reach essential goals. AM will be found now days in a variety of industrial applications including aerospace and health care to consumer goods. This review article discusses about brief AM technology, history, its industrial applications, challenges, and future prospective. Finally, case studies using AM has been considered.

Keywords Additive manufacturing · Industry 4.0 · Biomedical industry · Sustainability

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Abbreviations	
AM	Additive manufacturing
ASTM	American society for testing of materials
ISO	International organization for standardization
ISO/TC	International organization for standardization-Technical committee
SM	subtractive manufacturing
3D	Three-dimensional
IoT	Internet of things
SLM	Selective laser melting
SLA	Stereolithography
CSAM	Cold spray additive manufacturing
CS	Cold spray
IC	Internal combustion
CAD	Computer aided-design
USB	Universal serial bus
EBM	Electron beam melting
FDM	Fused deposition modeling
FFF	Fused filament fabrication

1 Additive manufacturing

AM, as defined by the ASTM and the ISO/TC 261 Committee for Standardization, is a set of technologies capable of joining materials to build a complete assembly from 3D model data developed using certain software tools, usually layer by layer, in contrast to subtractive manufacturing methods [1, 2]. However, before delving into the function of AM, it's important to first grasp the concept of Industry 4.0. Since around 2014, the 4th industrial revolution has ushered in a new era in industry, society, and economy. This has been made feasible by the exponential growth of technology and information and communication technology (ICT) during the previous decade, which has given rise to Industry 4.0. Industry 4.0, is an ongoing trend in intelligent automation technologies which born in Germany, with an objective to uplift the German economy. The application of modern manufacturing skills in the context of integrating newer information technologies is critical to economic competitiveness in this new era [3]. As shown in Fig. 1, Industry 4.0 allows cyber and physical systems to work together profitably, with the goal of creating smart industries by rethinking the role of humans.

IoT, Cloud computing, Big Data, and other key concepts are related with the virtual world, whereas Autonomous Robots and AM are associated with the physical sphere [4]. Internet of Things is defined as the approach of collecting information from physical items via computer networks or accelerated wireless links in cyber-physical systems. The data extracted from products, machines, and manufacturing lines amounts to a significant volume of statistical data that must be transferred and analysed. Big Data is a term used to describe this massive amount of data, which is another

key concept in Industry 4.0. Furthermore, cloud computing, which is concerned with the processing of all available data, is one of the most important concepts in the virtual industrial environment. Each of these cyber technologies contribute to the efficient use of existing data for future smart manufacturing [5].

This study focuses on the technological revolution under Industry 4.0, which includes 3D printing-type technologies that have a significant impact on product manufacturing. Three-dimensional printing, and Industry 4.0 have all been explored.

Types of AM.

Materials used (present and emerging), energy based AM or material deposition based AM, and the raw material employed (which is widely used criteria's) have all been used to classify AM processes in the literature (inset Fig. 2). To our knowledge, the most commonly used raw materials for cost assessment, business model recommendations, and sustainability procedures are filament and powder [6–11]. One of the most well-known and well-respected AM or 3D printing enterprises is summarized below:

- a. 3D systems (Canada).
- b. Form Labs (USA).
- c. Stratasys (USA & Canada).
- d. HP (US).
- e. Desktop Metal (Burlington).
- f. Ultimaker (Dutch).
- g. Carbon (Redwood).
- h. EOS (Munich).
- i. Mark forged (Massachusetts).

Despite some issues regarding its suitability for mass production, the use of AM in the industry is on the rise as a result of recent technological developments. It may offer a method to replace traditional manufacturing procedures in the near future, as it is an emerging technology for creating precise and strengthened intricate items with higher production speed. With the developments in AM technology, more improved technologies will be developed. Because metals are the most widely used material in the business, the issue of metal additive manufacturing has attracted much interest in this new period [12–16]. Newer techniques like cold spray have been used to fabricate biomedical implants for human bodies and also in for the fabrication of rocket nozzles which was time consuming using traditional manufacturing approach. It is used to develop a component contour that is as close as possible to the final shape while maintaining tolerance. Cold spray AM has enormous potential to change the size and distribution of Industry 4.0 with remarkable sustainable benefits with minimal impact on environment as it is a green technology [2].

Furthermore, it is envisaged that the future of industrial manufacturing would lead the industry toward the hybrid

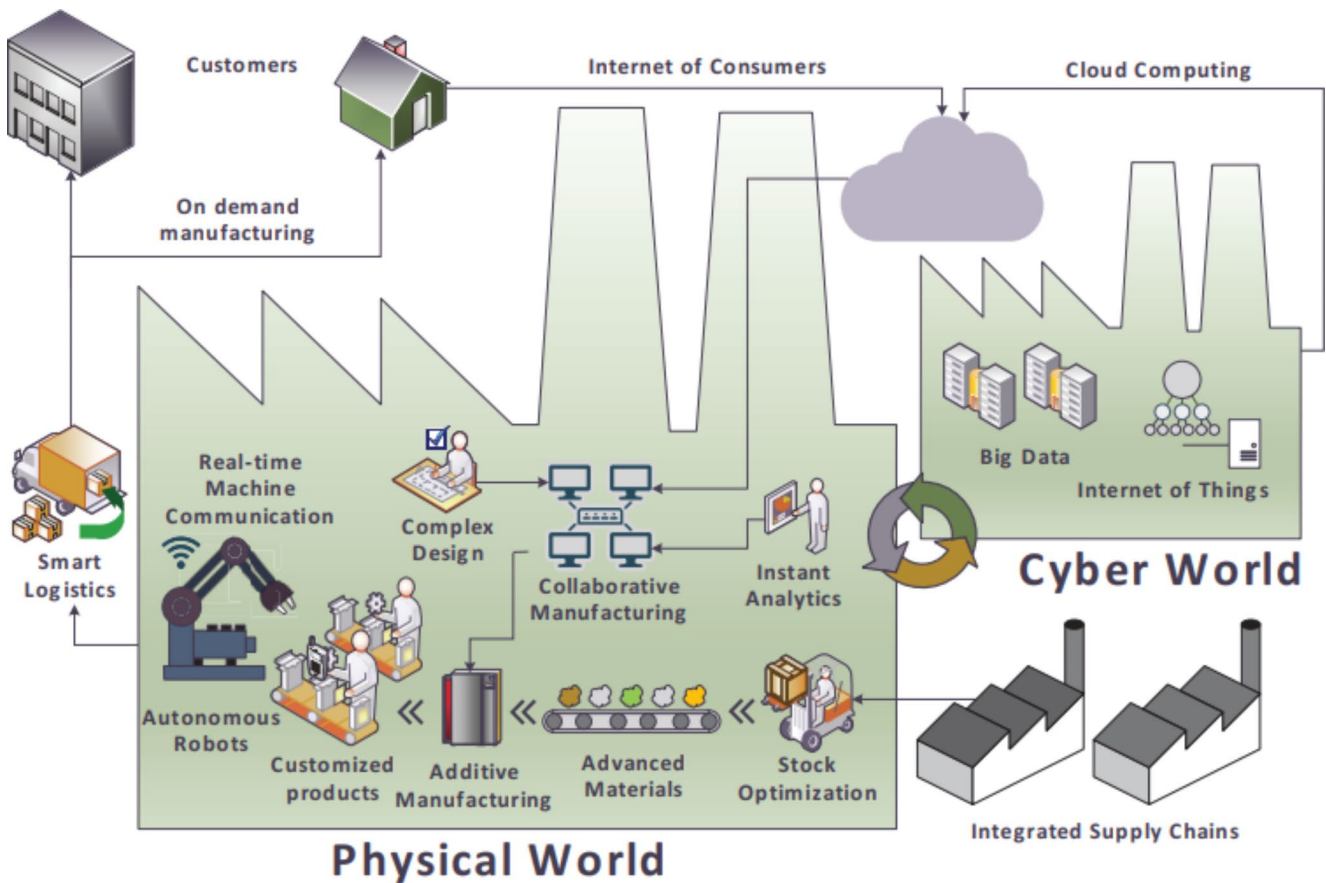


Fig. 1 Outline of smart industries with general properties needed in Industry 4.0 [1]

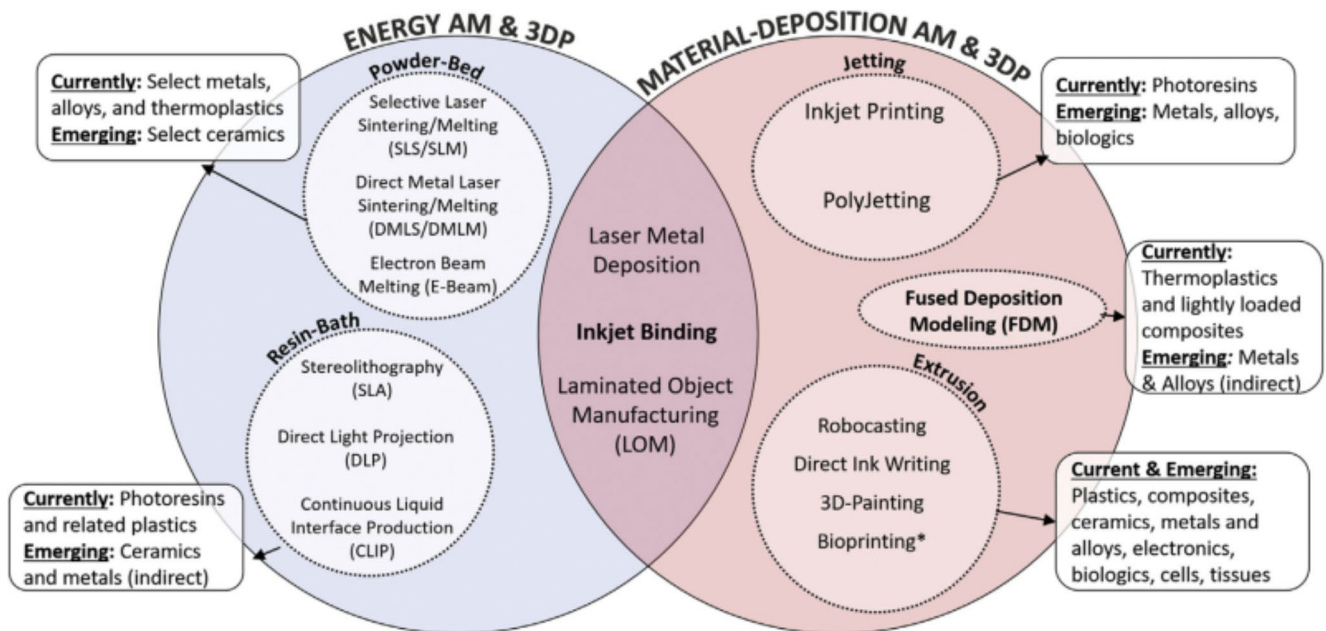


Fig. 2 Types of AM processes [24]

manufacturing approach. This increasingly popular discipline provides a technique to combine subtractive and additive technologies to produce far better products with improved surface quality, high fatigue strength, and other characteristics [17, 18]. Lee et al. [19] built a hybrid rapid prototyping setup that employed FDM as an additive process and had an extruder that could convert from AM to SM (subtractive manufacturing) without compromising work area. Du et al. [20] used a combination of SLM and precision machining to achieve the necessary surface finish. The issue of further increasing hybrid manufacturing performance is inextricably linked to advanced process planning, which integrates design and production. Zhu et al. [21] offer a system that combines AM/SM and inspection methods. In this framework, an algorithm is designed to arrange manufacturing operations/sequences with appropriate parameters while optimising manufacturing time and material consumption [22]. A similar concept was employed in a notable application, in which a hybrid technique was employed to reuse existing products by introducing an additional material and machining them successively [23].

Further improvement on hybrid technologies may result from advancements in information technology and effective use of data available after the fourth industrial revolution. The higher product quality will most likely satisfy industry needs in coming future as a result of both unique hybrid processes and good process planning.

1.1 Why AM?

AM is preferred over traditional manufacturing approaches due to its unmatched benefits. But these benefits can be obtained only with proper work strategy. You must know the benefits and how they apply to you as you develop your approach. You must first become familiar with the various technologies available and what each can provide, and then you must explore your options. Rapid prototyping in the 1990s is nothing compared to the AM technology available today. There are three ‘Affordability Pillars’ that AM can provide in comparison to traditional approaches available. The foundation of your AM strategy will be these pillars.

1.1.1 Value Stream Mapping (Pillar of Affordability #1)

In most cases, AM employs only the materials required for the part, resulting in a significant reduction in waste during manufacturing. It also avoids the lengthy lead times associated with producing moulds, casts, and completed (direct to manufacture) items in some materials [2]. AM can help you cut lead times and waste as part of your value stream mapping process. It can reduce your Buy-to-Fly ratio to almost 1:1, compared to 30:1 in many other approaches. When

working with really costly or precious metals, this is very critical, especially if the items are limited edition or short run. AM can cut down the number of steps in a manufacturing process, both in tooling and direct manufacture eliminating the requirement for human assembly to the point where the full assembly of the proper part could be printed.

1.1.2 Design for performance (pillar of affordability #2)

When a design modification is made late in the workflow, particularly after tooling has been created, the costs of that change skyrocket. Those costs are frequently high enough unless the product is severely faulty. Therefore the design modification may not be adopted. This means that small design adjustments, such as ‘nice-to-have’ features, will not be added to the product. AM technologies can help solve these problems by providing components and tools with extremely short lead times and the ability to easily incorporate design changes. Hence instead of preventing design modifications, an organization may concentrate on creating the high performance product possible without having to worry about the impact on manufacturing deadlines and costs. As a result companies should be able to attract and retain happier customers, more delighted customers, fewer returned products, and a better reputation with higher-quality products.

1.1.3 Reducing the bulk (Pillar of Affordability #3)

Each item used in an assembly requires more fasteners, clips, glue, and other materials, increasing the weight, size, price, and complexity of the assembly. Generally speaking, the fewer components in an assembly, the superior it will perform [13, 14]. Many AM materials are now so good that they can easily match the performance and specifications of traditional materials. As a result of decrease part count, there are fewer fasteners in the assembly, which implies lower cost and weight.

2 History of AM

To properly appreciate the current state of 3D printing, as well as its future prospects, it is necessary to first comprehend the technologies’ combined history and quick evolution. This not only puts the current level of 3D printing into context, but it also allows the reader to see how swiftly the subject is evolving and where it might be in five, ten, or fifteen years. There are five, or probably six, significant eras in the history of AM, or 3D printing. The first phase, which lasted from the late 1970s to the early 1980s and was characterised by isolated examples of what could be regarded

forerunners of AM technologies (“Proto AM”). The second phase, which lasted from the mid-1980s until around

1990, saw the creation and early launch of three important, fundamental 3D printing technologies, as well as the

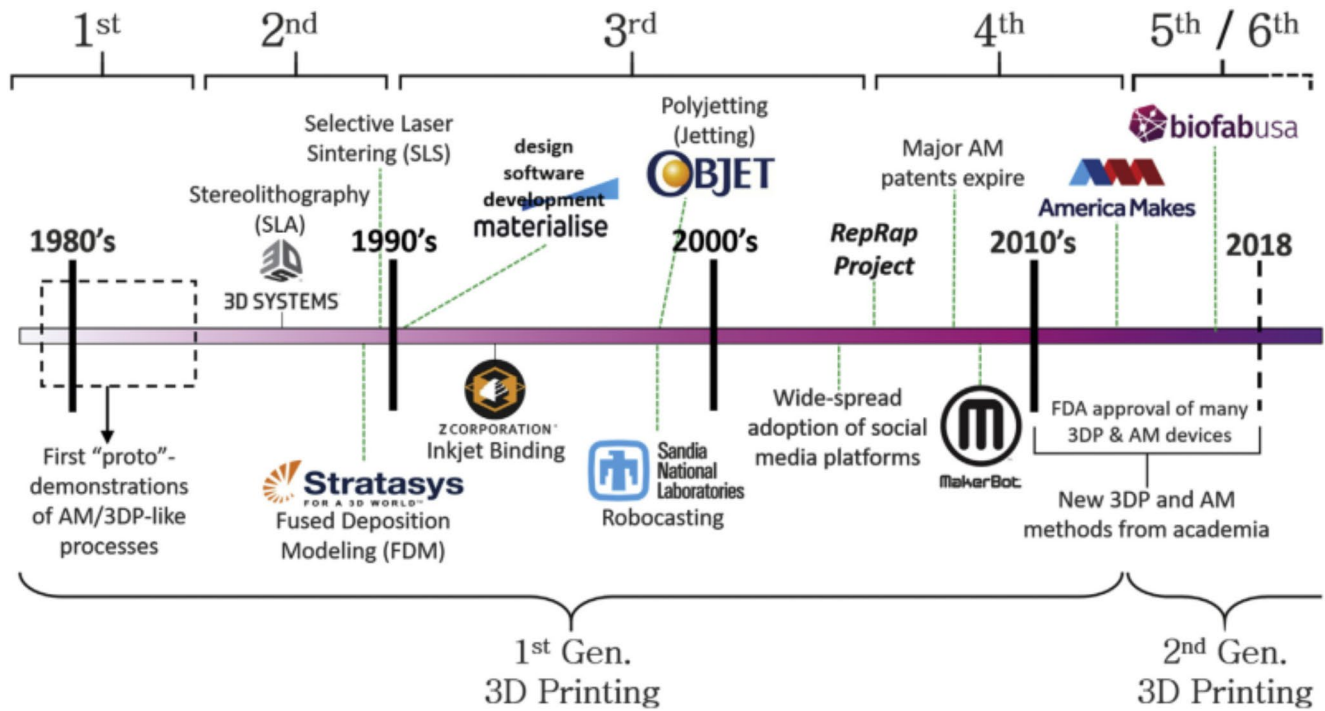


Fig. 3 The history of AM and 3D printing, a timeline containing main eras and key events have been compiled [24]

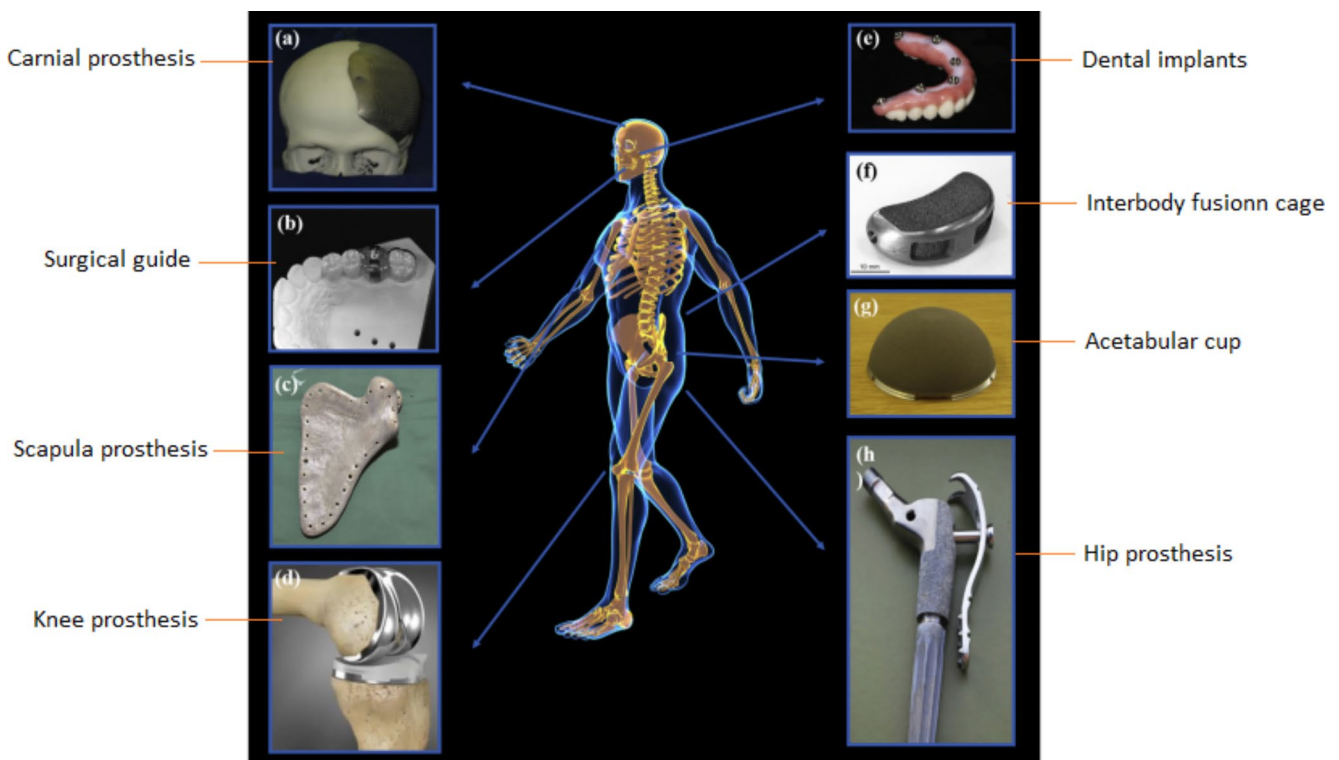


Fig. 4 Applications of 3D printing of the biometals in different parts of human body [30]

establishment of the first 3D printing firms, two of which are still major industry participants today. The third phase, which spans about 1990 to 2005, is marked by the maturation of 3D printing technology within the initial private firms, the introduction of new, key 3D printing technologies, and the parallel development and progress of computational and 3D imaging skills. The fourth period, which runs from 2005 to 2012 and coincides with the expiration of the authentic 3D printing patents, the mainstream adoption of social media, and the begin of the “maker movement,” is when 3D printing is widely introduced to and accepted by audiences outside of the traditional big industry players. The fifth era, which began in 2012/2013 and ended in 2017, or the present day, depending on your point of view, depicts what could be defined as a 3D printing arousal. New additive techniques, 3D printable materials, and perhaps even bioprinting began to gain popularity, become mainstream, and receive significant funding and support from key federal government initiatives and agencies [24]. The chronology in Fig. 3, depicts these five/six periods, as well as selected important events within and linked to AM and 3D printing.

3 AM applications

The demand for precise functional and mechanical properties, as well as production flexibilities, has sparked interest in AM in different industrial applications [25–29]. As per study [1], AM parts made for the aerospace and automotive industries now account for 20% of the total AM market.

3.1 Biomedical Implants

One of the most common applications of AM is in the medical field. Presently, 3D printed technology is mainly used to fabricate biomedical implants for repair of tissues, orthopedics, and surgical tools [30] (Fig. 4). Every patient is different in the medical and dentistry fields, therefore AM offers a lot of promise in individualised and customised solutions promising for.

generating complicated shapes also. The opportunity to practise before a surgery is one of the medical applications of AM that is already having a huge impact. Surgeons can use data from MRI and CT scans to create 3D models of the patient’s anatomy before doing surgery for practice. They then use this 3D CAD data to create 3D printed models, allowing them to practise difficult surgical operations on realistic models in order to perfect their skills [31]. Typical methodology followed for manufacturing of medical model is shown in Fig. 5.

One of the most common uses of 3D printing is in the dental sector. Dentists and dental laboratories can create precise and personalised remedies to dental problems utilising scans acquired from the actual patient’s mouth. In the dentistry business, AM is a big and developing player, and there are currently a lot of machines and materials designed expressly for it. Prosthetics are one of the most well-known 3D printing for medical purposes case studies. There have been multiple reports of businesses producing simple 3D printed prosthesis for children or people in impoverished nations who do not have access to other options.

However, there are some limitations associated with AM mainly related to high-temperature metal processing, which frequently results in undesirable mechanical properties like undesired phase transformations, part distortion, greater residual stresses, and poor mechanical properties [32–35]. The technology of supersonic powder deposition (CS) is effectively utilized to overcome these short-comings of high temperature metal processing [36]. This differs from conventional AM procedures in which powders are either laid down on a powder bed. Recently, Moridi et al., [37] used CSAM (Cold spray additive manufacturing) approach to generate solid state 3D printed Ti6Al4V implant having porous structure. When the compressive yield strength of solid-state 3D printed Ti-6Al-4 V alloy was compared to that of other AM techniques, it was found that there is an increase in yield strength up to 42% in the solid-state 3D printed parts. The biocompatibility of 3D printed structure with MC3T3-E1 SC4 murine preosteoblast cells was compared. The result emphasizing the materials potential

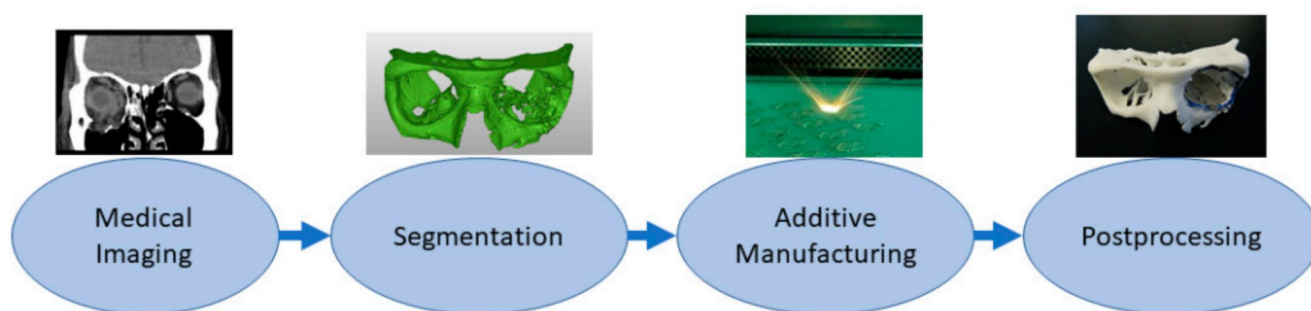


Fig. 5 Flow chart followed during manufacturing of medical model [31]

for the biomedical applications. Hence, employing a broad spectrum of metallic materials that are already being used in CS processing, one-step subcritical CS deposition can be used to build cellular structures in future. This may be easily adapted to manufacture 3D objects by combining a robot with a supersonic nozzle in CS, as businesses like Impact Innovations [38], Speed3D [39], and NRC Canada [40] have already done the same. As a viable manufacturing approach for the fabrication of biomedical implant materials in near future, 3D solid state CS printing has been proposed.

The ability to 3D print organs is one of the futuristic applications of AM outside of traditional manufacturing. This could be one of the most transformative applications of 3D printing, having the potential to revolutionise the world as we know it. Millions of people in need of transplant donors would no longer have to wait. Therefore, AM allows for not only personalization but also, more importantly, cost savings and increased success as summarized in Table 1.

3.2 Aerospace

Complex engine parts, replacement parts or restoration are common aircraft applications. AM allows for the fabrication of such items with considerably lower weight and minimum life-cycle costs which is vital for space shuttles and

Table 1 summarizes the benefits of AM in dental and medical fields [31]

Field	Observations
Maxillofacial & Orthopedic surgery	Time & cost savings
Transplants	Personalization
Pathology samples for students	Savings in cost
Surgery	Radiation exposure decreases, time savings, and better medical outcome
Implants	Antibiotics incorporation
Dental	Cost savings, and personalization
Dental	Personalization, cost savings, and digital storage
Pharmacy	Personalization
Dental appliances	Decrease in manual work
Pharmacy	Personalization, and manufacturing on demand
Orthopedics	Personalization, accuracy, reduction in costs and time, completely automated and computerised manufacturing
Implants	Supply chain possibilities
Surgery	Surgeon as designer, and innovation potential
Medical	Different materials can be used
Implants	Complicated geometries can be made
Implants	Implant forming templates
Dental implants	Better osseointegration and stability with a rough and porous surface texture
Surgery	better anatomical knowledge and surgical precision

airplanes. Using traditional processes, weight optimised designs are excessively expensive or difficult to construct [2]. In the case of Sentinel Satellites manufactured by oerlikon AM, this is unquestionably true where 40% reduction in weight achieved with topology optimization. Hence the ability to construct an aircraft structure that exceeded expectations was made possible by the versatility of AM technology which allows balanced stress distributions resulting in improved performance. The fuel efficiency is also increased by AM as machining of high temperature materials like Ni and similar alloys is difficult. Earlier in traditional approaches the machining is vital to achieve complicated cooling channels for high combustion temperatures. But with AM number of these manufacturing hurdles was removed.

Moreover, on-demand and on-site fabrication must be built for astronauts to manufacture parts for space station repair or maintenance. Small batches of parts with complicated geometries are required for airflow and heat dissipation function; hence AM techniques are appropriate for producing aircraft components [41]. AM can be used from brackets to instrument housings in choopers and fuselage structures to battery compartments in UAVs [42].

3.3 Automotive

Original equipment manufacturers have traditionally relied on AM for rapid prototyping in the automotive industry. However, improvements in AM have been slowly revolutionising the way end-use parts are designed, made, and distributed in recent years. According to Deloitte's 3D opportunities in the automobile sector study, reveals that companies do not want drastic changes in supply chains or products in the existing standard AM approach. AM is used to make design iterations, improve quality with cost-effective prototyping, and make customised tooling parts. Other AM approaches in automotive, however, exist that modify goods and supply chains more dramatically. This is what the following overview of additive's impact in the automobile sector will look at.

According to a forecast by SmarTech Analysis, by 2029, automobile 3D printing would have produced \$9 billion in income from the fabrication of end-use parts alone, up from \$1.39 billion in 2019 [43]. So, where does AM stand in this industry?

In any industry, speeding up the product design phase during new product development is critical. In this point, 3D printing can thankfully replace expensive and time-consuming CNC production. More specifically, it allows designers to go through multiple iterations at a low cost before finalizing on the finished product also known as rapid prototyping. For the past 25 years, Volkswagen, for instance, has been

experimenting with 3D printing technology. Deloitte refers to these applications as the current conventional AM path in the automotive industry. In order to develop in recent years, automakers have had to experiment with different business models. Many companies are turning to innovative technologies, such as AM, to keep development cycles short and costs low.

Furthermore, vehicle electrification is also a hot topic, with roughly half of all automakers intending to be market leaders in fully electric cars in the near future. As the automotive industry shifts away from IC engines, AM emerges as a viable option for developing lighter parts for electric vehicles. Light weighting is crucial for electric vehicles since it affects battery life directly. We may be familiar with Olli, a 3D printed autonomous electric minibus created by Local Motors in 2016 [43].

According to the manufacturer, around 80% of the parts were 3D printed, resulting in a 90% reduction in overall production time. Olli's top speed is 40 km/h, making it ideal for city centres, university campuses, and hospitals.

Furthermore, as the need for connected automobiles grows, so does the demand for electronic equipment such as sensors and antennae within the vehicle. With this growth comes a larger requirement for smaller, more complicated devices to be designed and manufactured. More complicated electronic components can be designed in-house and directly integrated into the vehicle using micro- and nanoscale 3D printing technology. Electronic 3D printing can cut down on the prices and time it takes to develop these gadgets. In nutshell to advance into the creation of more sophisticated, high-performance parts, practically every company in the market is investing in 3D printing technologies.

3.4 Architectural & civil

The architectural profession has profited from AM in two distinct ways: models and construction, from AM of historic sites [44] to the development of a settlement on the moon [45]. Architects will benefit from AM of models because it helps them to refine their designs on a micro level and fine-tune their architectural blueprints. AM also assists the construction sector by changing three essential characteristics, namely, decreasing manufacturing time and cost while improving flexibility.

To print building components using polymers, metals or aggregate-based materials; gantry systems and large robotic arm have been developed. The Massachusetts Institute of Technology has developed one such Digital Construction Platform as depicted in Fig. 6a, using a mobile base and placing robot arm on it. Due to this crashes with the structures can be prevented. Furthermore, in concrete printing Eindhoven University has developed 3D Concrete printing machine (Fig. 6b). In this nozzle deposit fresh cementitious material along a predetermined path and finally a structure is built layer by layer [46].

AM systems were used in a variety of civil projects, including:

- Depending on its 3D concrete printing idea, Loughborough University created a curved bench with dimensions measuring $2 \times 0.9 \times 0.8 \text{ m}^3$. The printing took about 42 h [47].
- XtreeE [48] used a 6-axis robot arm to print a complicated wall-element sized $1.36 \times 1.50 \times 0.17 \text{ m}^3$. The component is built of ultra-high-performance concrete and was designed with thermal insulation in mind. The printing took about 12 h.
- For the Dubai Future Foundation, WinSun [49] printed the parts of a single-story office structure with a floor

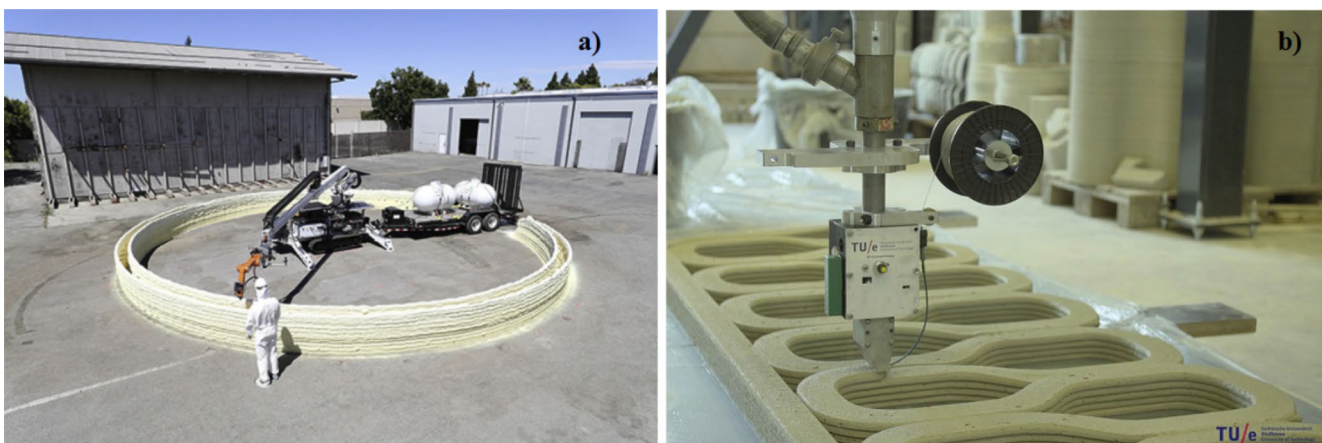


Fig. 6 (a) Digital Construction Platform, and (b) 3D Concrete printing machine [46]

space 250 m². It took 17 days to complete the print job, which is identical to Contour Crafting. The parts were then shipped to Dubai, where they were assembled in two days [50, 51].

- The Eindhoven University in the Netherlands used 3D concrete printing to build a bicycle bridge with a length of 6.5 m and a breadth of 3.5 m. The printing took about 48 h to print all elements [52].

Apis Cor [53], CyBe [54], Total Kustom [55], BetAbram [56], and WASP [57] executed other projects.

Because the opportunities for experimental investigation in building projects are limited, the design phase for buildings also includes extensive structural verifications following established rules. Simulation of AM methods is thus another key subject of research to develop additive construction. Further, the material and its failure behaviour must be precisely described in order to evaluate the reliability and serviceability of designed AM parts. However, for completed AM components, there is a considerable shortage of experimental data and proven models. Figure 7, depicts how AM benefits are used to various businesses. Because of its versatility and ability to manufacture custom products on demand, AM has been extended to other sectors like food [58] and clothing [59].

4 Production challenges in AM

With the clear merits of AM in mind for industry 4.0, whether or not AM technology achieve success in broader spectrum depends strongly how well these printed components perform when put under service conditions. It is also important that AM's ability to create complicated shapes will also transform into useful end product [60–64]. More crucial is that the cost during whole lifecycle time of the printed object must remain competitive.

AM in its early stages (mid1980's) was used mainly for designing functional prototypes, concept models, and visualization tools but recent developments related to material technology and printers have expanded AM to factory tooling, end use products, and spare parts. Currently AM is employed mainly in small scale production but slowly and slowly it is becoming valued part of whole production process. Recent report shows that 63% of the industries used AM for prototyping while 21% deploy AM to manufacture products that were hard to manufacture by other technologies. In some cases, industry engineers used AM to test their idle curiosities; in others, AM machines were lying idle in the corner to collect dust.

These numbers clearly indicates that there exists something in the mind of industries which prevent manufacturers form integrating emerging AM technology into their production process. Hence their exists some challenges which required to be addressed before AM is fully welcomed by

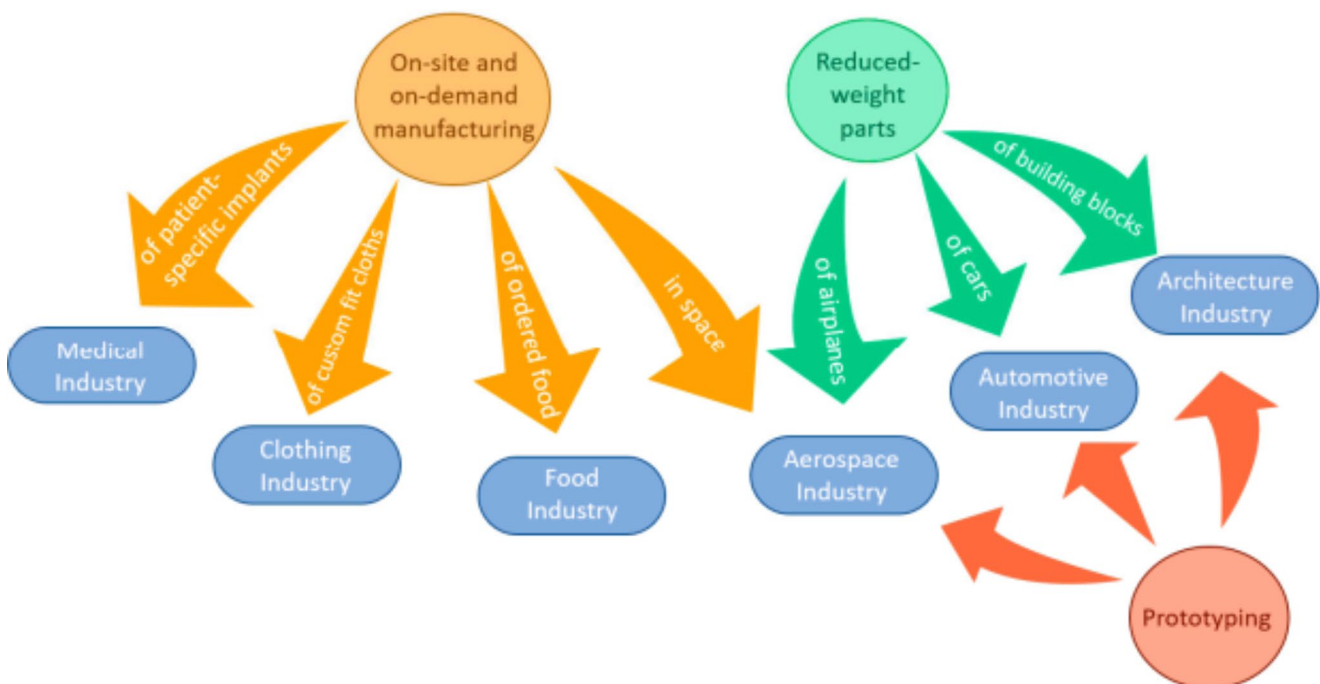


Fig. 7 AM application features in various industries [1]

the industry 4.0 to become a key part of their production process (Fig. 8).

4.1 Technical challenges

As discussed above AM is used mainly for the purpose of prototyping. But why this? One reason behind this is that number of industries and their engineers were restricted by traditional design constraints. Therefore, to push the adoption of AM beyond prototyping purpose, there exist technical challenges related primarily to materials and their processing. As AM is quite young technology in comparison to traditional processes and their still present a gap



Fig. 8 AM challenges in industry 4.0

which required to be closed with regard to AM development, its standardization, and materials qualification. The economic success of AM on large scale in industry 4.0 will depend upon the assurance of manufacturers which affirm that the material properties used to fabricate complicated structures will be confined to the standards and accepted norms predefined by industry [2]. Presently only limited materials were processed using AM within required specifications and standardization them for also necessary. The over changing goal will be availability and development of a data base which provides mechanical and thermal properties of commonly used AM materials. As a result, there is a need to choose appropriate materials and process combinations for AM of various components for various applications. The Table 2 summarizes the mechanical properties of commonly used materials fabricated using various AM methods.

But AM material related challenges go even further. If we talk about AM materials with regard to environmental relation, one of its advantages is recyclability. While majority of AM metals can be recycled for next print, many polymers can't. Those recycled may suffer potential quality loss. Hence to meet full sustainable goals further research

Table 2 Mechanical properties of commonly used materials fabricated using various AM methods

AM technique	Material	Ultimate tensile strength (Mpa)	Young modulus (Gpa)	% elongation	Reference
EBM	Ti-6Al-4 V	163–286	14.5–38.5	-	[65]
SLM	Ti-6Al-4 V	948 ± 27	-	7.28 ± 1.12	[66]
SLM	Ti-6Al-4 V	1220 ± 60	-	3.2 ± 1.5	[67]
EBM		915–1200		13–25	
EBM	Ti-6Al-4 V	127.1–148.4	120	13.8 ± 0.9	[68]
CSAM	Ti-AL-4 V (HT)	765	-	-	[2]
	Ti-AL-4 V	480			
CSAM	Inconel-718 (HT)	800	-	-	[2]
	Inconel-718	650			
SLM	AlSi7Mg	368	-	9.2	[69]
CSAM	304 L (HT)	800	-	-	[2]
	304 L	650			
CSAM	Cu (HT)	220	-	-	[2]
	Cu	295			
FDM	PLA	8.991	0.408	0.61	[70]
	ABS	2.31	0.119	0.42	
SLM	Ti-6Al-4 V	1120	-	-	[71]
EBM	Ti-6Al-4 V	928	-	3	[72]
FFF	17-4Ph stainless steel	132.27 ± 2.86	275/10 ⁹	-	[73]
EBM	Ti-6Al-4 V (HT)	965 ± 5	-	6 ± 0	[74]
SLM	Ti-6Al-4 V (As built)	1279 ± 13	-	6 ± 0.7	[75]
	Ti-6Al-4 V (Stress relieved)	1187 ± 10	-	7 ± 2.7	
	Ti-6Al-4 V (HT)	998 ± 14	-	6 ± 2	
EBM	High entropy alloy	497 ± 2	-	63 ± 1	[76]
	CoCrFeNiMn				
SLM	High entropy alloy	601	-	-	[77]
	CoCrFeNiMn				
SLM	High entropy alloy	745	-	32	[78]
	FeCoCrNi				

is needed and now even AM companies starts collaborating with few chemical companies for fast track new materials development and standardization.

In material processing area AM assured to provide flexibility into traditional manufacturing processes, but reliability is essential. AM technologies are costly today and they still lacks in process stability, quality, and reproducibility. Even though AM process print whole product in single step diminishing the need of further assembly but some parts required extra surface finish operations to meet the required tolerances and surface finish. As complicated structures can be fabricated with AM technology, manufacturers struggling to deliver good quality without aid of proper metrological tools and appropriate AM methodologies.

4.2 IT integration challenges

The whole AM process to greater extent is manually. In other words first a model of part to be printed is designed in CAD, sliced for 3D printing. Thereafter transferred to the suitable printer using USB stick. Whole process is viewed and controlled from a display available on the printer. However final checks related to quality will perform after printing completes. This manual labor to some extent is justified to few AM cases or for prototyping where not required huge data collection and there is no need to integrate AM into software solutions. In industry 4.0 scenarios is changing towards mass production and every manufacturer is looking to cut down costs via integration approach. Some vendors

already start providing APIs that connect directly with printers, but are not standardized largely thereby making this integration task challenging and expensive.

4.3 Design challenges

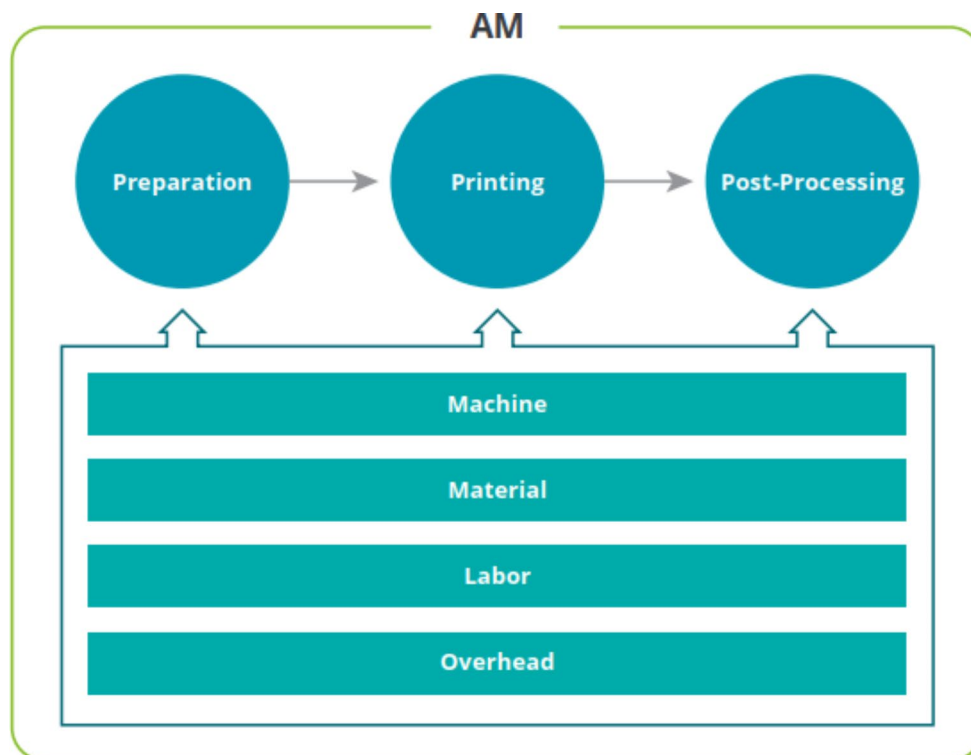
Design engineers who spend their entire life working with traditional manufacturing processes consider same design constraints when it comes to AM. Despite shifting to new design approach they come back to well define comfortable traditional design paradigms. In industry 4.0 the design process is totally reframed by AM. The outcome is condensed, little linear process with few design steps. In nut shell designers have to think beyond conventional design strategies and must focused on end product performance with different manufacturing approaches.

In comparison to conventional methods of manufacturing, AM lack uniform norms and standard procedures for design. Every AM machine manufacturer comes with their own technical recommendations which were not matured enough in comparison to conventional manufacturing approach [2]. To date the biggest challenge which exists is that no standardized proven framework is available regard to AM.

4.4 Capability challenges

New management and engineering skills were needed for successful AM transition. Today we are facing skill gap as

Fig. 9 AM cost model



it is hard to find skilled labor which applies 3D printing to real world manufacturing. Graduates even though learn this technology but it is difficult to find potential candidates who understand the capabilities of AM technology. Majority of the skilled-labor is not familiar with distinct AM materials and design process requirements in order to explore full AM potential. Hence current shortfall of talent calls for novel education policies or initiatives to provide skilled, adaptable, and capable work force for industry 4.0. Existing design and management courses offered related to manufacturing and production are not capable to deliver proper skill set required for the efficient AM technology deployment. We required a work force which is capable of working in a team with proper knowledge of modeling software and scanning systems.

4.5 Financial challenge

Not only both AM systems and materials costly, but a high cost of mass production also a significant obstacle for AM technology [79]. However, compared to the past, the cost of AM is substantially lower. For AM the model of cost is organized in certain steps where each step (Fig. 9) has its own cost factors which were different from traditional ones.

4.6 Approach to overcome challenges

To overcome these AM challenges industries may follow 4-step approach. Being an beginner in AM field this 4-step approach may benefit manufacturers and they may get opportunity to grow and learn quickly getting an edge in the emerging AM field in Industry 4.0.

1. Study whether an AM solution fits into organization.
2. Calculate business case.
3. Develop a road map before scaled production.
4. Generate organizational shift by developing positive attitude for AM inside organization.

5 AM future in Industry 4.0

AM has a bright future ahead of it. In a variety of industries, 3D printing has emerged as the preferred manufacturing method, with the potential for continued expansion. Every industrial unit wishes to produce difficult shapes in large quantities and at a low cost. Furthermore, the current scenario, which is being felt around the world as a result of COVID-19, has resulted in more progress and consolidation of 3D printing as a result of the increased demand for individualized elements swiftly [80]. The 3D printing method will get cheaper and quicker in the near future.

Researchers and clinicians will focus on mass production the most. Increased applications in existing businesses, as well as new potential in non-industrial markets like food, fashion products, eyeglasses, and textiles, will drive 3D printing's growth. Future research will focus on multifunctional structures, ceramics, and composite materials like metals and ceramics combination that can generate materials with lower brittleness, reducing inventory through on-demand production, decreasing time-to-market, automating repair processes, and developing novel complicated parts [81, 82]. Printing technology, design tools, and procedures must all be improved in order to overcome present difficulties in AM processes and provide more profitable and productive industry products [83]. However, AM improves existing items while also allowing for the creation of completely new ones that were previously difficult or impossible to produce [59, 84, 85].

6 Case studies

AM of injection moulding inserts has grown in popularity in recent years, owing to its faster design-to-production time and shape freedom with aid of topology optimization (TO) [86–99]. TO was applied to a metallic mould insert that will be created using the Laser Powder Bed Fusion (LPBF) technology. A mould insert for injection moulding ABS parts was provided by a consumer as the case study for research. The insert must be made using LPBF and material grade 300 maraging steel. Mounting holes and centering holes, together with mould cavities and serving cold runners, are the major characteristics created for the assembly of the insert with the mould box, and therefore will be critical factors to take into account for the optimization. With TO, a significant decrease of 50% in mass and 43% in production time was accomplished in the analysed case study, and these improvements have a direct impact on associated costs [100].

MX3D, a business that specializes in Robotic Wire Arc Additive Manufacturing (WAAM), has completed the printing of an industrial pipeline clamp. If further developed, the WAAM technology could be advantageous in the future in the sense that no large investments are required to maintain a wide variety of stock (plate) materials; very little to no waste materials if built from the ground up; minimising final machining time; more variety in design possible and less reliance on available tools and base components.“

7 Conclusions

AM in industry 4.0 open up doors for newer oppourtunities concerning design and manufacturing. There is no question that AM abilities are an important aspect of the 4th industrial revolution since they allow for the fabrication of customized and personalized products on-site. In reality, intelligent manufacturing enables a highly flexible manufacturing process that can quickly change individualized mass production and create high-quality goods. Customers, manufacturers, and designers responsibilities will all be radically changed in the future of production in this way.

Many advancements and opportunities have resulted from AM in a variety of industries, primarily medical, aerospace, architecture/civil, and automotive. Compared to traditional manufacturing methods, more complicated structures, geometries, higher efficiencies, customized design, higher performance and good environmental sustainability can achieved with AM. Due to this AM technology is adopting beyond prototype for the end and spare parts production. But before wide spread AM adoption on large scale certain obstacles need to overcome like technological challenges, lack of IT standards, shortage of well trained skilled labor, and rigid adherence of engineers and designers to well established principles of design with constraints. AM's future prospects include being a less expensive and faster technology that can also be used for mass production. Furthermore, expensive tools and fixtures are no longer required, resulting in less post-processing, material waste, and human interaction. These are the characteristics that will define the future industry. Ultimately, AM technology is still in its infancy, and more research is needed to lower material and machine prices, develop faster and more precise printing procedures, and make it self-contained. Manufacturing's future is heavily reliant on advancements in manufacturing technology and procedures, as well as the updating of current manufacturing systems.

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